Title: MIRROR DEVICE AND PROJECTION APPARATUS COMPRISING THE SAME

Abstract: The present invention provides a projection apparatus, comprising: a plurality of mirror devices for modulating and reflecting the incident light emitted from a light source; light synthesizer comprising both a synthesis surface where the reflection lights from the mirror devices are synthesized and an incidence surface which is placed on a flat surface crossing with the synthesis surface and to which the incident light is incident; and a projection lens for projecting the reflection light.
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MIRROR DEVICE AND PROJECTION APPARATUS COMPRISING THE SAME

This is a Non-provisional application of a pending US Patent Provisional Application No. 60/967,836 filed on September 6, 2007. The Patent Application 60/967,836 is a Continuation In Part (CIP) Application of U.S. patent applications 10/698,620 filed on November 1, 2003, and 11/121,543 filed on May 3, 2005 issued into Patent 7,268,932. The Application 11/121,543 is further a Continuation In Part (CIP) Application of three previously filed Applications. These three Applications are 10/698,620 filed on November 1, 2003, 10/699,140 filed on November 1, 2003 now issued into Patent 6,862,127, and 10/699,143 filed on November 1, 2003 now issued into Patent 6,903,860 by one of the Applicants of this Patent Applications. The disclosures made in these Patent Applications are hereby incorporated by reference in this Patent Application.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an image projection apparatus implemented with a mirror device commonly known as a "digital micromirror device" or "micromirror device". More particularly, this invention relates to an image projection system that includes a plurality of mirror devices for modulating and reflecting the incident light emitted from a light source; light synthesizer that has both a synthesis surface to synthesize the reflection lights from the mirror devices and an incidence surface placed on a flat surface crossing with the synthesis surface.

Description of the Related Art

Even though there have been significant advances made in recent years on the technologies of implementing electromechanical micromirror devices as spatial light modulator, there are still limitations and difficulties when these devices are employed to provide high quality image displays. Specifically, when the display images are digitally controlled, the image qualities are adversely affected due to the fact that the image is not displayed with a sufficient number of gray scales.

Electromechanical micromirror devices have drawn considerable interest because of their application as spatial light modulators (SLMs). A spatial light modulator requires an array of a relatively large number of micromirror devices. In general, the number of devices required ranges from 60,000 to several million for each SLM. Fig. 1A refers to a digital video system disclosed in a US Patent 5,214,420, that includes a display screen 2. A light source 10 is used to generate light energy for the ultimate illumination of the display screen 2. Light 9 generated is further concentrated and directed toward lens 12 by mirror 11. Lens 12, 13 and 14 form a beam columnator, which operates to columnate light 9 into a column of light 8. A spatial light modulator 15 is controlled by a computer 19 through data transmitted over data cable 18 to selectively redirect a portion of the light...
from path 7 toward lens 5 to display on screen 2. As shown in Fig. IB, the SLM 15 has a surface 16 that includes an array of switchable reflective elements, e.g., micromirror devices 32, such as elements 17, 27, 37, and 47 as reflective elements attached to a hinge 30. When element 17 is in one position, a portion of the light from path 7 is redirected along path 6 to lens 5, where it is enlarged or spread along path 4 to impinge onto the display screen 2, so as to form an illuminated pixel 3. When element 17 is in another position, light is not redirected towards display screen 2 and hence pixel 3 remains dark.

The on-and-off states of the micromirror control scheme, as that implemented in the Patent 5,214,420 and by most of the conventional display systems, impose a limitation on the quality of the display. Specifically, in a conventional configuration of the control circuit, the gray scale (PWM between ON and OFF states) is limited by the LSB (least significant bit, or the least pulse width). Due to the ON-OFF states implemented in conventional systems, there is no way to provide a shorter pulse width than LSB. The least brightness, which determines gray scale, is the light reflected during the least pulse width. The limited gray scales lead to degradations of image display.

Specifically, in Fig. IC shows a conventional circuit diagram of a control circuit for a micromirror according to US Patent 5,285,407. The control circuit includes memory cell 32. Various transistors are referred to as M* where "*" designates a transistor number, and each transistor is an insulated gate field effect transistor. Transistors M5, and M7 are p-channel transistors; transistors M6, M8, and M9 are n-channel transistors. The capacitances, C1 and C2, represent the capacitive loads of the memory cell 32. Memory cell 32 includes an access switch transistor M9 and a latch 32a, which is the basis of the static random access switch memory (SRAM) design. All access transistors M9 in a row receive a DATA signal from a different bit-line 31a. The particular memory cell 32 to be written is accessed by turning on the appropriate row select transistor M9, using the ROW signal functioning as a word-line. Latch 32a is formed from two cross-coupled inverters, M5/M6 and M7/M8, which permit two stable states. State 1 is Node A high and Node B low, and state 2 is Node A low and Node B high.

The dual states switching, as illustrated by the control circuit, controls the micromirrors to position either at an ON or an OFF angular orientation, as that shown in Fig. 1A. The brightness, i.e., the gray scales of display for a digitally control image system is determined by the length of time the micromirror stays at an ON position. The length of time a micromirror is controlled at an ON position is in turned controlled by a multiple bit word. For simplicity of illustration, Fig. ID shows the "binary time intervals" when controlled by a four-bit word. As shown in Fig. ID, the time durations have relative values of 1, 2, 4, 8 that in turn define the relative brightness for each of the four bits, where 1 is for the least significant bit and 8 is for the most significant bit.
According to the control mechanism as shown, the minimum controllable difference between gray scales is a brightness represented by a “least significant bit” that maintains the micromirror at an ON position.

When adjacent image pixels are shown with a great degree of difference in the gray scales due to a very coarse scale of controllable gray scale, artifacts are shown between these adjacent image pixels. That leads to image degradations. The image degradations are especially pronounced in bright areas of display where there are “bigger gaps” between gray scales of adjacent image pixels. For example, it can be observed in an image of a female model that there are artifacts shown on the forehead, the sides of the nose, and the upper arm. The artifacts are generated by technical limitations in that the digitally controlled display does not provide sufficient gray scales. Thus, in bright areas of the display, (e.g., the forehead, the sides of the nose, and the upper arm) the adjacent pixels are displayed with visible gaps of light intensities.

As the micromirrors are controlled to have a fully on and fully off position, the light intensity is determined by the length of time the micromirror is at the fully on position. In order to increase the number of gray scales of a display, the speed of the micromirror must be increased such that the digital control signals can be increased to a higher number of bits. However, when the speed of the micromirrors is increased, a stronger hinge is necessary for the micromirror to sustain the required number of operational cycles for a designated lifetime of operation. In order to drive micromirrors supported on a stronger hinge, a higher voltage is required. In this case, the voltage may exceed twenty volts, and may even be as high as thirty volts. Micromirrors manufactured by applying the CMOS technologies would probably not be suitable for operation this higher range of voltages, and therefore, DMOS micromirror devices may be required. In order to achieve higher degree of gray scale control, more complicated manufacturing processes and larger device areas are necessary when DMOS micromirrors are implemented. Conventional modes of micromirror control are therefore facing a technical challenge in that accuracy of gray scale has to be sacrifice for the benefit of smaller and more cost effective micromirror displays, due to the operational voltage limitations.

There are many patents related to light intensity control. These patents include US Patents 5,589,852, 6,232,963, 6,592,227, 6,648,476, and 6,819,064. There are further patents and patent applications related to the different shapes of light sources. These patents include US Patents 5,442,414, 6,036,318, and Application 20030147052. US Patent 6,746,123 discloses special polarized light sources for preventing light loss. However, these patents and patent application do not provide an effective solution to overcome the limitations caused by insufficient gray scales in the digitally controlled image display systems.
Furthermore, there are many patents related to spatial light modulation including US Patents 2,025,143, 2,682,010, 2,681,423, 4,087,810, 4,292,732, 4,405,209, 4,454,541, 4,592,628, 4,767,192, 4,842,396, 4,907,862, 5,214,420, 5,287,096, 5,506,597, and 5,489,952. However, these inventions have not addressed and provided direct resolution for a person of ordinary skill in the art to overcome the limitations and difficulties discussed above.

Therefore, a need still exists in the art of image display systems, applying digital control of a micromirror array as a spatial light modulator, for new and improved systems such that the difficulties and limitations discussed above can be resolved.

**SUMMARY OF THE INVENTION**

In consideration of the above description, one aspect of the present invention is to miniaturize a mirror device and to configure a more compact projection apparatus by implementing this miniaturized mirror device.

A first exemplary embodiment of the present invention is a projection apparatus, includes: a plurality of mirror devices for modulating and reflecting the incident light emitted from a light source, a means for light synthesis (hereafter referred to as "light synthesizer") include both a synthesis surface, where the reflection light from the mirror devices are synthesized, and an incidence surface (placed on a flat surface crossing Intersecting in the same plane as On top of with the synthesis surface) to which the incident light is incident, and a projection lens for projecting the reflection light.

A second exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein the flat surface on which the incidence surface is placed is approximately orthogonal to the synthesis surface.

A third exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, further includes a package in which the mirror device is placed, wherein the package includes a transparent light transmission member, transmitting the incident light and the reflection light that is incoming from the mirror device, incident at different angles, wherein the incident light incident to the light transmission member enters the incidence surface that crosses the synthesis surface.

A fourth exemplary embodiment of the present invention is the projection apparatus according to the third exemplary embodiment, wherein multiple mirror devices are placed in a single package. Don't know if editing reflects true meaning.

A fifth exemplary embodiment of the present invention is the projection apparatus according to the fourth exemplary embodiment, wherein light shield members are respectively placed between the multiple mirror devices.

A sixth exemplary embodiment of the present invention is the projection apparatus
according to the third exemplary embodiment, wherein the light transmission member and
the light synthesizer are joined by a thermal conduction member.

A seventh exemplary embodiment of the present invention is the projection apparatus according to the sixth exemplary embodiment, wherein the light transmission member and the light synthesizer have the coefficient of thermal expansion approximately equal to the coefficient of thermal expansion of the thermal conduction member.

An eighth exemplary embodiment of the present invention is the projection apparatus according to the third exemplary embodiment, further includes a light shield member included between the mirror device and light synthesizer, wherein the light shield member is fixed to the light transmission member or light synthesizer.

A ninth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein the incident light is incident to at least two of the incidence surfaces that cross the synthesis surface.

A tenth exemplary embodiment of the present invention is the projection apparatus according to the ninth exemplary embodiment, wherein at least two of the incidence surface to which the incident light is incident crosses the synthesis surface approximately orthogonally.

An eleventh exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein the light synthesizer has at least one reflection surface between the synthesis surface and mirror device.

A twelfth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein a reflection light, which is reflected by the mirror device towards a direction other than the incidence pupil of the projection lens, is reflected towards a surface that is opposite to the incidence surface.

A thirteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein a light absorption layer is included on a surface that is opposite to the incidence surface.

A fourteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, further includes a light transmission member placed between the light synthesizer and the mirror device, wherein a portion of the reflection light reflected by the light transmission member is reflected towards a surface that is opposite to the incidence surface by not sure if this is right which the incident light enters the light synthesizer.

A fifteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein a polarization element is
 included between the light synthesizer and the mirror device.

A sixteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, further includes two of the mirror devices, wherein the mirror device has a rectangular contour, and the two mirror devices are placed such that the equivalent sides of each rectangular device are mutually orthogonal on the same plane or on parallel planes.

A seventeenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, wherein incident lights, with at least two different wavelengths, are simultaneously incident to one of the mirror devices, wherein the mirror device modulates the incident light on the basis of a video image signal corresponding to either, or any, of the wavelengths of the incident lights.

An eighteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, further includes three mirror devices, wherein the lights emitted from the light source have three independent frequency domains, or no less than four frequency domains including [i] and [ii], or including [i] and [iii], where:

[i] is the three frequency domains,

[ii] is a frequency domain in which part of the frequencies overlap with either of the aforementioned three frequency domains and which includes a different frequency, and

[iii] is a frequency domain adjacent to either of the three frequency domains.

A nineteenth exemplary embodiment of the present invention is the projection apparatus according to the first exemplary embodiment, further includes a light source control circuit, wherein the light source includes a plurality of laser light sources.

A twentieth exemplary embodiment of the present invention is the projection apparatus according to the nineteenth exemplary embodiment, wherein the light source control circuit controls the emission light intensity of the light source in accordance with an input signal.

A twenty-first exemplary embodiment of the present invention is the projection apparatus according to the nineteenth exemplary embodiment, wherein multiple laser light sources simultaneously emit light, wherein at least a portion of two of the individual light fluxes, from the light emitted from at least two of the multiple laser light sources, are intermixed in an illumination light path.

A twenty-second exemplary embodiment of the present invention is the projection apparatus according to the nineteenth exemplary embodiment, wherein at least a light of one color emitted from the multiple laser light sources has a different light path length of
the illumination light path to the mirror device or a different angle of irradiation onto the
mirror device than the lights of the other colors.

A twenty-third exemplary embodiment of the present invention is the projection
apparatus according to the first exemplary embodiment, wherein the optical axis of the
incident light forms an angle that is no larger than 14 degrees with the optical axis of the
reflection light from the mirror device synthesized by the light synthesizer.

A twenty-fourth exemplary embodiment of the present invention is the projection
apparatus according to the first exemplary embodiment, wherein the F-number of the
projection lens is no less than 4.

A twenty-fifth exemplary embodiment of the present invention is the projection
apparatus according to the first exemplary embodiment, further includes a plurality of
mirror devices, which is so arranged as to cancel a shift or shifts in the projection positions
of a projection image due to a temperature rise in the projection apparatus.

A twenty-sixth exemplary embodiment of the present invention is a projection
apparatus, includes: a light source; an illumination optical system for guiding the incident
light emitted from the light source; a plurality of light modulator arrays, in each of which
light modulation elements for modulating and reflecting the incident light are arrayed in
two dimensions; a light synthesizer includes an incidence surface to which the incident
light is incident, a synthesis surface on which the modulation lights from the light
modulator arrays are synthesized, an undesirable light guide surface to which the
undesirable portion of the modulation light is directed, and an ejection surface from which
a synthesized modulation light is ejected; a projection lens for projecting the synthesized
modulation light, wherein the optical axis of the incident light or the undesirable
modulation light is approximately orthogonal to the normal line of the synthesis surface.

A twenty-seventh exemplary embodiment of the present invention is the projection
apparatus according to the twenty-sixth exemplary embodiment, wherein the distance
between at least one of the multiple light modulator arrays and the light synthesizer is
different from the distance(s) between the other light modulator array(s) and the light
synthesizer.

A twenty-eighth exemplary embodiment of the present invention is the projection
apparatus according to the twenty-sixth exemplary embodiment, wherein the light source
emits a plurality of the incident lights, wherein the light path length of at least one of the
incident lights to the light modulator array is different from the light path length of another
of the incident lights to the light modulator array.

A twenty-ninth exemplary embodiment of the present invention is the projection
apparatus according to the twenty-sixth exemplary embodiment, wherein the light source, which is a laser light source, is constituted by multiple sub-light sources and which further includes a light source control circuit for controlling the entirety of the light source and the individual sub-light sources, respectively.

A thirtieth exemplary embodiment of the present invention is the projection apparatus according to the twenty-ninth exemplary embodiment, wherein the light source control circuit controls the emission light intensity of the light source in accordance with an input signal.

A thirty-first exemplary embodiment of the present invention is the projection apparatus according to the twenty-sixth exemplary embodiment, wherein the optical axes of the multiple modulation lights are approximately parallel to one another.

A thirty-second exemplary embodiment of the present invention is the projection apparatus according to the twenty-sixth exemplary embodiment, wherein the light modulator array has a rectangular contour, and two the multiple light modulator arrays are placed such that equivalent sides of the individual mirror devices are mutually orthogonal on the same plane or on parallel planes.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention is described in detail below with reference to the following figures.

Fig. 1A is a functional block diagram showing the configuration of a projection apparatus according to a conventional technique;

Fig. 1B is a top view diagram for showing the configuration of a mirror element of the projection apparatus according to a conventional technique;

Fig. 1C is a functional block circuit schematic diagram showing the configuration of the drive circuit of a mirror element of the projection apparatus according to a conventional technique;

Fig. 1D is a timing diagram showing the format of image data used in the projection apparatus according to a conventional technique;

Fig. 2 is a side view diagram showing the assembly of optical components of a multi-panel system;

Fig. 3A is side view diagram for illustrating the etendue in light transmission using a discharge lamp light source and projecting an image by way of an optical device;

Fig. 3B is a side view diagram for illustrating the use of a laser light source and the projection of an image by way of an optical device;
Fig. 3C is a side view diagram for illustrating the use of a discharge lamp light source and the projection of an image by way of an optical device;

Fig. 4 is a side view diagram for showing the configuration for limiting a mirror deflection angle in a conventional mirror device;

Fig. 5 is a diagram exemplifying the configuration for regulating a mirror deflection angle in a conventional mirror device;

Fig. 6 is a diagram exemplifying the configuration for regulating a mirror deflection angle in a conventional mirror device;

Fig. 7 is a diagram exemplifying the configuration for regulating a mirror deflection angle in a conventional mirror device;

Fig. 8A is a diagram exemplifying the configuration of the mirror element of a mirror device according to a preferred embodiment of the present invention;

Fig. 8B is a diagram delineating the state in which incident light is reflected towards a projection optical system by deflecting the mirror of a mirror element;

Fig. 8C is a diagram delineating the state in which incident light is not reflected towards a projection optical system by deflecting the mirror of a mirror element;

Fig. 8D is a diagram delineating the state in which incident light is reflected towards and way from a projection optical system repeatedly by free-oscillating the mirror of a mirror element;

Fig. 9A is a top view of an exemplary modification of the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 9B is an outline diagram showing a cross-section of the exemplary modification of the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 10A is a top view showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 10B is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 11 is a diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 12 is a diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 13A is a top view diagram showing another form of an electrode included in
the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 13B is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 14 is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 15A is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 15B is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 16A is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 16B is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 17A is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 17B is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 17C is a side view diagram showing another form of an electrode included in the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 18 is a diagram exemplifying steps 1 through 9 of the production process of a mirror device according to the embodiment of the present invention;

Fig. 19 is a diagram exemplifying steps 10 through 13 of the production process of a mirror device according to the embodiment of the present invention;

Fig. 20 is a diagram exemplifying a dicing method used in a production process of
a mirror device according to the embodiment of the present invention;

Fig. 21 is a functional block diagram showing the configuration of a single-panel projection apparatus according to the embodiment of the present invention;

Fig. 22A is a functional block diagram showing the configuration of a multi-panel projection apparatus according to the embodiment of the present invention;

Fig. 22B is a functional block diagram showing the configuration of an exemplary modification of a multi-panel projection apparatus according to the embodiment of the present invention;

Fig. 22C is a functional block diagram showing the configuration of an exemplary modification of a multi-panel projection apparatus according to another preferred embodiment of the present invention;

Fig. 23A is a functional block diagram exemplifying the configuration of a control unit includes in a single-panel projection apparatus according to the embodiment of the present invention;

Fig. 23B is a functional block diagram exemplifying the configuration of a control unit in a multi-panel projection apparatus according to the embodiment of the present invention;

Fig. 24A is a functional block diagram exemplifying the configuration of a light source drive circuit includes in a projection apparatus according to the embodiment of the present invention;

Fig. 24B is a functional block diagram showing an exemplary modification of the configuration of a light source drive circuit included in a projection apparatus according to the embodiment of the present invention;

Fig. 25 is a chart exemplifying the setup of a light source pulse pattern in controlling a mirror by means of binary data performed in a projection apparatus according to the embodiment of the present invention;

Fig. 26 is a chart showing the relationship between the emission light intensity and the applied current to a light source drive circuit used in the embodiment of the present invention;

Fig. 27A is a functional block diagram exemplifying the configuration of a mirror device according to the embodiment of the present invention;

Fig. 27B is an outline diagram of the cross-section of the mirror element of a mirror device according to the embodiment of the present invention;

Fig. 28 is a chart showing the transition time in a pulse width modulation of the
mirror of a spatial light modulator according to the embodiment of the present invention;

Fig. 29 is a functional block diagram exemplifying a placement of ROW lines for controlling mirrors of a spatial light modulator according to the embodiment of the present invention;

Fig. 30A is a functional block diagram showing the data structure of image data used in the embodiment of the present invention;

Fig. 30B is a functional block diagram showing the data structure of image data used in the embodiment of the present invention;

Fig. 31 is a chart exemplifying the setup of a light source pulse pattern used for controlling a mirror by means of non-binary data performed in a projection apparatus according to the embodiment of the present invention;

Fig. 32 is a chart exemplifying the setup of a light source pulse pattern used for controlling a mirror by means of binary data performed in a projection apparatus according to the embodiment of the present invention;

Fig. 33 is a chart showing an exemplary modification of a light source pulse pattern used for controlling a mirror by means of binary data performed in a projection apparatus according to the embodiment of the present invention;

Fig. 34 is a chart showing an exemplary modification of a light source pulse pattern used for controlling a mirror by means of non-binary data performed in a projection apparatus according to the embodiment of the present invention;

Fig. 35 is a chart showing an exemplary modification of the control for a spatial light modulator using non-binary data in the embodiment of the present invention;

Fig. 36A is a chart exemplifying a control signal of a projection apparatus according to the embodiment of the present invention;

Fig. 36B is a chart exemplifying a control signal of a projection apparatus according to the embodiment of the present invention;

Fig. 36C is a chart exemplifying a control signal, which is shown by enlarging a part thereof, of a projection apparatus according to the embodiment of the present invention;

Fig. 37 is a chart exemplifying a control signal of a chirp modulation of a projection apparatus according to the embodiment of the present invention;

Fig. 38 is a chart exemplifying a control signal, using binary data, of a projection apparatus according to the embodiment of the present invention;

Fig. 39 is a chart exemplifying a control signal, using binary data, of a projection
apparatus according to the embodiment of the present invention;

Fig. 40A is a chart exemplifying a control signal of a projection apparatus
according to the embodiment of the present invention;

Fig. 40B is a chart exemplifying a control signal of a projection apparatus
according to the embodiment of the present invention;

Fig. 41A is a chart exemplifying a control signal of a projection apparatus
according to the embodiment of the present invention;

Fig. 41B is a chart exemplifying a control signal of a projection apparatus
according to the embodiment of the present invention;

Fig. 42 is a chart exemplifying a control signal of a projection apparatus according
to the embodiment of the present invention;

Fig. 43 is a chart exemplifying a control signal of a projection apparatus according
to the embodiment of the present invention;

Fig. 44 is a chart exemplifying a control signal of a projection apparatus according
to the embodiment of the present invention;

Fig. 45 is a chart exemplifying a control signal of a projection apparatus according
to the embodiment of the present invention;

Fig. 46 is a chart describing the principle of γ correction of video image data;

Fig. 47 is a chart showing the principle of γ correction by controlling the emission
light intensity of a light performed in a projection apparatus according to the embodiment
of the present invention;

Fig. 48 is a chart describing an example of the conversion of binary data into
non-binary data performed in a projection apparatus according to the embodiment of the
present invention;

Fig. 49 is a chart describing an example of the conversion of binary data into
non-binary data performed in a projection apparatus according to the embodiment of the
present invention;

Fig. 50 is a chart describing an example of the conversion of binary data into
non-binary data performed in a projection apparatus according to the embodiment of the
present invention;

Fig. 51 is a chart describing an example of the conversion of binary data into
non-binary data performed in a projection apparatus according to the embodiment of the
present invention;

Fig. 52 is a chart showing a γ correction of a brightness input in eight-bit
non-binary data, by exemplifying the implementation in four stages, performed in a projection apparatus according to the embodiment of the present invention;

Fig. 53A is a chart exemplifying a $\gamma$ correction by means of intermittent pulse emission performed in a projection apparatus according to the embodiment of the present invention;

Fig. 53B is a chart exemplifying a $\gamma$ correction by means of intermittent pulse emission performed in a projection apparatus according to the embodiment of the present invention;

Fig. 53C is a chart exemplifying a $\gamma$ correction by means of intermittent pulse emission performed in a projection apparatus according to the embodiment of the present invention;

Fig. 53D is a chart exemplifying a $\gamma$ correction by means of intermittent pulse emission performed in a projection apparatus according to the embodiment of the present invention;

Fig. 54A is a chart exemplifying a $\gamma$ correction by means of an intermittent pulse emission, thereby increasing the effects of the correction on the lower brightness side, performed in a projection apparatus according to the embodiment of the present invention;

Fig. 54B is a chart exemplifying the $\gamma$ correction curve performing a $\gamma$ correction by means of a light source pulse pattern exemplified in Fig. 54A, thereby increasing the effects of the correction on the lower brightness side;

Fig. 55A is a chart exemplifying the case of performing a $\gamma$ correction in consideration of human visual characteristic perception, by means of an intermittent pulse emission in a projection apparatus according to the embodiment of the present invention;

Fig. 55B is a chart exemplifying the $\gamma$ correction curve performing a $\gamma$ correction in consideration of human visual characteristic perception, by means of the light source pulse pattern exemplified in Fig. 55A;

Fig. 56 is a chart exemplifying the case of performing a gray scale control by keeping a mirror in a constant ON state and controlling the intensity of emission of a light source, which is performed in a multi-panel projection apparatus according to the embodiment of the present invention;

Fig. 57 is a chart exemplifying the case of performing a gray scale control by keeping a mirror in a constant ON state and controlling the pulse emission of a light source, which is performed in a multi-panel projection apparatus according to the embodiment of the present invention;
Fig. 58 is a chart exemplifying the case of performing a gray scale control by keeping a mirror in a constant ON state and controlling the intensity of emission of a light source, which is performed in a single-panel projection apparatus according to the embodiment of the present invention;

Fig. 59 is a chart exemplifying the case of performing a gray scale control by keeping a mirror in a constant ON state and controlling the pulse emission of a light source, which is performed in a single-panel projection apparatus according to the embodiment of the present invention;

Fig. 60 is a diagram describing the principle of increasing the range of a gray scale control by a combination of the ON/OFF control of a mirror and the emission intensity control of a light source, which is performed in a single-panel projection apparatus, according to the embodiment of the present invention;

Fig. 61 is a chart exemplifying the case of preventing a color break by a combination of the ON/OFF control of a mirror and the oscillation control of the mirror, performed in a single-panel projection apparatus, according to the embodiment of the present invention;

Fig. 62A is a front cross-sectional diagram of an assembly body that packages a mirror device using a cover glass and a package substrate;

Fig. 62B is a top view diagram of the assembly body shown in Fig. 62A, with the cover glass and support member removed;

Fig. 62C is a top view diagram of the assembly body shown in Fig. 62A;

Fig. 62D is a bottom view diagram of the assembly body shown in Fig. 62A, with a columnar thermal transfer member placed at the center of the bottom surface of a device substrate;

Fig. 62E is a bottom view diagram of the assembly body shown in Fig. 62A, with a thermal transfer member placed along a side of the bottom surface of a device substrate;

Fig. 63A is a front cross-sectional diagram of an assembly body that packages a mirror device using a package substrate having an opening part;

Fig. 63B is a bottom view diagram of the assembly body shown in Fig. 63A;

Fig. 64 is a front cross-sectional diagram of an assembly body that packages a mirror device so as to be electrically connected to a device substrate by equipping a cover glass with a circuit-wiring pattern by using a package substrate having a cavity;

Fig. 65A is a front cross-sectional diagram of an assembly body that packages two mirror devices by using a package substrate;
Fig. 65B is a top view diagram of the assembly body shown in Fig. 65A, with a cover glass and an intermediate member removed; Fig. 65C is a top view diagram of the assembly body shown in Fig. 65A; Fig. 66A is a front view diagram of a two-panel projection apparatus comprising a plurality of mirror devices packaged by a single package; Fig. 66B is a rear view diagram of the two-panel projection apparatus shown in Fig. 66A; Fig. 66C is a side view diagram of the two-panel projection apparatus shown in Fig. 66A; Fig. 66D is a top view diagram of the two-panel projection apparatus shown in Fig. 66A; Fig. 67 is a front view diagram of an exemplary modification of a two-panel projection apparatus shown in Fig. 66A; Fig. 68A is a top view diagram of another exemplary modification of the two-panel projection apparatus shown in Fig. 66A; Fig. 68B is a side view diagram of another exemplary modification of the two-panel projection apparatus shown in Fig. 66A; Fig. 69 is a top view diagram of the mirror array of a spatial light modulator according to the present embodiment; Fig. 70A shows a cross-section of a mirror element that is configured to be equipped with only one address electrode and one drive circuit, as another embodiment of the mirror element of a mirror device according to the embodiment of the present invention; Fig. 70B is an outline diagram of the mirror element shown in Fig. 70A; Fig. 71A shows a top view diagram, and a cross-sectional diagram, both of a mirror element structured such that the area size S1 of a first electrode part of one address electrode is greater than the area size S2 of a second electrode part (S1 > S2), and such that the connection part between the first and second electrode parts is in the same structural layer as the first and second electrode parts; Fig. 71B shows a top view diagram, and a cross-sectional diagram, both of a mirror element structured such that the area size S1 of a first electrode part of one address electrode is greater than the area size S2 of a second electrode (S1 > S2), and such that the connection part between the first and second electrode parts is in a different structural layer from that of the first and second electrode parts;
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Fig. 71C shows a top view diagram, and a cross-sectional diagram, both of a mirror element structured such that the area size S1 of a first electrode part of one address electrode is equal to the area size S2 of a second electrode (S1=S2), and such that the distance G1 between a mirror and the first electrode part is less than the distance G2 between the mirror and the second electrode part (G1<G2);

Fig. 72 is a diagram showing the data inputs to a mirror element shown in Fig. 71A, the voltage application to an address electrode, and the deflection angles of the mirror, in a time series;

Fig. 73 is a functional block diagram illustrating the control of a spatial light modulator according to the present embodiment;

Fig. 74 is an illustrative diagram showing the configuration of a multi-panel projection apparatus comprising three spatial light modulators;

Fig. 75 illustrates the relationship between the deflection of a mirror and the reflecting direction of an illumination light in the configuration of Fig. 69;

Fig. 76 is an illustrative diagram showing diffraction light generated when the light is reflected by a mirror;

Fig. 77 is an illustrative cross-sectional diagram depicting a situation in which an f/2.4 light flux is reflected by a conventional spatial light modulator, for which the deflection angles of the ON light state and OFF light state of a mirror are set at ±12 degrees, respectively;

Fig. 78A is an illustrative cross-sectional diagram depicting a situation in which an f/10 light flux, which possesses a coherent characteristic, is reflected by a spatial light modulator, for which the deflection angles of the ON light state and OFF light state of a mirror are set at ±3 degrees, respectively;

Fig. 78B is a diagram further showing an expansion of diffraction light by depicting, in three dimensions, the relationship between the deflection angle of the mirror and the light flux thereof shown in Fig. 78A;

Fig. 79 is an illustrative cross-sectional diagram depicting a situation in which an f/10 light flux emitted from a light source, which possesses a coherent characteristic, is reflected by a spatial light modulator, for which the deflection angles of the ON light state and OFF light state of the mirror shown in Fig. 78A are set at ±13 degrees, respectively;

Fig. 80A is a top view diagram of a mirror array, with the deflection axis of the mirror shown in Fig. 69A changed;

Fig. 80B is an illustrative diagram that shows the relationship between the
deflection of the mirror and the reflecting direction of light in the configuration shown in Fig. 80A;

Fig. 81 is a diagram further showing the expansion of diffraction light by depicting, in three dimensions, the relationship between the deflection angle of the mirror shown in Fig. 79 and the light flux, in the case in which the directions of deflection axis of a mirror element are changed, as shown in Fig. 80A;

Fig. 82 is an illustrative cross-sectional diagram depicting a situation in which an f/10 light flux emitted from a light source, which possesses a coherent characteristic, is reflected by a spatial light modulator, for which the deflection angles of the ON light state and OFF light state of a mirror are set at +13 degrees and -3 degrees, respectively; and

Fig. 83 is an illustrative cross-sectional diagram depicting a situation in which an f/10 light flux emitted from a light source, which possesses a coherent characteristic, is reflected by a spatial light modulator, for which the deflection angles of the ON light state and OFF light state of a mirror are set at +3 degrees and -13 degrees, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Image projection apparatuses implemented with a spatial light modulator (SLM), such as a transmissive liquid crystal, a reflective liquid crystal, a mirror array and other similar image modulation devices, are widely known.

A spatial light modulator is formed as a two-dimensional array of optical elements, ranging in number from tens of thousands to millions of miniature modulation elements, with the individual elements enlarged and displayed, as the individual pixels corresponding to an image to be displayed, onto a screen by way of a projection lens.

Spatial light modulators generally used for projection apparatuses primarily include two types: 1.) a liquid crystal device, formed by sealing a liquid crystal between transparent substrate, for modulating the polarizing direction of incident light and providing them with a potential and 2.) a mirror device deflecting miniature micro electro mechanical systems (MEMS) mirrors with electrostatic force and controlling the reflecting direction of illumination light.

One embodiment of the above described mirror device is disclosed in US Patent 4,229,732, in which a drive circuit using MOSFET and deflectable metallic mirrors are formed on a semiconductor wafer substrate. The mirror can be deformed by electrostatic force supplied from the drive circuit and is capable of changing the reflecting direction of the incident light.

Meanwhile, US Patent 4,662,746 has disclosed an embodiment in which one or two elastic hinges retain a mirror. If the mirror is retained by one elastic hinge, the elastic
hinge functions as a bending spring. If the mirror is retained by two elastic hinges, they function as torsion springs to incline the mirror, and thereby deflecting the reflecting direction of the incident light.

As described above, the on-and-off state of the micromirror control scheme as that implemented in US Patent 5,214,420 and in most of the conventional display systems, impose a limitation on the quality of a display. Specifically, in conventional configurations of control circuits, the gray scale (PWM between ON and OFF states) is limited by the LSB (least significant bit, or the least pulse width). Due to the ON-OFF states implemented in the conventional systems, it is impossible to provide a shorter pulse width than LSB. The least brightness, which determines gray scale, is the light reflected during the least pulse width. A limited number of gray scales lead to degradation in the image quality of a display.

Specifically, Fig. 1C exemplifies a circuit diagram of a conventional control circuit for a micromirror, according to US Patent 5,285,407. The control circuit includes memory cell 32. Various transistors are referred to as "M\(^*\)", where "\(^*\)" denotes a transistor number, and each transistor is an insulated gate field effect transistor. Transistors M5, and M7 are p-channel transistors; transistors M6, M8, and M9 are n-channel transistors. The capacitances, C1 and C2, represent the capacitive loads of the memory cell 32. The memory cell 32 includes an access switch transistor M9 and a latch 32a, which is the basis of the static random access switch memory (SRAM) design. All access transistors M9 in a ROW receive a DATA signal from a different bit-line 31a. The particular memory cell 32 is accessed and written by turning on the appropriate row select transistor M9, using the row signal functioning as a word line. Latch 32a is formed from two cross-coupled inverters, M5/M6 and M7/M8, which permit two stable states. State 1 is Node A high and Node B low, and state 2 is Node A low and Node B high.

The mirror, driven by a drive electrode, abuts a landing electrode structured differently from the drive electrode, and thereby a prescribed tilt angle is maintained. A "landing chip", which possesses a spring property, is formed on the point of contact between the landing electrode and the mirror, so that the deflection of the mirror to the reverse direction, upon change in the control, is assisted. The parts forming the landing chip and the landing electrode are maintained at the same potential, so that contact will not cause a shorting or other similar disruption.

Outline of PWM Control

As described above, switching between the dual states, as illustrated by the control circuit, controls the micromirrors to position either at an ON or an OFF angular orientation, as shown in Fig. IA. The brightness, i.e., the gray scales of display for a digitally control
image system, is determined by the length of time the micromirror stays at an ON position. The length of time a micromirror is controlled at an ON position is turned controlled by a multiple bit word. For simplicity of illustration, Fig. 1D shows the "binary time intervals" when controlled by a four-bit word. As shown in Fig. 1D, the time durations have relative values of 1, 2, 4, 8 that in turn define the relative brightness for each of the four bits, where 1 is for the least significant bit and 8 is for the most significant bit. According to the control mechanism shown, the minimum controllable difference between gray scales is a brightness represented by a "least significant bit" that maintains the micromirror at an ON position.

In a simple exemplary display system operated with a n bits brightness control signal for controlling the gray scales, the frame time is divided into $2^n - 1$ equal time slices. For a 16.7 milliseconds frame period and n-bit intensity values, the time slice is 16.7/($2^n$) milliseconds.

Having established these time slices for controlling the length of time for displaying each pixel in each frame, the pixel intensities are determined by the number of time slices represented by each bit. Specifically, a display of a black pixel is represented by 0 time slices. The intensity level represented by the LSB is 1 time slice, and maximum brightness is $2^n - 1$ time slices. The number time slices that a micro mirror is controlled to operate at an On-state in a frame period determines a specifically quantified light intensity of each pixel corresponding to the micromirror reflecting a modulated light to that pixel. Thus, during a frame period, each pixel corresponding to a modulated micromirror controlled by a control word with a quantified value of more than 0 is operated at an on state for the number of time slices that correspond to the quantified value represented by the control word. The viewer's eye integrates the pixels' brightness so that the image appears the same as if it were generated with analog levels of light.

For addressing deformable mirror devices, a pulse width modulator (PWM) receives the data formatted into "bit-planes". Each bit-plane corresponds to a bit weight of the intensity value. Thus, if each pixel's intensity is represented by an n-bit value, each frame of data has n bit-planes. Each bit-plane has a 0 or 1 value for each display element. In the example described in the preceding paragraphs, each bit-plane is separately loaded during a frame. The display elements are addressed according to their associated bit-plane values. For example, the bit-plane representing the LSBs of each pixel is displayed for 1 time slice.

**Outlines of Mirror Size and Resolution**

The size of a mirror for constituting such a mirror device is between 4µm and 20µm on each side. The mirrors are placed on a semiconductor wafer substrate in such a
manner as to minimize the gap between adjacent mirrors. Smaller gaps reduce random and interfering reflection lights from the gap to prevent such reflections from degrading the contrast of the displayed images. The mirror device is formed a substrate that includes an appropriate number of mirror elements. Each mirror element is applied to modulate a corresponding image display element known as a pixel. The appropriate number of image display elements is determined according to image display standards in compliance to the resolution of a display specified by the Video Electronics Standards Association (VESA) and to the television-broadcasting standard. For example, in the case of configuring a mirror device in compliance with the WXGA (with the resolution of 1280x768) as specified by VESA and in which the size of each mirror is 10μm, the diagonal length of the display area will be about 0.61 inches, thus producing a sufficiently small mirror device

**Outline of Projection Apparatus**

The projection apparatuses using deflection-type ("deflectable") light modulators are primarily categorized into two types: 1.) a single-panel projection apparatus includes a single spatial light modulator, changing the frequency of a projection light in time series and displaying a color image, and 2.) a multi-panel projection apparatus includes a plurality of spatial light modulators, constantly modulating illumination light with different frequencies by means of individual spatial light modulators and displaying a color image by synthesizing these modulated lights.

The single-panel projection apparatus is configured as described above in reference to Fig. 1A.

In contrast, Fig. 2 shows an example of the optical configuration of a multi-panel system.

Referring to Fig. 2, the illumination light from a light source 1001 is projected to the total reflection surface of a total internal reflection (TIR) prism 1002 at a critical angle (or higher) and is directed to a prism for color synthesis and separation. The TIR prism 1002 is used for separating the light paths of the light between the illumination light and the light modulated by a deflectable spatial light modulator. The color separation/synthesis prism includes configured by placing a first color separation/synthesis prism 1003b and a first junction prism made by joining a second color separation/synthesis prism 1003r to a third color separation/synthesis prism 1003g. A first dichroic film, which reflects only the blue light of the illumination light and transmits other colors, is placed on the emission surface of the first color separation/synthesis prism 1003b. The blue illumination light reflected by the first dichroic film is totally reflected by the incidence surface of the first color separation/synthesis prism 1003b and is incident to a first spatial light modulator 1004b at a desired incident angle. The modulation light
reflected towards the ON light by the first spatial light modulator 1004b, proceeding in a perpendicular direction to the first spatial light modulator 1004b, is totally reflected by the incident surface of the first color separation/synthesis prism 1003b and reflected by the first dichroic film towards the projection light path. The red and green illumination lights transmitting through the first dichroic film pass through an air layer and enter the second color separation/synthesis prism 1003r. A second dichroic film, which reflects only red light, is placed on the junction surface between the second color separation/synthesis prism 1003r and third color separation/synthesis prism 1003g. Therefore, the second dichroic film reflects the red light of the illumination light to the second color separation/synthesis prism 1003r. The reflected red illumination light is totally reflected by the light incident surface of the second color separation/synthesis prism 1003r and enters into a second spatial light modulator 1004r. The light modulated by the second spatial light modulator 1004r is reflected by the incident surface and second dichroic film to proceed towards the projection light path. The green light passes through the second dichroic film is modulated by a third spatial light modulator 1004g and is reflected towards the projection light path. The individual color lights modulated by the first through third spatial light modulators 1004b, 1004r and 1004g and reflected toward the same light path transmit through the total reflection surface of the TIR prism 1002 and are projected by a projection lens 1005 onto the projection surface.

The multiple panel configuration prevents the problem of a color break. Unlike a single-panel projection apparatus, color break problem is resolved because each primary color is constantly projected. Further, this configuration produces images with a higher level of brightness because the light from a light source is effectively utilized. On the other hand, the processes of assembling the multi-panel projection apparatus are more complicated. For example, the spatial light modulators must be placed in proper locations corresponding to the respective colors and the assembling processes require more alignment adjustments. There are further problems due to the size increase of such apparatus.

Outline of the Introduction of Laser Light Source

In the projection apparatus implemented with a reflective spatial light modulator configured as the above-described mirror device, there is a close relationship among the numerical aperture (NA) NA1 of an illumination light path, the numerical aperture NA2 of a projection light path, and the tilt angle $\alpha$ of a mirror.

Assuming that the tilt angle $\alpha$ of a mirror is 12 degrees. When a modulated light reflected by the mirror and incident to the pupil of the projection light path is set perpendicular to a device substrate, the illumination light is incident at an angle inclined by
2\(\alpha\), that is, 24 degrees, relative to the perpendicular axis of the device substrate. For the light beam reflected by the mirror to be most efficiently incident to the pupil of the projection lens, it is desirable for the numerical aperture of the projection light path to be equal to the numerical aperture of the illumination light path. If the numerical aperture of the projection light path is smaller than that of the illumination light path, the illumination light cannot be sufficiently transmitted into the projection light path. On the other hand, if the numerical aperture of the projection light path is larger than that of the illumination light path, the illumination light can be entirely transmitted onto the projection lens becomes excessively large, which increases the inconvenience in terms of configuring the projection apparatus. Furthermore, in this case, the light fluxes of the illumination light and projection light must be directed apart from each other because the optical members of the illumination system and those of the projection system must be physically placed in separate locations in an image display system. From the above considerations, when a spatial light modulator with the tilt angle of a mirror at 12 degrees is used, the numerical aperture (NA) \(N_{A1}\) of the illumination light path and the numerical aperture NA2 of the projection light path are preferably set as follows:

\[
N_{A1} = N_{A2} = \sin \alpha = \sin 12^\circ
\]

Letting the F-number of the illumination light path be \(F_1\) and the F-number of the projection light path be \(F_2\), the numerical aperture can be converted into an F-number as follows:

\[
F_1 = F_2 = \frac{1}{(2*NA)} = \frac{1}{(2*sin12^\circ)} = 2.4
\]

In order to maximize the transmission of illumination light emitted from a light source with non-directivity in the emission direction of light, such as a high-pressure mercury lamp or xenon lamp, which are generally used for a projection apparatus, it is necessary to maximize the projection angle of light on the illumination light path side. Since the numerical aperture of the illumination light path is determined by the specific tilt angle of a mirror to be used, the tilt angle of the mirror needs to be large in order to increase the numerical aperture of the illumination light path.

Increasing of the tilt angle of mirror, however, requires a higher drive voltage and a larger distance between the mirror and the electrode for driving the mirror because a greater physical space needs to be secured for tilting the mirror. The electrostatic force \(F\) generated between the mirror and electrode is derived by the following equation:

\[
F = (\varepsilon*S*V^2)/(2*d^2),
\]

where "\(S\)" is the area size of the electrode, "\(V\)" is the voltage, "\(d\)" is the distance between the electrode and mirror, and "\(\varepsilon\)" is the permittivity of vacuum.
The equation makes clear that the drive force is decreased in proportion to the second power of the distance d between the electrode and mirror. It is possible to increase the drive voltage to compensate for the decrease in the drive force associated with the increase in the distance; conventionally, however, the drive voltage is about 5 to 10 volts in the drive circuit, by means of a CMOS process used for driving a mirror, and therefore a relatively special process such as a DMOS process is required if a drive voltage in excess of about 10 volts is needed. A DMOS process would increase the cost of a mirror device and hence, is undesirable.

Furthermore, for the purpose of cost reduction, it is desirable to obtain as many mirror devices as possible from a single semiconductor wafer substrate in order to improve the productivity. That is, shrinking the pitch between mirror elements reduces the size of the mirror device overall. However, it is clear that the area size of an electrode is reduced in association with a size reduction of the mirror, which also leads to less driving power.

Along with these requirements for miniaturizing a mirror device, there is a design tradeoff for further consideration because of the fact that the larger a mirror device, the brighter is the display image when the conventional light lamp is used as the light source. Attributable to a optical functional relationship generally known as etendue, the efficiency of the non-polarized light projected from the conventional lamp may be substantially reduced. The adverse effects must be taken into consideration as an important factor for designing and configuring an image projection system, particularly for designing the light sources. Fig. 3A is diagram for explaining an optical parameter etendue by exemplifying the case of using an arc discharge lamp light source and projecting an image by way of an optical device.

Let "y" represent the size of a light source 4150 and "u" represent the angle of light with which an optical lens imports the light from the light source. Further, let "u'" be the converging angle on the image side converged by using the optical lens 4106, and "y'" be the size of an image projected onto a screen 4109, by way of a projection lens 4108 after using an optical device 4107 for the converged light. Here, there is a relationship known as the etendue among the size y of the light source 4150, the import angle u of light, the converging angle u' on the image side, and the size y' of an image, as follows:

\[ y \cdot u = y' \cdot u' \]

Based on this relationship, the smaller the optical device 4107 attempting to image the light source 4150, the smaller the import angle u of light becomes. Because of this, when the optical device 4107 is made smaller, the image becomes darker as a result of limiting the import angle u of light. Therefore, when using an arc discharge lamp with low directivity, the import angle u of light needs to be appropriately large in order to maintain...
the brightness of an image.

Fig. 3C is a diagram illustrating the use of an arc discharge lamp light source and the projection of an image by way of an optical device. The light output from an arc discharge lamp light source 4105 is converged by using an optical lens 4106, and irradiated onto the optical device 4107. Then, the light passing through the optical device 4107 is projected onto a screen 4109 by way of a projection lens 4108.

The larger the optical lens used in this case, the higher the converging capacity and the better the usage efficiency of light. However, increasing the size of the optical device 4107 is contradictory to the demand for shrinking the spatial light modulator or making the projection apparatus more compact.

In contrast, a laser light source has a higher directivity of light and a smaller expansion of light flux than those of a discharge lamp light source. Therefore, a projected image can be made sufficiently bright without the need to increase the size of the optical lens or optical device. Further, if the projected image is not sufficiently bright, the brightness can be increased by increasing the output of the laser light source. Also in this case, because of the high directivity of laser light, the light intensity can be increased without allowing a substantial expansion of light flux.

Fig. 3B is a diagram illustrating the use of a laser light source and the projection of an image by way of an optical device.

The laser light emitted from a laser light source 4200 is made to be incident to an optical device 4107 by way of an optical lens 4106. Then, the light passing through the optical device 4107 is projected onto a screen 4109 by way of a projection lens 4108.

In this case, the usage efficiency of light for the optical lens 4106 and optical device 4107 is improved by taking advantage of the high directivity of the laser light. A projected image can be made brighter without a need to increase the size of the optical lens 4106 or optical device 4107. This eliminates the problem of etendue, making it possible to miniaturize the optical lens 4106 and optical device 4107, leading to a more compact projection apparatus.

**Outline of Resolution Limit**

An examination of the limit value of the aperture ratio of a projection lens used for a projection apparatus, which displays the display surface of a spatial light modulator in enlargement, in view of the resolution of an image to be projected, leads to the following.

Where "Rp" is the pixel pitch of the spatial light modulator, "NA" is the aperture ratio of a projection lens, "F" is an F-number, and "λ" is the wavelength of light, the limit "Rp" with which any adjacent pixels on the projection surface are separately observed is
derived by the following equation:

\[ R_p = 0.61 \times \frac{\lambda}{\text{NA}} = 1.22 \times \lambda \times F \]

When the pitch between mirror elements is decreased by using a miniaturized mirror, the relationship among the aperture ratio NA, which is theoretically required for resolving individual mirrors, the F-number for the projection lens, and the corresponding deflection angle of the mirror, is given by the following tables for the wavelength of light at \( \lambda = 400 \text{ nm} \), which is the worst condition within the range of visible light, the green light (at \( \lambda = 650 \text{ nm} \)) and the red light (at \( \lambda = 800 \text{ nm} \)), respectively.

The NA required for resolving, in the projected image, adjacent mirror elements and the tilt angle of a mirror for separating the illumination light and projection light with the respective NA: at \( \lambda = 400 \text{ nm} \)

<table>
<thead>
<tr>
<th>Mirror device pixel pitch: ( \mu \text{m} )</th>
<th>Aperture ratio: NA</th>
<th>F-number for projection lens</th>
<th>Deflection angle of mirror: degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.061</td>
<td>8.2</td>
<td>3.49</td>
</tr>
<tr>
<td>5</td>
<td>0.049</td>
<td>10.2</td>
<td>2.79</td>
</tr>
<tr>
<td>6</td>
<td>0.041</td>
<td>12.3</td>
<td>2.33</td>
</tr>
<tr>
<td>7</td>
<td>0.035</td>
<td>14.3</td>
<td>2.00</td>
</tr>
<tr>
<td>8</td>
<td>0.031</td>
<td>16.4</td>
<td>1.75</td>
</tr>
<tr>
<td>9</td>
<td>0.027</td>
<td>18.4</td>
<td>1.55</td>
</tr>
<tr>
<td>10</td>
<td>0.024</td>
<td>20.5</td>
<td>1.40</td>
</tr>
<tr>
<td>11</td>
<td>0.022</td>
<td>22.5</td>
<td>1.27</td>
</tr>
</tbody>
</table>
At $\lambda$=650nm:

<table>
<thead>
<tr>
<th>Mirror device pixel pitch: $\mu$m</th>
<th>Aperture ratio: NA</th>
<th>F-number for projection lens</th>
<th>Deflection angle of mirror: degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.099</td>
<td>5.0</td>
<td>5.67</td>
</tr>
<tr>
<td>5</td>
<td>0.079</td>
<td>6.3</td>
<td>4.54</td>
</tr>
<tr>
<td>6</td>
<td>0.066</td>
<td>7.6</td>
<td>3.78</td>
</tr>
<tr>
<td>7</td>
<td>0.057</td>
<td>8.8</td>
<td>3.24</td>
</tr>
<tr>
<td>8</td>
<td>0.050</td>
<td>10.1</td>
<td>2.84</td>
</tr>
<tr>
<td>9</td>
<td>0.044</td>
<td>11.3</td>
<td>2.52</td>
</tr>
<tr>
<td>10</td>
<td>0.040</td>
<td>12.6</td>
<td>2.27</td>
</tr>
<tr>
<td>11</td>
<td>0.036</td>
<td>13.9</td>
<td>2.06</td>
</tr>
</tbody>
</table>

At $\lambda$=800nm:

<table>
<thead>
<tr>
<th>Mirror device pixel pitch: $\mu$m</th>
<th>Aperture ratio: NA</th>
<th>F-number for projection lens</th>
<th>Deflection angle of mirror: degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.122</td>
<td>4.1</td>
<td>6.97</td>
</tr>
<tr>
<td>5</td>
<td>0.098</td>
<td>5.1</td>
<td>5.58</td>
</tr>
<tr>
<td>6</td>
<td>0.081</td>
<td>6.1</td>
<td>4.65</td>
</tr>
<tr>
<td>7</td>
<td>0.070</td>
<td>7.2</td>
<td>3.99</td>
</tr>
<tr>
<td>8</td>
<td>0.061</td>
<td>8.2</td>
<td>3.49</td>
</tr>
<tr>
<td>9</td>
<td>0.054</td>
<td>9.2</td>
<td>3.11</td>
</tr>
<tr>
<td>10</td>
<td>0.049</td>
<td>10.2</td>
<td>2.79</td>
</tr>
<tr>
<td>11</td>
<td>0.044</td>
<td>11.3</td>
<td>2.54</td>
</tr>
</tbody>
</table>

Based on the above tables, it is clear that a sufficient F-number for a projection lens required for resolving, in the projected image, individual pixels with, for example, $10\mu$m pixel pitch is theoretically $F=20.5$. The projection lens has an extremely small
aperture when the wavelength of illumination light is $\lambda = 400$ nm. In the meantime, the mirror would have a sufficient deflection angle of mere 1.4 degrees to provide the required resolution. The mirror device can be controlled and the mirror elements may be driven with a very low drive voltage.

However, as discussed above, the image brightness would be significantly reduced when a conventional non-coherent lamp as light source is implemented with an illumination lens matched with such a projection lens. Accordingly, a laser light source is implemented to circumvent the above described problem attributable to the etendue. The implementation of the laser light source makes it possible to increase the F-number for the illumination and projection optical systems to the number indicated in the table and to reduce the deflection angle of a mirror element as a result, thus enabling the configuration of a compact mirror device with a low drive voltage. F-number

Furthermore, the introduction of a laser light source provides the benefit of lowering the drive voltage by introducing the laser light source, making it possible to further reduce the thickness of the circuit-wiring pattern of the control circuit controlling the mirror. It is possible to further reduce power consumption by setting the deflection angle of the mirror at a minimum for each frequency of light as the target of modulation. That is, the deflection angle of the mirror can be reduced for a mirror device modulating, for example, blue light as compared to the deflection angle of a mirror modulating red light. It is thus possible for a projection apparatus to be configured without increasing the sizes of the optical components used in the apparatus when, for example, single color laser light sources are used for light sources, the respective illumination light paths are individually provided, and the optimal NAs are set for the respective illumination light paths.

It is also possible to cause the laser light source to perform pulse emission by configuring a circuit that alternately emits the pulse emission of the ON and OFF lights for a predetermined period. Controlling the pulse emission of the light source makes it possible to adjust intensity in accordance with the image signal (that is, in accordance with the brightness and hue of the entire projection image) and to express the finer gradations of the display image. Further, lowering the output of the laser light makes it possible to vary the dynamic range of an image and to darken the entire screen in response to a dark image.

Furthermore, performing a pulse control makes it possible to turn OFF a laser light source as appropriate during a period where no image is displayed or during a period of changing the colors of a display image in one frame. As a result, a temperature rise due to the irradiation of extraneous light onto a mirror device can be alleviated.

Note that the use of a light emitting diode (LED) in place of a laser light source makes it possible to obtain a similar benefit.
Outline of Oscillation Control

US Patent Application 20050190429 discloses another method other than the method of minimizing the tilt angle of the mirror for reducing a drive voltage. In this disclosure, a mirror is controlled to freely oscillate in an oscillation state. The oscillation has an inherent oscillation frequency. The mirror operated in oscillating state projects an intensity of light that is about 25% to 37% of the emission light intensity when a mirror is controlled under a constant ON state.

According to such a control, it is no longer required to drive the mirror at a high speed to achieve a higher resolution of gray scale. A high level of gray scale resolution is achievable with a hinge of a low spring constant for supporting the mirror. The drive voltage may be reduced. This method, combined with the method of decreasing the drive voltage by decreasing the deflection angle of a mirror, as described above, would produce an even greater improvement.

As described above, the use of a laser light source makes it possible to decrease the deflection angle of a mirror and to shrink the mirror device without causing a degradation of brightness, and further, the use of the above described oscillation control enables a higher level of gradation without causing an increase in the drive voltage.

However, if an electrode for driving the mirror and a stopper for determining the deflection angle of the mirror are individually configured, as in the conventional method, the problem of inefficient space usage remains.

Fig. 4 is a cross sectional view for showing the structure of a mirror device for controlling a mirror deflection angle in the conventional mirror device, as disclosed in US Patent 5,583,688. This mirror device includes a landing yoke 310, which is connected to a mirror 300. The yoke 310 deflects with the mirror 300. The yoke 310 includes a tip 312 formed in a part of the landing yoke 310. The tip 312 contacts a metallic layer, which is formed separately from the address electrode 314 to stop the mirror before the mirror 300 deflects to an angular position to come into contact with the address electrode 314, thereby regulating the deflection angle of the mirror 300. In such a configuration, the landing yoke and tip occupy part of the space available for placing an electrode, making it difficult to increase the size of the address electrode.

Fig. 5 shows the structure for regulating a mirror deflection angle in the conventional mirror device, as disclosed in US Patent Application 20060152690. Although this patent application discloses a structure that has eliminated the landing yoke, however, the mirror device still has a tip as a separate component for determining the deflection angle of the mirror. The tip functioning as a stopper is disposed in the space that would be available for placing an address electrode. In a mirror device with configuration
shown in Fig. 3, it would be difficult to increase the size of the address electrode.

Fig. 6 shows cross sectional views of a mirror to illustrate the structure for regulating a mirror deflection angle in the conventional mirror device, as disclosed in US Patent 6,198,180. In the mirror device disclosed by the patent, the configuration includes a stop post, which is separate from a capacitor panel to define the maximum deflection angle of the mirror. Therefore, the electrode size is still limited by the extra space occupied by the capacitor stop post and the capacitor panel.

Fig. 7 shows a cross section view of a mirror device for illustrating the structure for regulating a mirror deflection angle in the conventional mirror device, as disclosed in US Patent 6,992,810. The mirror device includes a mechanical stop element, which regulates the deflection angle of a mirror, directly under the mirror. The mechanical stop element abuts on a landing electrode that is maintained at the same potential as the mirror. This disclosure also makes it difficult to increase the electrode size.

In order to resolve the problems noted above, the first embodiment of the present invention is accordingly configured to integrate the electrode used for driving the mirror element with the stopper used for determining the maximum deflection angle of the mirror in a mirror device.

<Embodiment 1>

The following is a detail description of a mirror device according to the present embodiment.

Figs. 8A, 8B, 8C and 8D are diagrams for depicting the configuration of the mirror element of a mirror device according to the present embodiment. Fig. 8A is a top view diagram of a mirror element with the mirror omitted. Figs. 8B, 8C and 8D are outline diagrams of a cross-section of a mirror element taken along the A-A' line of Fig. 8A, showing the position of the mirror in different deflection states. The deflection states of the mirror exemplified in Figs. 8B, 8C and 8D are described in detail later.

In the mirror element 4001 shown in Figs. 8A through 8D, the mirror 4003 is made of a highly reflective material, such as aluminum or gold, and is supported by the elastic hinge 4007. The entirety or a part of the hinge (e.g., the connection part with a fixing part, the connection part with a moving part or the intermediate part) is made of a silicon material, a metallic material, or the like, and is placed on the device substrate 4004. Here, the silicon material may include poly-silicon, single crystal silicon, amorphous silicon, and the like; while the metallic material may include aluminum, titanium, or an alloy of them. Alternatively, a composite material produced by layering different materials may be used.

The mirror 4003 is formed in the approximate shape of a square, with the length of
one side, for example, between 4 µm and 10 µm. The mirror pitch is, for example, anywhere between 4 µm and 10 µm. The deflection axis 4005 of the mirror 4003 is on the diagonal line thereof. The lower end of the elastic hinge 4007 is connected to the device substrate 4004, which includes a circuit for driving the mirror 4003. The upper end of the elastic hinge 4007 is connected to the lower surface of the mirror 4003. An electrode for securing conductivity and/or an intermediate member for strengthening a member or for strengthening the connection may be placed between the elastic hinge 4007 and device substrate 4004 or between the elastic hinge 4007 and mirror 4003.

Figs. 9A and 9B are diagrams showing an exemplary modification of a mirror element of a mirror device according to the present embodiment. Fig. 9A is a top view diagram of the mirror element with the mirror removed. Fig. 9B is an outline diagram showing a cross-section of the mirror element taken along the line C-C depicted in Fig. 9A.

Note that multiple elastic hinges (refer to 4007a and 4007b) may be placed along the deflection axis 4005 of the mirror 4003, as shown in Figs. 9A and 9B. Such a placement of elastic hinges stabilizes the deflecting direction when the mirror is deflected. When multiple elastic hinges are employed, as shown in Figs. 9A and 9B, the interval between each of the elastic hinges, or between each of the intermediate members placed between the hinge and substrate, should be as large as possible, preferably no less than 30% of the deflection axis length of the mirror.

As exemplified in Fig. 8B, the electrodes 4008(4008a and 4008b) used for driving the mirror 4003 are placed on the top surface of the device substrate 4004 and opposite to the bottom surface of the mirror 4003. The form of the address electrodes 4008 may be symmetrical or asymmetrical relative to the deflection axis 4005. The address electrodes 4008 are made of aluminum, tungsten, or other similar material.

Figs. 10A, 10B, 11, 12, 13A, 13B, 14, 15A, 15B, 16A, 16B, 17A, 17B and 17C are diagrams that describe the different forms of address electrodes included in the mirror element 4001 according to the present embodiment.

The present embodiment is configured such that the address electrode 4008 also functions as a stopper for determining the deflection angle of the mirror. The deflection angle of the mirror is the angle determined by the aperture ratio of a projection lens that satisfies a theoretical resolution determined by the pitch of adjacent mirrors on the basis of the equation below:

\[ R_p = 0.61 \cdot \frac{\lambda}{NA} = 1.22 \cdot \frac{\lambda}{F} \]

In other words, the deflection angle of a mirror may not be set at a lower angle...
than the determined angle. Since a laser light is transmitted with a uniform phase, the
diffracted light has a higher light intensity than the light emitted from a mercury lamp.
Therefore, the adverse effects of the diffracted light generally occurs to the non-coherent
light projected from a lamp as a light source can be prevented by setting the deflection
angle of mirror at a larger angle than the appropriate angle calculated from the numerical
aperture NA of the light flux of a laser light source and the F-number for a projection lens,
thereby preventing the diffracted light from being reflected towards the projection lens. In
an exemplary embodiment, the deflection angle of a mirror may be 10 to 14 degrees, or 2 to
10 degrees, relative to the horizontal state of the mirror 4003. In a configuration in which
the address electrode also serves as a stopper, the space available for the electrode is
significantly increased compared to a conventional configuration with the address
electrode formed separately from the stopper. The mirror device implemented with such
mirror element can therefore be further miniaturized. "Stiction" is a well-known
phenomenon in which a mirror 4003 sticks to the contact surface between the mirror 4003
and address electrode 4008 (i.e., also a stopper) due to surface tension or intermolecular
force when the mirror is deflected. Accordingly, part of the address electrode 4008 may be
configured as a circular arc, as shown in Figs. 10A and 10B, so as to reduce contact with
the mirror 4003 to a single point, or to a line of contact, as shown in Fig. 11, in order to
reduce stiction between the mirror 4003 and address electrode 4008. The performance of
the mirror elements in the mirror device may be adversely affected as a result of excessive
contact force between the parts of the address electrode in contact with the mirror 4003.
In order to prevent the adverse effects, the mirror may be configured to incline in the same
angle as the tilt angle of the mirror 4003 to adjust the contact pressure, as shown in Fig. 12.
Note that the address electrode 4008 contacts the mirror 4003 face to face in a single spot
in the example shown in Fig. 12. The address electrode 4008 may also contact the mirror
4003 in multiple places, as shown in Figs. 13A and 13B, and is not limited to a single spot.
The configuration as shown in Figs. 13A and 13B is preferable because the deflecting
direction of the mirror is stably maintained. In this case, the individual contact points are
preferably placed apart from each other at a distance no less than 30% of the diagonal size
of the mirror.

Further, a part of the address electrode 4008, including at least the part contacting
the mirror 4003, may be provided with an inactive surface material, such as halide, in order
to reduce the occurrence of stiction between the mirror 4003 and address electrode 4008.

Moreover, an elastic member formed as an integral part of the electrode may be
used as a stopper.

The address electrode is configured to have a shape of a trapezoid includes a top
and a bottom side, which are approximately parallel to the deflection axis 4005. The trapezoid further includes sloped sides approximately parallel to the contour line of the mirror 4003 of the mirror device, in which the deflection axis 4005 of the mirror 4003 is matched with the diagonal line thereof, as shown in Fig. 9A. Since the electrode and stopper are not separately manufactured as in the conventional method, the electrode-stopper may be conveniently manufactured. The electrode may also be configured by dividing the above-described trapezoid into multiple parts. In order to prevent undesirable reflection light from entering into the projection light path, at least a part of the electrode may be covered with a low reflectance material or a thin film layer having the film thickness substantially equivalent to 1/4 of the wavelength λ of the visible light.

A difference in potentials needs to be generated between the mirror and electrode to drive the mirror by electrostatic force. The present embodiment using the electrode also as stopper is configured to provide the surface of the electrode and/or the rear surface of the mirror with an insulation layer(s) in order to prevent an electrical shorting at the point of mirror contact with the electrode. If the surface of the electrode is provided with an insulation layer, the configuration may also be such that the insulation layer is provided to only a part of the electrode, including the part in contact with the mirror. Figs. 8B, 8C and 8D exemplify the case of providing the surface of the address electrode 4008 (i.e., 4008a and 4008b) with an insulation layer 4006. The insulation layer is made of an oxidized compound, azotized compound, silicon, or silicon compound, e.g., SiC, SiO₂, Al₂O₃, and Si. The material and thickness of the insulation layer is determined so that the dielectric strength voltage is maintained at no less than the voltage required to drive the mirror, preferably no less than 5 volts. For example, the dielectric strength voltage may be configured to be two times the drive voltage of the mirror or higher, 3 volts or higher, or 10 volts or higher. Further, selecting an insulation material resistant to the etchant used in the production process makes it possible for the material to also function as the electrode protective film in the process of etching a sacrificial layer in the production process (which is described in detail later), thereby simplifying the production process.

The following description is for an exemplary embodiment to show the size and shape of an address electrode.

Referring to Fig. 14, where "L₁" is the distance between the deflection axis and the edge of the electrode on the side closer to the deflection axis of the mirror 4003, "L₂" is the distance between the deflection axis and the edge of the electrode on the side farther from the deflection axis, and "d₁" and "d₂" are the distances between the mirror's bottom surface and the electrode at the respective edges. "Pl" is a representative point on the
electrode edge on the side closer to the deflection axis of the mirror, and "P2" is a representative point on the electrode edge on the side farther from the deflection axis.

The exemplary embodiment as shown in Fig. 17 is a case in which the electrode is formed so that: \( d_1 < d_2 \). In this configuration, the stopper that determines the tilt angle of the mirror 4003 is preferably placed at the point "P2", in consideration of a production variance of the electrode height that influences the deflection angle of the mirror. The present embodiment is accordingly configured to satisfy the relationship of:

\[
d_1 > \frac{(L1*d2)}{L2}
\]

This configuration provides an efficient space utilization of the space under the mirror and maintains a stable deflection angle of the mirror.

Note that, while in the example shown in Fig. 14, the points P1 and P2 form a continuous slope, an electrode with a stepped slope may also be formed, as shown in Figs. 15A and 15B, for ease of production.

Furthermore, it is possible to configure the electrode so that the deflection angle of the mirror 4003, when it comes into contact with the electrode on one side, is the same as the deflection angle of the mirror 4003, when it comes in contact with the electrode on the other side, as shown in Fig. 16A, or such that the aforementioned two deflection angles are different, as shown in Fig. 16B.

When the reduction of stiction between the electrode and mirror is a consideration, the closer the contact point to the deflection axis, the more advantageous it is because the momentum impeding the motion of the mirror due to stiction is smaller. If stiction is still a concern, even when an address electrode is coated with a layer for preventing stiction, the configurations as shown in Figs. 20A, 20B and 20C are viable. In Figs. 17A, 17B and 17C the stoppers are not formed closer to the deflection axis, i.e. not on the external parts of the electrode farthest from the deflection axis.

When the electrode is configured so that \( d_1 = d_2 \), the point on the electrode determining the deflection angle of the mirror is P2, and the configuration is determined to satisfy the following equation:

\[
\cot \theta = \frac{d_2}{L2}
\]

Next is a step-by-step description of the production process of the mirror device according to the present embodiment.

Figs. 18 and 19 illustrate the production process of the mirror device according to the present embodiment.

In step 1 of Fig. 18, a drive circuit and a wiring pattern (both not shown in the
drawing), used in driving and controlling the mirror, are formed on a semiconductor wafer substrate 1301.

Subsequently, an address electrode 1302, which is to be connected to the drive circuit, is formed in step 2. Then, the drive circuit formed on the substrate 1301 is tested to confirm whether or not there is an abnormality in the operation of the drive circuit or in the electrical continuity of the address electrode 1302. If there is no abnormality in the drive circuit or address electrode 1302, the process proceeds to the next step.

In step 3, an insulation layer 1303 is formed on the address electrode 1302. The insulation layer 1303 prevents an electric shorting during the operation of the mirror and also prevents the electrode from being corroded by the etching in the following process. The insulation layer may be made from Si$_3$N$_4$ or Si or other similar material.

Then in step 4, a first sacrificial layer 1304 is deposited on the semiconductor wafer substrate 1301, on which the drive circuit and address electrode 1302 have previously been formed. The first sacrificial layer 1304 may be made of SiO$_2$ or the like, and is used in forming a mirror surface (to be formed in a later step) by providing a space between the semiconductor wafer substrate 1301 and mirror. The thickness of the first sacrificial layer 1304 eventually determines the height of the elastic hinge supporting the mirror, in the present embodiment.

Then in step 5, a part of the first sacrificial layer 1304 is removed by etching. This step will determine the height and form of the elastic member (to be formed in a later step).

In step 6 an elastic member 1305, including a part that connects the elastic member 1305 to the semiconductor wafer substrate 1301, is formed on the semiconductor wafer substrate 1301 and on the first sacrificial layer 1304 formed in step 4. In the present embodiment, the elastic member 1305 eventually constitutes an elastic hinge used in supporting the mirror and is constituted by, for example, a silicon material such as single crystal silicon, poly-silicon, and amorphous silicon (a-Si), or a metallic material such as aluminum, titanium, or an alloy of these metallic materials. Note that the amount of material deposited to form the elastic member, in this step, will determine the eventual thickness of the elastic hinge.

Then in step 7, a photoresistant layer 1306 is deposited on the structure on the semiconductor wafer substrate 1301 formed in the previous step.

In step 8, the photoresist 1306 is exposed to light by using a mask to transfer a desired form of the structure, and then the elastic member 1305 deposited on the semiconductor wafer substrate 1301 is etched, and thereby the desired form of the structure
is obtained. Further, by applying etchant in the present step, the elastic member 1305 deposited on the semiconductor wafer substrate 1301 in step 6 is divided into individual elastic hinges, corresponding to the respective mirrors for the mirror elements constituting the mirror device.

Then in step 9, a second sacrificial layer 1307 is further deposited on the structure (resulting from step 8) on the semiconductor wafer substrate 1301. The second sacrificial layer 1307 may be made of a similar composite to that of the first sacrificial layer 1304 or made of, for example, SiO₂. Here, the second sacrificial layer 1307 is deposited so as to be higher than the top surface of the part that will constitute the elastic hinge.

Then, turning to Fig. 19, the photoresist 1306 and second sacrificial layer 1307 are polished in step 10 until the top surface of the elastic member 1305 that will constitute the elastic member is exposed.

Then in step 11, a mirror layer 1308 is deposited so as to be connected to the top surface of the photoresist 1306 and elastic member 1305, which have been exposed in step 10. The mirror layer 1308 in this process is made of, for example, aluminum, gold, silver, or the like. In this process, a mirror support layer 1309, which is constituted by a material different from that of the mirror, may also be formed between the mirror layer and elastic member in order to reinforce the connection to the elastic hinge by supporting the mirror layer 1308, or to make it difficult for the stopper to stick to the mirror when the mirror deflects. The mirror support layer 1309 is made of, for example, titanium and tungsten.

In step 12, a photoresist (not shown in the drawing) is coated on the mirror layer 1308, deposited in step 11, and etched after exposure to a mirror pattern using a mask. Thus, individual mirrors are separated.

In the present step (i.e., 12), the first sacrificial layer 1304, photoresist 1306 and second sacrificial layer 1307 still exist under the mirror, and therefore no direct external force is applied to the elastic member 1305. Although the mirror layer, in its original state, can be divided into sections as individual mirrors, it is preferable to further form a protective layer on the top surface of the mirror layer 1308 in order to prevent a decrease in the reflectivity due to causes such as the attachment of foreign materials onto or damage to the top surface of the mirror layer 1308. A protective layer on the mirror layer 1308 also makes it possible to prevent foreign materials from attaching to (and causing the breakage of) the elastic member 1305 or to the mirror and damaging the mirror during the dicing process that divides the structure formed on the semiconductor wafer substrate 1301 into individual mirror devices.

The dicing process, the process by which the plurality of mirror devices formed on the semiconductor wafer substrate 1301 is divided into individual mirror devices, is
exemplified in Fig. 20. The dicing method shown in Fig. 20 uses at least one auxiliary member to maintain the same alignment, as that of the plurality of mirror devices 1401 formed on the semiconductor wafer substrate 1301 pre-division. The present embodiment shown in Fig. 20 is configured to use, as one of the auxiliary members, a special tape (i.e., a UV tape) 1402, such as an adhesive tape, which is commonly used in a semiconductor process and which loses its adhesive property by emitting an ultraviolet light. In Fig. 20, the aforementioned UV tape 1402 is first attached to the bottom surface of the semiconductor wafer substrate 1301, comprising the plurality of mirror devices 1401, then, the entirety of the semiconductor wafer substrate 1301, along with the UV tape 1402 attached to the bottom surface, is fixed onto a frame 1403 of a dicing apparatus. The plurality of mirror devices 1401 is cut with a circular saw known as a diamond saw 1404. The UV tape 1402 is expanded along with the individual devices after dividing the individual mirror devices 1401 from the semiconductor wafer substrate 1301, and thereby, the cut mirror devices 1401 are expanded, together with the tape 1402, to generate gaps and completely divide into the individual mirror devices 1401. Then, as an ultraviolet light is emitted onto the bottom surface of the UV tape 1402, which is attached to the bottom surfaces of the completely divided individual mirror devices 1401, the adhesive property is lost and the UV tape 1402 is easily peeled off of the mirror devices 1401.

In addition to the diamond saw 1404 described above, the dicing process may also be carried out by another method, such as laser cutting, high pressure water jet cutting, cutting by further etching scribe lines using another etchant, and a cutting of the semiconductor wafer substrate 1301 after forming scribe lines.

Returning to Fig. 19, when step 12 is completed, the first sacrificial layer 1304, photoresist 1306, second sacrificial layer 1307, and protective layer are removed in step 13 by using an appropriate etchant to form the deflectable mirrors, which have been protected by the aforementioned layers. By applying this process, the elastic member 1305 and mirror layer 1308 is formed on the semiconductor wafer substrate 1301 and the drive circuit and electrode are formed to deflect the mirrors.

Afterwards, an anti-stiction process is applied to prevent the moving parts from sticking to one another, that is, to prevent a state in which a normal control for a mirror is disabled by the mirror coming in contact with and being retained by, the electrode.

Then, the completed mirror device is sealed into a package, and along with the package, becomes the end product.

Note that the semiconductor wafer substrate 1301, address electrode 1302, insulation layer 1303, elastic member 1305 and mirror layer 1308, which are shown in Fig. 19 correspond, respectively, to the device substrate 4004, address electrodes 4008a and
4008b, insulation layer 4006 and mirror 4003, which are shown in Fig. 8B.

The following description outlines the natural oscillation frequency of the oscillation system of a mirror device according to the present embodiment.

The reduction of the drive voltage is applied to achieve a higher resolution of gray scales by controlling the mirrors in a free oscillation is already described above. For a mirror device controlled by a pulse width modulator to operate with a free oscillation intermediate state by applying a control word with a LSB, there is a functional relationship between the length of time represented by the LSB and the natural frequency of the oscillation for a mirror supported on a hinge. The natural oscillation cycle T of an oscillation system = \( 2 \times \pi \times V(I/K) = \text{LSB time}/X \) [%];

where:

I: the rotation moment of an oscillation system,
K: the spring constant of an elastic hinge,
LSB time: the LSB cycle at displaying n bits, and

\( X \) [%]: the ratio of the light intensity obtained by one oscillation cycle to the Full-ON light intensity of the same cycle

Note that:

"I" is determined by the weight of a mirror and the distance between the center of gravity and the center of rotation;

"K" is determined from the thickness, width, length, material and cross-sectional shape of an elastic hinge;

"LSB time" is determined from one frame time, or one frame time and the number of reproduction bits, in the case of a single-panel projection method;

"X" is determined as described above, particularly from the F-number of a projection lens and the intensity distribution of an illumination light. For example, when a single-panel color sequential method is employed, the ratio of emission intensity by one oscillation is assumed to be 32%, and the minimum emission intensity in a 10-bit grayscale is to be obtained by an oscillation, then "I" and "K" are designed so as to have a natural oscillation cycle as follows:

\[ T = \frac{I}{(60 \times 3 \times 2^{10 \times 0.32})} = 17.0 \mu \text{sec}. \]

In contrast, when a conventional PWM control is employed to make the changeover transition time \( t_M \) of a mirror approximately equal to the natural oscillation frequency of the oscillation system of the mirror and the LSB is regulated so that a shortage of the light intensity in the interim can be sufficiently ignored, the gray scale
reproducible with the above described hinge is about 8-bit, even if the LSB is set at five times the changeover transition time. That is, a 10-bit grayscale can be reproduced by using the elastic hinge that would have made it possible to reproduce about an 8-bit grayscale according to the conventional control.

In the single-panel projection apparatus described above, an example configuration attempting to obtain, for example, 13-bit grayscale is as follows:

\[
\text{LSB time} = \left( \frac{1}{60} \right) \left( \frac{1}{3} \right) \left( \frac{1}{2} \right) = 0.68 \mu \text{sec}
\]

If a configuration is such that the light intensity obtained in one cycle for the optical projection system is 38\% of the intensity obtained from controlling a mirror in a constant ON state for the same cycle, the oscillation cycle \(T\) is as follows:

\[
T = 0.68/0.38\% = 1.8 \mu \text{sec}
\]

In contrast, when attempting to obtain an 8-bit grayscale in the multi-panel projection apparatus described above, an example comprisal is as follows:

\[
\text{LSB time} = \left( \frac{1}{60} \right) \left( \frac{1}{3} \right) \left( \frac{1}{2} \right)^8 = 21.7 \mu \text{sec}
\]

If a configuration is such that the light intensity obtained in one cycle for the optical projection system is 20\% of the intensity obtained from controlling a mirror in a constant ON state for the same cycle, the oscillation cycle \(T\) is as follows:

\[
T = 21.7/20\% = 108.5 \mu \text{sec}.
\]

As described above, the present embodiment is configured to set the natural oscillation cycle of the oscillation system, which includes an elastic hinge, between 1.8\(\mu\)sec and 108.5\(\mu\)sec; and to use three deflection state, i.e., a first deflection state, in which the light modulated by the mirror element is reflected towards the projection light path, a second deflection state, the light is reflected in a direction away from the projection light path, and a third deflection state, in which the mirror oscillates between the first and second deflection states. A higher resolution of gray scales is achievable without increasing the drive voltage of the mirror element.

As described above, the present embodiment is configured to make the electrode also function as stopper for defining and limiting the maximum deflection angle of the mirror. Space utilization is improved when the mirror element is miniaturized with expanded area to form the electrode.

**<Embodiment 2>**

The following detail description is provided for the preferred embodiment of the present invention with reference to the accompanying drawings.

Fig. 21 is a functional block diagram for showing the configuration of a projection
apparatus according to a preferred embodiment of the present invention.

A projection apparatus 5010, according to the present embodiment, is a so-called single-panel projection apparatus 5010 comprising a single spatial light modulator (SLM) 5100, a control unit 5500, a Total Internal Reflection (TIR) prism 5300, a projection optical system 5400, and a light source optical system 5200, as exemplified in Fig. 21.

The projection optical system 5400 includes the spatial light modulator 5100 and TIR prism 5300 in the optical axis of the projection optical system 5400, and the light source optical system 5200 is positioned in such a manner that the optical axis thereof matches that of the projection optical system 5400.

The TIR prism 5300 directs the illumination light 5600, which is incoming from the light source optical system 5200 placed on the side towards the spatial light modulator 5100 at a prescribed inclination angle as incident light 5601 and transmits a reflection light 5602, reflected by the spatial light modulator 5100, to the projection optical system 5400.

The projection optical system 5400 projects the reflection light 5602, coming in from the spatial light modulator 5100 and TIR prism 5300, onto a screen 5900 as projection light 5603.

The light source optical system 5200 includes a variable light source 5210 for generating the illumination light 5600. The light source system further includes a condenser lens 5220 for focusing the illumination light 5600, a rod type condenser body 5230, and a condenser lens 5240.

The variable light source 5210, condenser lens 5220, rod type condenser body 5230, and condenser lens 5240 are sequentially placed in the aforementioned order on the optical axis of the illumination light 5600 projected from the variable light source 5210 into the side face of the TIR prism 5300.

The projection apparatus 5010 employs a single spatial light modulator 5100 for projecting a color display on the screen 5900 by applying a sequential color display method. That is, the variable light source 5210, comprising a red laser light source 5211, a green laser light source 5212, and a blue laser light source 5213 (which are not shown in the drawing) that allows independent controls for the light emission states, divides one frame of display data into multiple sub-fields (in this case, three sub-fields: red (R), green (G) and blue (B)) and makes each of the light sources emit each respective light in a time series at the time band corresponding to the sub-field of each color. This process will be described in greater detail later.

Fig. 22A is a functional block diagram for showing the configuration of a projection apparatus according to another preferred embodiment of the present invention.
The projection apparatus 5020 is a commonly known as multiple-plate projection apparatus comprising a plurality of spatial light modulators 5100, which is the main difference from projection apparatus 5010 described above. Further, the projection apparatus 5020 includes a control unit 5502 in place of the control unit 5500.

The projection apparatus 5020 includes a plurality of spatial light modulators 5100, and further includes a light separation/synthesis optical system 5310 disposed between the projection optical system 5400 and each of the spatial light modulators 5100.

The light separation/synthesis optical system 5310 includes a TIR prism 5311, a prism 5312 and a prism 5313.

The TIR prism 5311 directs the illumination light 5600, incident from the side of the optical axis of the projection optical system 5400, to the spatial light modulator 5100 as incident light 5601.

The prism 5312 has separates the red (R) light from an incident light 5601, incident by way of the TIR prism 5311 and, making the red light incident to the red light-use spatial light modulators 5100, directs the reflection light 5602R of the red light to the TIR prism 5311.

Likewise, the prism 5313 separates the blue (B) and green (G) lights from the incident light 5601, passing through the TIR prism 5311 to project onto the blue color-use spatial light modulators 5100 and green color-use spatial light modulators 5100, directs the reflection light 5602 of the green light and blue light to the TIR prism 5311.

Therefore, the spatial light modulations of the three color lights R, G and B are carried out simultaneously at three spatial light modulators 5100, respectively, and the reflection lights resulting from the respective modulations are projected onto the screen 5900 as the projection light 5603, by way of the projection optical system 5400; thus a color display is carried out.

Note that various modifications are possible for a light separation/synthesis optical system and is not limited to the light separation/synthesis optical system 5310.

Fig. 22B is a functional block diagram for showing the configuration of a modified embodiment of a multi-panel projection apparatus according to another preferred embodiment of the present invention.

The alternate embodiment includes a light separation/synthesis optical system 5320 in place of the above described light separation/synthesis optical system 5310. The light separation/synthesis optical system 5320 includes a TIR prism 5321 and a cross dichroic mirror 5322.

The TIR prism 5321 directs an illumination light 5600, projected from the lateral
direction of the optical axis of the projection optical system 5400, to the spatial light modulators 5100 as incident light 5601.

The cross dichroic mirror 5322 separates red, blue and green lights from the incident light 5601, incoming from the TIR prism 5321, making the incident lights 5601 of the three colors enter the red-use, blue-use and green-use spatial light modulators 5100, respectively, and also converging the reflection lights 5602, reflected by the respective color-use spatial light modulators 5100, and directing the light towards the projection optical system 5400.

Fig. 22C is a functional block diagram for showing the configuration of yet another modified embodiment of a multi-panel projection apparatus according to the present embodiment.

The projection apparatus 5040 is configured, in contrast from the above described projection apparatuses 5020 and 5030, to place, so as to be adjacent to one another in the same plane, a plurality of spatial light modulators 5100 corresponding to the three colors R, G and B on one side of a light separation/synthesis optical system 5330. This configuration makes it possible to consolidate the multiple spatial light modulators 5100 into the same packaging unit, and thereby saving space.

The light separation/synthesis optical system 5330 includes a TIR prism 5331, a prism 5332 and a prism 5333. The TIR prism 5331 has the function of directing, to spatial light modulators 5100, the illumination light 5600, incident in the lateral direction of the optical axis of the projection optical system 5400, as incident light.

The prism 5332 serves the functions of separating a red color light from the incident light 5601 and directing it towards the red color-use spatial light modulator 5100, and of capturing the reflection light 5602 and directing it to the projection optical system 5400.

Likewise, the prism 5333 serves the functions of separating the green and blue incident lights from the incident light 5601, making them incident to the individual spatial light modulators 5100 equipped for the respective colors, and of capturing the green and blue reflection lights 5602 and directing them towards the projection optical system 5400.

Fig. 23A is a functional block diagram exemplifying the configuration of the control unit 5500 as disclosed in the above described single-panel projection apparatus 5010. The control unit 5500 includes a frame memory 5520, an SLM controller 5530, a sequencer 5540, (a video image analysis unit 5550,) a light source control unit 5560, and a light source drive circuit 5570.

The sequencer 5540, implemented by a microprocessor to control the operation


timing of the entire control unit 5500 and spatial light modulators 5100. The frame memory 5520 stores one frame of input digital video data 5700 received from an external device (not shown in the drawing), connected to a video signal input unit 5510. The input digital video data 5700 is updated in real time every time the display of one frame is completed.

The SLM controller 5530 processes the input digital video data 5700 received from the frame memory 5520 (which are described later), separates the read data into multiple sub-fields 5701 through 5703, and outputs the data to the spatial light modulators 5100 as binary data 5704 and non-binary data 5705, which are used for implementing the ON/OFF control and oscillation control (which are described later) of a mirror 4003 of the spatial light modulator 5100.

The sequencer 5540 outputs a timing signal to the spatial light modulators 5100 in sync with the generation of the binary data 5704 and non-binary data 5705 at the SLM controller 5530.

The video image analysis unit 5550 provides output data of a light source profile control signal 5800, used for generating various light source patterns (which are described later), on the basis of the input digital video data 5700 inputted from the video signal input unit 5510.

The light source control unit 5560 controls the light source drive circuit 5570 to control the operation of the variable light source 5210 for projecting the illumination light 5600 according to a light source profile control signal. The light source profile signal is generated from the light source profile control signal taking into account of the input of the light source profile control signal 5800, received from the video image analysis unit 5550 through the sequencer 5540. The sequencer further generates light source pulse patterns 5801 through 5811 as will be described later.

The light source drive circuit 5570 drives the red laser light source 5211, the green laser light source 5212 and the blue laser light source 5213 of the variable light source 5210 to emit light to generate the light source pulse patterns 5801 through 5811 (which are described later), which are input from the light source control unit 5560.

A single light source drive circuit 5570 drives the laser light sources is depicted in an exemplary configuration as shown at of The three colors; such a configuration may be flexibly configured. An alternative configuration may be such that the three laser light sources (521 i., 5212, and 5213) are driven by three independent light source drive circuits.

The variable light source 5210 shown here further includes a red laser light source 5211, a green laser light source 5212 and a blue laser light source 5213. The configuration may be flexibly adjusted with an alternative configuration includes a single
light source capable for emitting light containing all wavelengths corresponding to colors, including, red (R), green (G) and blue (B).

Further, shown here is such that the operation of the variable light source 5210 is controlled by the input of the light source profile control signal 5800, which is generated by the video image analysis unit 5550, into the light source control unit 5560 by way of the sequencer 5540. The video image analysis unit 5550, however, is not necessarily required. In the absence of the video image analysis unit 5550, the sequencer 5540 may also generate the light source profile control signal 5800 and input it into the light source control unit 5560.

Fig. 23B is a functional block diagram exemplifying the configuration of the control unit of a multi-panel projection apparatus according to the present embodiment.

The control unit 5502 includes a plurality of SLM controllers 5531, 5532 and 5533, which control each of the plurality of spatial light modulators 5100 equipped for the colors R, G and B. The comprisal of the controllers is the main difference from the above described control unit 5500; otherwise they are similar.

That is, the SLM controller 5531, SLM controller 5532 and SLM controller 5533, corresponding to the respective color-use spatial light modulators 5100, are included on the same substrate as those of the respective spatial light modulators 5100. This configuration makes it possible to place the individual spatial light modulators 5100 and the corresponding SLM controller 5531, SLM controller 5532 and SLM controller 5533 close to each other, thereby enabling a high speed data transfer rate.

Further, a system bus 5580 is equipped for commonly connecting the frame memory 5520, light source control unit 5560, sequencer 5540, and SLM controllers 5531 through 5533, in order to speed up and simplify the connection path of each connecting element.

Note that the exemplary configuration shown here is such that a single light source drive circuit 5570 drives the laser light sources of the respective colors; such a configuration is arbitrary. An alternative configuration may be such that the three laser light sources (5211, 5212, and 5213) are driven by three independent light source drive circuits. Don't know if this accurately reflects their idea.

Also, the variable light source 5210 shown here is constituted by the red laser light source 5211, green laser light source 5212, and blue laser light source 5213; the configuration is arbitrary. An alternative configuration may be a single light source capable of emitting light containing all wavelengths corresponding colors, including, red (R), green (G) and blue (B).
Also, Fig. 23B exemplifies the case of inputting the light source profile control signal 5800, which is generated by the video image analysis unit 5550, into the light source control unit 5560 by way of the sequencer 5540. The video image analysis unit 5550, however, is not necessarily required. In the absence of the video image analysis unit 5550, the sequencer 5540 may also generate the light source profile control signal 5800 and inputs it into the light source control unit 5560.

Fig. 23B also shows each of the spatial light modulators 5100 of the three colors equipped with their individual SLM controllers; such a configuration is arbitrary. An alternative configuration may be such that a single SLM controller is used to control the multiple spatial light modulators 5100. In this case, a single chip SLM controller is capable of controlling multiple spatial light modulators 5100, thereby making it possible to produce a more compact apparatus.

Fig. 24A is a functional block diagram for showing the configuration of the light source drive circuit 5570 (i.e., the light source drive circuits 5571, 5572 and 5573) according to the present embodiment. Note that the configuration here exemplifies the case of equipping the light source drive circuit for each of the colors: red (R), green (G) and blue (B).

The light source drive circuit showed in Fig. 24A includes a plurality of constant current circuits 5570a (i.e., I (R, G, B)i through I (R, G, B)n) and a plurality of switching circuits 5570b (i.e., switching circuits SW (R, G, B)i through SW (R, G, B)n), which correspond to the respective constant current circuits 5570a, in order to obtain the desired light intensities of emission Pi through Pn for the light source optical system 5200 (i.e., the red laser light source 5211, green laser light source 5212 and blue laser light source 5213).

The switching circuit 5570b carries out a switching operation in accordance with a designated emission profile of the light source optical system 5200 (i.e., the red laser light source 5211, green laser light source 5212 and blue laser light source 5213).

The setup values of the output current of the constant current circuits 5570a (i.e., constant current circuits I (R, G, B)i), when the gray scale of the emission intensity of the light source optical system 5200 is designated at N bits (where N>n), are as follows:
Here, what is shown is an example of a gray scale display on the basis of an emission intensity; a similar gray scale display is achievable even if the emission period (i.e., an emission pulse width), and the emission interval (i.e., an emission cycle) are variable.

The relationship between the emission intensity of the variable light source and drive current for each color is as follows. Note that "k" is an emission efficiency corresponding to the drive current:

\[
P_1 = k \cdot (VH_1)
\]
\[
P_2 = k \cdot (I_{th1} + I_1 + I_2 + \ldots + I_{n-1} + I_n)
\]

Fig. 24B is a functional block diagram for showing an alternate embodiment of the configuration of the light source drive circuit according to the present embodiment.

For simplicity, Fig. 24B shows the constant current circuits 5570a (I (R, G, B)i through I (R, G, B)n) as Ii through In and the switching circuits 5570b (SW (R, G, B), through SW (R, G, B)n) as switching circuits 5570b (SWi through SWn).

As will described later, the light source drive circuits 5570 according to the present embodiment is configured to make the individual constant current circuit 5570a (i.e., I (R, G, B)i in this case) supply a current value equivalent to the threshold current Ith of the light source optical system 5200, or a current value close to the aforementioned threshold current, as a bias current Ith when a semiconductor laser or the like is used as the light source optical system 5200, because a high speed current drive is required. This makes it possible to stabilize the respective switching operation of the light source drive circuits 5570 of the present embodiment and also enable a high speed emission.

The light source drive circuits 5570 (i.e., the light source drive circuits 5571, 5572,
and 5573) exemplified in Fig. 24B includes bias current circuits 5570c, which are continuously connected to the light source optical systems 5200 (i.e., the red laser light source 5211, green laser light source 5212 and blue laser light source 5213), are used for applying a bias current \( I_b \), in addition to the constant current from the constant current circuits 5570a.

Further, the connection of the constant current circuits 5570a to the entirety of the light source optical systems 5200 is configured by means of a switching circuit 5570d (SW\(_{\text{pulse}}\) is included in the downstream side of the switching circuits 5570b.

Fig. 24B shows the configuration wherein the relationship between the emission intensity \( P_n \) and drive current of the variable light source for each wavelength is as follows, where "\( k \)" is the emission intensity in terms of drive current:

\[
\begin{align*}
P_b &= k^*I_b (I_b=I_f) \\
P_c &= k^*(I_{th}+I_f) \\
P_2 &= k^*(I_{th}+I_1+I_2) \\
& \quad \vdots \\
P_n &= k^*(I_{th}+I_1+I_2+\ldots+I_{n-1}+I_n)
\end{align*}
\]

The relationship between each switching operation and emission output is as follows:

SW\(_{\text{pulse}}\)=OFF: \( P_b = k^*I_b - 0 \) [mW] (where \( I_b = I_f \))

SW\(_1\): \( P_1 = k^*(I_b+I_f) \)

SW\(_2\): \( P_2 = k^*(I_{th}+I_1+I_2) \)

\( \quad \vdots \)

\( \quad \vdots \)

SW\(_n\): \( P_n = k^*(I_{th}+I_1+I_2+\ldots+I_{n-1}+I_n) \)

With this, it is possible to achieve an emission profile that has an emission intensity \( P_b \) nearly zero, as shown in Fig. 25.

The use of the switching circuits 5570d as that shown in Fig. 24B makes it possible to implement a circuit operation unaffected by a drive current switching over caused by the switching circuits 5570b (SW\(_i\) through SW\(_n\) that are connected to the respective constant current circuits 5570a. Particularly, a further effect is expected if the above-described switching circuits (SW\(_i\) through SW\(_n\)) are switched over when the variable light source (i.e., the variable light source 5210) is not emitting light.
While the bias current value is designated at a fixed current value in the configuration of Fig. 24B, it is also possible to connect the bias current circuits 5570c to the light source control unit 5560 to generate a variable bias current.

Fig. 26 is a diagram for showing the relationship between the applied current I and the emission intensity P in the light source drive circuit described for Fig. 24A. Note that the relationship between the applied current from the constant current circuits 5570a of the light source drive circuit (shown in Fig. 24B) and the emission light intensity P is similar. In the case of the light source drive circuit, however, the threshold current Ith shown in Fig. 26 is replaced with a bias current Ib. An emission light intensity corresponding to the current Ib is an emission light intensity Pb that is nearly zero ("0").

Figs. 24A and 24B exemplify the case of changing the emission profiles of the variable light source for each sub-frame corresponding to each gray scale bi.; A parallel use with the display gray scale function of the spatial light modulators 5100 reduces the number of required current levels, making it possible to not only reduce the number of constant current circuits 5570a and switching circuits 5570b but also to attain the same grade of gray scale of the display gray scales, or higher.

Next is a description, in detail, of one exemplary configuration of the spatial light modulator 5100 according to the present embodiment. The spatial light modulator 5100 according to the present embodiment is a deflective mirror device arraying a plurality of mirror elements.

Fig. 27A is a functional block diagram exemplifying the internal configuration of a spatial light modulator 5100 according to the present embodiment.

Fig. 27B is a functional block diagram exemplifying the configuration of each pixel unit constituting the spatial light modulator 5100 according to the embodiment.

As exemplified in Fig. 27A, the spatial light modulator 5100 according to the present embodiment includes a mirror element array 5110, column drivers 5120, ROW line decoders 5130, and an external interface unit 5140.

The external interface unit 5140 includes a timing controller 5141 and a selector 5142. The timing controller 5141 controls the ROW line decoder 5130 on the basis of a timing signal from the SLM controller 5530. The selector 5142 supplies the column driver 5120 with digital signal incoming from the SLM controller 5530.

In the mirror element array 5110, a plurality of mirror elements 4001 is arranged in arrays at the positions where individual COLUMN lines, which are vertically extended respectively from the column drivers 5120, crosses individual ROW lines which are horizontally extended respectively from the ROW decoders 5130.
Note that the present exemplary configuration shows the ROW line decoder 5130 includes two ROW line decoders 5130a and 5130b that are provided on either side, with the mirror element array 5110 sandwiched between. One half of the mirror elements 4001, arrayed in the mirror element array 5110, are controlled by the ROW line decoder 5130a, and the other half are controlled by the ROW line decoder 5130b, and thereby the loading time of the electric charge to the capacitor, by way of the gate transistor is reduced, and the operation of tilting the mirrors can be accomplished at a higher speed.

Alternatively, the ROW line decoder 5130 may be equipped on only one side of the mirror element array 5110 to control all the mirror elements 4001.

As exemplified in Figs. 8A through 8D, the individual mirror element 4001 includes a mirror 4003 supported on the device substrate 4004 via the elastic hinge 4007. Furthermore, a cover glass (not shown) covers and protects the mirror 4003.

Address electrodes 4008a and 4008b are placed on the device substrate 4004 symmetrically about the elastic hinge 4007, sandwiched in the middle.

When a predetermined potential is applied to the address electrode 4008a, it attracts the mirror 4003 with a coulomb force and tilts the mirror 4003 so that the mirror 4003 abuts the address electrode 4008a. This causes the incident light 5601 incident to the mirror 4003 to be reflected towards the light path of an OFF position, that is, shifted from the optical axis of a projection optical system 5400.

When a predetermined potential is applied to the address electrode 4008b, it attracts the mirror 4003 with a Coulomb force and tilt the mirror 4003 so that the mirror 4003 abuts the address electrode 4008b. This causes the incident light 5601 incident to the mirror 4003 to be reflected towards the light path of an ON position, matching the optical axis of the projection optical system 5400.

Further, while not shown in a drawing here, an OFF stopper and an ON stopper may be equipped in the device. In that case, the mirror 4003 reflects the incident light 5601 when abutting the OFF stopper (in place of the address electrode 4008a) or abutting the ON stopper (in place of the address electrode 4008b.)

Fig. 28 is a chart showing the transition time between the ON state and OFF state of the mirror 4003. In a transition from the OFF state, in which the mirror 4003 abuts the address electrode 4008a, to the ON state in which the mirror 4003 is abuts the address electrode 4008b, a rise time $t_r$, in the early stage of starting the transition, is required before the mirror 4003 fully reaches the ON state; in a transition from the ON state to the OFF state, a fall time $t_f$ is likewise required before the mirror fully reaches the OFF state.

Since the reflection light 5602 is in the transition state during both the rise time $t_r$
and the fall time $t_f$, the control using the ON/OFF states generates an error in the grayscale display. Therefore, the present embodiment is configured to suppress the emission of the variable light source 5210 in the transition state, thereby eliminating the use of the reflection light 5602 in the transition state.

When using a nondirective light source, such as a conventional high pressure mercury lamp or xenon lamp, the expansions of incident light 5601 and reflection light 5602 are large, and therefore the tilt angle of the mirror 4003 needs to be set at about $\pm 12$ degrees (24 degrees total) in order to increase the contrast by avoiding the interference between the aforementioned two lights 5601 and 5602. Consequently, both the rise time $t_{r24}$ and fall time $t_{f24}$ are extended in the ON/OFF control of the mirror 4003, and the voltage ($V_{24}$) applied to the ON electrode 5115 and OFF electrode 5116, to tilt the mirror 4003 by means of static electric attraction, is also increased.

In contrast, the projection apparatus according to the present embodiment employs the variable light sources 5210, the red laser light source 5211, green laser light source 5212 and blue laser light source 5213. The coherent lights, as implemented, allows the projection system to properly function with smaller tilt angle $\theta$. The mirror 4003 is now controlled to operate in a range of about $\pm 8$ degrees (= 16 degrees total). As a result, the rise time $t_{r6}$ and fall time $t_{f6}$ can also be reduced from the conventional rise time $t_{r24}$ and fall time $t_{f24}$.

Also, the voltage ($V_{16}$) to be applied to the ON electrode 5115 and OFF electrode 5116 can also be reduced from the conventional voltage ($V_{24}$) because the distance between the mirror 4003 and either of the aforementioned electrodes is shortened, as described later.

Fig. 27B shows a mirror device 4003 includes a mirror element 4001 supported on an elastic hinge 4007 for retaining the mirror 4003; address electrodes 4008a and 4008b; and two memory cells, i.e., a first memory cell 4010a and a second memory cell 4010b, which apply a voltage to the address electrodes 4008a and 4008b in order to control the mirror 4003 under a desired deflection state.

The first and second memory cells 4010a and 4010b each have a dynamic random access memory (DRAM) structure comprising field effect transistors (FETs) and a capacitance in this configuration. The structures of the individual memory cells 4010a and 4010b are not limited as such and may instead be configured as, for example, a static random access memory (SRAM) structure.

Furthermore, the individual memory cells 4010a and 4010b are connected to the respective address electrodes 4008a and 4008b, the COLUMN line 1, the COLUMN line 2, and a ROW line.
In the first memory cell 4010a, an FET-I (i.e., a gate transistor 5116c) is connected to the address electrode 4008a, the COLUMN line 1, and the ROW line. A capacitance Cap-1 (i.e., an OFF capacitor 5116b) is connected between the address electrode 4008a and GND (i.e., the ground). Likewise in the second memory cell 4010b, an FET-2 (i.e., a gate transistor 5115c) is connected to the address electrode 4008b, the COLUMN line 2, and the ROW line. A capacitance Cap-2 (i.e., an ON capacitor 5115b) is connected between the address electrode 4008b and GND.

Application of a predetermined voltage to the address electrodes 4008 thus controls the signals on the COLUMN line 1 and ROW line for deflecting the mirror 4003 towards the address electrode 4008a. Likewise, controlling the signals on the COLUMN line 2 and ROW line applies a predetermined voltage to the address electrode 4008b, thereby making it possible to tilt the mirror 4003 towards the address electrode 4008b.

More specifically, the turning on and off of both the gate transistor 5116c and gate transistor 5115c are controlled by the ROW line. That is, the mirror elements 4001 on one horizontal line aligned with an arbitrary ROW line are simultaneously selected and the charging/discharging the electrical charge to/from the OFF capacitor 5116b and ON capacitor 5115b are controlled by the COLUMN lines 1 and 2. As a result the ON/OFF states of the mirror 4003 of the individual mirror elements aligned on one horizontal line are carried out.

Note that a drive circuit for each of the memory cells 4010a and 4010b is commonly equipped internally in the device substrate 4004. Controlling the respective memory cells 4010a and 4010b, in accordance with the signal of image data, enables the control of the deflection angle of the mirror 4003 and the demodulation and reflection of the incident light.

Fig. 29 is a functional block diagram exemplifying a placement of ROW lines to control mirrors of a spatial light modulator according to an exemplary modification of the present embodiment.

In the case of the exemplary modification, ROW lines 5131-1 and 5131-2 can be equipped to simultaneously drive the gate transistors 5115c and 5116c, respectively, as exemplified in Fig. 29.

The ROW lines 5131-1 and 5131-2 are driven from the row line decoders 5130 using a common drive circuit (not shown in the drawing).

As described above, the ROW lines 5131-1 and 5131-2, driving the gate transistor 5115c and gate transistor 5116c, make it possible to reduce the loading time of charge to the ON capacitor 5115b and OFF capacitor 5116b, by way of the gate transistor 5115c and
5116c, respectively, and accomplish a high speed operation of tilting the mirror 4003, such as an ON/OFF and oscillation.

The following is a description of an example operation of a projection apparatus according to the present embodiment.

Input digital video data 5700 inputted into a video signal input unit 5510 is outputted to frame memory 5520 and also to a video image analysis unit 5550.

An SLM controller 5530 reads the input digital video data 5700 from the frame memory 5520, converts the read data into, for example, binary data 5704 that is pulse width-modulated, or into non-binary data 5705, and inputs the converted data to a column driver 5120 by way of an external interface unit 5140, as a control signal to the spatial light modulator 5100 for the ON/OFF control or oscillation control of the mirror 4003.

The pulse width-modulated binary data 5704 is data possessing a pulse width in accordance with the weighting value of each bit.

The non-binary data 5705 is the data obtained by converting the input digital video data 5700 into a bit string that includes continuous bits of "1" corresponding to a brightness value, with each bit of the non-binary data 5705 having the same weighting (e.g., "1").

Further, a sequencer 5540 outputs a synchronous signal, such as VSYNC, which is outputted from the SLM controller 5530 in sync with the input digital video data 5700, to the ROW line decoder 5130 of the spatial light modulator 5100.

With this, the displaying/updating of one screen (i.e., one frame) is carried out by the ROW line decoder 5130 controlling, in sync with each scan line of the input digital video data 5700, the ON/OFF or oscillation states of the mirrors 4003 and the mirror elements 4001 belonging to one ROW line.

Note that, when carrying out a color display in a color sequence method using a single-panel projection apparatus (comprising one SLM) 5010 exemplified in Fig. 21, one frame (i.e., a frame 5700-1) of the input digital video data 5700 is constituted by multiple subfields, i.e., the subfields 5701, 5702 and 5703, which are aligned in a time series corresponding to the respective colors R, G and B, as exemplified in Fig. 30A. The above described binary data 5704 or non-binary data 5705, or a mixed data (not shown in the drawing) obtained by combining these pieces of data, is generated for each of the aforementioned subfields.

When using a multi-panel projection apparatuses (comprising three SLMs) 5020, 5030 and 5040, a plurality of subfields 5700-2 (which are equivalent to subfields 5701, 5702 and 5703) corresponding to the respective colors R, G and B are simultaneously
outputted to the plurality of spatial light modulators 5100, respectively, as exemplified in Fig. 30B, and the spatial light modulations for the respective colors are simultaneously performed.

Also in this case, the above described binary data 5704 or non-binary data 5705 is generated for each field 5700-2.

The present embodiment is configured such that the video image analysis unit 5550 of the control unit 5500 detects the timing of the change in signal waveform of the binary data 5704 or non-binary data 5705 from the input digital video data 5700, generates a light source profile control signal 5800 to control the red laser light source 5211, green laser light source 5212 and blue laser light source 5213, of the variable light source 5210, and inputs the generated signal to the light source control unit 5560 by way of the sequencer 5540.

This configuration implements the control for the variable light source 5210 in sync with the timing of the change in signal waveforms of the binary data 5704 or non-binary data 5705 of the input digital video data 5700, as described later.

That is, as exemplified in Figs. 25 and 31, the projection apparatus according to the present embodiment is configured such that the SLM controller 5530 controls the spatial light modulator 5100 so that at least two mirror elements (i.e., mirror elements 4001) perform a modulation corresponding to the least significant bit (LSB) within a predetermined period of one frame. Further, the light source control unit 5560 (i.e., the video image analysis unit 5550) changes the emission profiles of the variable light source in a period equal to or less than the predetermined period and obtains the minimum grayscale output.

The emission profile shows the emission state change of the variable light source 5210, such as the emission intensity, emission period, emission pulse width, emission interval, and the number of emission pulses.

This configuration makes it possible to control each mirror element 4001. The modulation control signals are corresponding to the LSB of all mirror elements 4001 in each group occur within a predetermined period of time when the mirror element array 5110 of a spatial light modulator 5100, or a plurality of mirror elements 4001 of the mirror element array 5110, are controlled by dividing into a plurality of groups, and to control the emission profile of the variable light source 5210 in high speed within a period in which the modulation states of desired mirror elements match.

As a result, the projection apparatus of the present embodiment is enabled to achieve a higher resolution of gray scales that is even higher than that of the spatial light
modulator 5100 controlled by using a greater number of bits.

Note that light source control unit 5560 includes a larger number of types of emission profiles than the number of display grayscale bits of the spatial light modulator 5100.

In the case of the present embodiment, when carrying out a gray scale display of binary image data by using sub-frames having periods corresponding to the weighting of individual data bits for each frame by means of a pulse width modulation (PWM), the influence of the transition period of the modulation states is different for each frame. Further, each sub-frame period is different in accordance with the corresponding display grayscale bit as described above, and therefore, the emission profile for each sub-frame is different. Further, when performing a grayscale display in excess of the display grayscale of the spatial light modulator 5100, the number of sub-frames will further increase.

Fig. 25 exemplifies the control of the variable light source 5210 for controlling the spatial light modulator 5100 by means of binary data 5704.

In this case, the ON/OFF state of the mirror 4003 changes as indicated by a mirror modulation control waveform 5120a by tracing the waveform of the binary data 5704, the change in the rise, and the change in the fall, of the mirror modulation control waveform 5120a, however, are delayed by the respective amount of the rise time \( t_r \) and fall time \( t_f \) relative to the binary data 5704.

The present embodiment is configured to control the variable light source 5210 so as to be turned on only for the period in which the ON section of the binary data 5704 overlaps with the ON period of the mirror modulation control waveform 5120a with the rise time \( t_r \) and fall time \( t_f \) removed, in at least an LSB-corresponding modulation period \( t_{\text{LSB}} \), as indicated by the light source pulse patterns 5801, 5802 and 5803.

With this control, the variable light source 5210 is turned off during the transition periods of the rise time \( t_{\text{r}} \), in which the mirror 4003 shifts from the OFF to ON states, and of the fall time \( t_{\text{f}} \), in which the mirror 4003 shifts from the ON to OFF states. This configuration better enables an implementation of high gradation, as compared to the performance of the spatial light modulator 5100, by reducing, for example, an error factor in the LSB-corresponding modulation period \( t_{\text{LSB}} \).

That is, in the case of the present embodiment, the light source control unit 5560 controls the variable light source 5210 so that the period in which the modulation states of the spatial light modulator 5100 shift, influencing the display image, is reduced.

The spatial light modulator 5100 attains a desired display gray scale by changing the voltages applied to the individual mirror elements 4001 and the deflection state of the
mirror 4003. The transition action of the spatial light modulator 5100 between the respective modulation states has been a limiting factor in the resolution and linearity of the display gray scale and the minimum display gray scale.

With an aim towards preventing the degradation of the resolution and linearity, the present embodiment is configured to use a variable light source 5210 capable of being controlled in a higher speed than the modulation state transition period of the spatial light modulator 5100 and to change the emission profiles of the variable light source 5210 in high speed within the transition period, thereby improving the display gray scale accuracy in a projection apparatus.

The light source pulse pattern 5801 exemplifies the case of controlling the variable light source 5210 so as switch between the switch-off state with the emission intensity \( P_b \) and the switch-on state with the constant emission intensity \( P_i \).

The light source pulse pattern 5802 exemplifies the case of controlling the emission intensity of the variable light source 5210 during the switch-on period so that the emission intensity gradually increases stepwise from an emission intensity \( P_i \) (corresponding to the MSB) to an emission intensity \( P_2 \), to an emission intensity \( P_3 \), to an emission intensity \( P_4 \), to an emission intensity \( P_5 \) (corresponding to the LSB), in accordance with the pulse widths of the binary data 5704, for which the switch-on period gradually decreases from the MSB toward the LSB, depending on the weightings of respective bits.

Further, the light source pulse pattern 5803 exemplifies the case of performing a control so as to compensate for a light volume loss during the period the emission is suppressed in the section of one rise time \( t_r \) by locally adding the pulse of an emission intensity \( P_{hi} \), which is larger than the emission intensity \( P_i \), immediately after the rise time \( t_r \) of the mirror modulation control waveform 5120a.

The light source pulse pattern 5804 exemplifies the case of compensating for a light volume loss during the period of one rise time \( t_r \) by adding two pulses of emission intensity \( P_{h2} \).

These controls can be implemented by selectively turning ON the above described switching circuit 5570b.

Such control of the light source pulse pattern 5802 makes it possible to compensate for a shortage of emission intensity due to a switch-off in the period of a rise time \( t_r \) and fall time \( t_f \) on the LSB side, in which the pulse width is small and the influences of the aforementioned rise time \( t_r \) and fall time \( t_f \) increases.

Considering the N string of rows of the mirror element array 5110 corresponding
to the N lines of horizontal scan lines, as exemplified in Fig. 32, there is the difference between the first row (Row-1) and the last row (Row-N) in the delay time to of the control start timings of the mirror modulation control waveform 5120a.

For such a case, a configuration is accordingly devised in which the switch-on timing is shifted by the [rise time $t_r$ + delay time $t_{D2}$] for the rise side of the pulse and by the [fall time $t_f +$ delay time to] for the fall side of the pulse, and thereby the ON period of the mirror modulation control waveform 5120a overlaps with the ON period of the light source pulse pattern 5805, at least during the period of the LSB-corresponding modulation period $t_{LSB}$.

In this case, in order to secure an overlap in the LSB-corresponding modulation period $t_{LSB}$, the following conditions must be satisfied:

- [delay time $t_D +$ rise time $t_r$] $<$ LSB-corresponding modulation period $t_{LSB}$, and
- [delay time $t_D +$ fall time $t_f$] $<$ LSB-corresponding modulation period $t_{LSB}$

Therefore, the present embodiment is configured such that the SLM controller 5530 groups the mirror elements 4001 of the spatial light modulator 5100 so that the emission period of the changed emission profile is less than the modulation period corresponding to the least significant bit and controls the mirror elements 4001 in units of the group.

Further, the SLM controller 5530 changes the modulation periods corresponding to the least significant bit (LSB) of the individual mirror elements (i.e., LSB-corresponding modulation period $t_{LSB1}$ and LSB-corresponding modulation period $t_{LSB2}$) on an as needed basis so that the modulation periods corresponding to the least significant bit (LSB) (i.e., LSB-corresponding modulation period $t_{LSB}$) of the individual mirror elements 4001 overlap at least in a part, as exemplified in Fig. 33.

Next is a description of the case of controlling a spatial light modulator (SLM) using non-binary data, with reference to Figs. 31, 34 and 35.

In this example, the SLM controller 5530 controls the spatial light modulator 5100 using non-binary image data (i.e., non-binary data 5705).

As shown in Figs. 31 and 34, when a modulation control for the spatial light modulator 5100 is carried out by using the non-binary data 5705, which has been obtained by converting image data from a binary form into a non-binary form, it is predicted that a plurality of sub-frames, in which the display gray scale to be displayed is the same, will be generated because each bit of the non-binary data 5705 has the same weight. When such a spatial light modulator is controlled, the emission profiles of a variable light source 5210 corresponding to sub-frames, of which the display grayscale to be displayed are the same,
are the same profile, and therefore the emission profile does not need to be changed for each sub-frame.

The examples in Figs. 31 and 34 illustrate the case of assigning the upper four bits (D6 through D3) from the MSB to the ON/OFF control of the mirror 4003 and the lower three bits (D2 through DO) from the LSB to the oscillation control, thereby implementing a gray scale control.

Focusing on one mirror 4003 (i.e., the mirror element 4001), Fig. 31 exemplifies the case of turning on and off (i.e., flashing) the variable light source 5210 by means of the ON/OFF control at a predetermined cycle during the ON period of the mirror 4003 (i.e., the mirror modulation control waveform 5120a) in the light source pulse pattern 5807. The start timing of an ON/OFF cycle, however, is controlled to be synchronous with the ON period of a mirror modulation control waveform 5120a by avoiding the rise time \( t_f \) of the present mirror modulation control waveform 5120a.

Further, the light source pulse pattern 5807 exemplifies the case of controlling the variable light source 5210 to be continuously turned on during the period in which the ON period of the mirror modulation control waveform 5120a shifts to the oscillation (OSC) control mode and during the period of the oscillation control mode.

As described above, controlling the cycle of flashing of the variable light source 5210 during the ON period of the mirror 4003 makes it possible to attain a minute display gray scale equivalent to, or more than, the ON/OFF control of the mirror 4003.

The light source pulse pattern 5808 exemplifies the case of continuously turning on the variable light source 5210 after turning it off once function synchronously with the fall time \( t_f \) when the mirror modulation control waveform 5120a shifts from the ON state to oscillation state. In this case, the column driver 5120 is turned off during a transition from the ON state of the mirror modulation control waveform 5120a to the oscillation state, and thereby noise can be reduced in the aforementioned transition period.

The light source pulse pattern 5809 exemplifies the case of flashing the variable light source 5210 in a predetermined cycle independent of the ON/OFF state or oscillation state of the mirror modulation control waveform 5120a. However, the variable light source 5210 is controlled, by the flashing cycle and start timing, to be turned off during the rise time \( t_r \) and fall time \( t_f \) of the mirror modulation control waveform 5120a. This configuration makes it possible to reduce the noise attributed to light emission during the rise time \( t_r \) and fall time \( t_f \).

Fig. 34 exemplifies the case of controlling the timing of flashing and turning on the variable light source 5210, by taking a delay time \( t_d \) into consideration when the
-58-
aforementioned delay time to occurs in the control timing of a mirror element 4001 belonging to a different row of the mirror element array 5110, in the case of controlling the spatial light modulator 5100 using non-binary data 5705.

The light source pulse pattern 5810 exemplifies the case of controlling the variable light source 5210 in a predetermined cycle by delaying [delay time tD + rise time tR] and [delay time tD + fall time tF] relative to the ON period of the mirror modulation control waveform 5120a. Further, the light source pulse pattern 5810 makes the end of a switch-off and the end of the oscillation mode of the first row (Row-1) match one other.

In contrast, the light source pulse pattern 5811 differs from the above described light source pulse pattern 5810 in that the former makes the end of a switch-off and the end of the oscillation mode of the last row (Row-N) match each other, otherwise the two patterns are similar to each other.

Fig. 35 exemplifies a modified embodiment of the control of the spatial light modulator 5100 using non-binary data.

In the light source pulse pattern 5812, the heights of the flashing pulse (that is, the emission intensity) of the variable light source 5210 are changed so as to gradually decrease stepwise in each of the OFF states, ON states, and oscillation states of the mirror modulation control waveform 5120a.

The variable light source 5210 is controlled by pulses to flash (noted as "flashing pulse" hereinafter) so as to emit light in the emission intensity P4 during, for example, the OFF period of the mirror modulation control waveform 5120a, and is controlled to flash so as to emit light in the emission intensity P3 during the first half of the ON period of the mirror modulation control waveform 5120a and also in the emission intensity P2 in the second half of the ON period thereof. Further, the variable light source 5210 is controlled under a flashing pulse so as to emit light in the emission intensity Pi during the oscillation period of the mirror modulation control waveform 5120a.

Further, the switch-on pulse for the emission light intensities P4, P3, P2 and Pi are constituted by the flashing pulse in finer minute cycles.

Controlling the variable light source 5210 by means of the light source pulse pattern 5812 makes it possible to attain a display gray scale with finer gradations than the single gray scale display of the spatial light modulator 5100.

Here, the pulse emission characteristic of the variable light source 5210 for implementing the above-described control according to the present embodiment is examined.

In the multi-panel projection apparatus which includes the spatial light modulators
5100 for each of the colors and which uses the variable light source 5210 comprising the red laser light source 5211, green laser light source 5212 and blue laser light source 5213, as shown in Fig. 22A, the display period of a sub-frame corresponding to the least significant bit (LSB) for attaining a 10-bit individual color display grayscale is 16.3 [μsec] (refer to Fig. 30B).

In order to limit the influence of the transition period between the individual deflection states of a mirror to no more than the equivalent of 1/5*LSB in a common mirror device, it is necessary to achieve "LSB display period" = 4*t_r (where t_r is a rise time) as shown in Fig. 28, requiring the transition time of the mirror 4003 be limited to no more than 4.1 [μsec].

Even when using a mirror device capable of achieving such a characteristic, the pulse emission needs to possess a pulse emission characteristic of 9.2 [μsec] in order to have at least 75% steady state for the variable light source 5210 to attain the aforementioned pulse emission, such as the light source pulse pattern 5801 (i.e., Light pulse pattern-1) exemplified in Fig. 25 of the present embodiment.

Therefore, the present embodiment includes the variable light source 5210 and light source control unit 5560, which possess at least a pulse emission characteristic of 9.2 [μsec].

The following describes a similar examination of the single-panel projection apparatus according to the present embodiment, as exemplified in Fig. 21.

In the projection apparatus 5010 using the R, G and B variable light sources and a single spatial light modulator 5100, as shown in Fig. 21, the display period of a sub-frame corresponding to the least significant bit (LSB) for attaining a 10-bit individual color display grayscale is 5.43 [μsec] (refer to Fig. 30A).

In order to limit the influence of the transition period between the individual deflection states of the mirror 4003 to no more than the equivalent of 1/5*LSB in a common mirror device, it is necessary to achieve "LSB display period" = 4*t_r (where t_r is a rise time) as shown in Fig. 28, requiring the transition time of the mirror 4003 be limited to no more than 1.36 [μsec].

Even when using a mirror device capable of achieving such a characteristic, the pulse emission needs to possess a pulse emission characteristic of at least 3.1 [μsec] in order for the variable light source 5210 to attain the pulse emission such as the light source pulse pattern 5801 (i.e., Light pulse pattern-1) exemplified in Fig. 25 of the present embodiment.

Therefore, in the projection apparatus 5010, the present embodiment includes the
variable light source 5210 and light source control unit 5560, which possess at least a pulse emission characteristic of 3.1 [μsec].

What follows is a description an example of and reason for setting the displacement angle of the mirror 4003, which constitutes the spatial light modulator 5100, in each deflection period and deflection state at no more than ±8 degrees, as in the case of the present embodiment.

As described above, the present embodiment allows a use of color laser light sources, for example, a semiconductor laser for the red laser light source 5211, green laser light source 5212 and blue laser light source 5213, as the variable light source 5210.

When a mirror device as described above is used as the spatial light modulator 5100 for a projection apparatus, such as the above described projection apparatuses 5010, 5020, 5030 and 5040, and if a semiconductor laser is selected for the variable light source 5210, as described above, the semiconductor laser enables a reduction of the deflection angle of the mirror 4003 required for obtaining the desired contrast, as compared with a case using a conventional light source, such as a high pressure mercury lamp.

As a result, in the structure of the spatial light modulator 5100 constituted by a mirror device, the distance between the mirror 4003 and address electrodes, such as the address electrodes 4008b and 4008a, can be reduced, and therefore a coulomb force maintaining or changing the deflection state(s) of the mirror 4003 is reduced in proportion to the second power of the distance between the mirror 4003 and address electrode. This reduction makes it possible to apply a sufficient voltage to the address electrodes, such as the address electrodes 4008b and 4008a, and also to control the mirror 4003 by taking advantage of a larger coulomb force, thereby shortening the mirror transition time, the rise time $t_r$ and fall time $t_f$, which are noted in Fig. 28.

As described above, the present embodiment is configured to change the emission profiles of the variable light source 5210 so as to reduce the influence of the mirror transition periods, rise time $t_r$ and fall time $t_f$.

If the variable light source 5210 is controlled to emit no light or a reduced emission intensity level of light during the transition period of the mirror 4003 as, for example, the light source pulse patterns 5801 through 5803 (i.e. the Light pulse patterns 1 through 3), which are exemplified in Fig. 25, a light intensity obtained in one frame period (or a light intensity obtained by an entire "white" display) will be reduced (i.e., lost) by the amount of the transition period of the mirror 4003.

Therefore, decreasing the deflection angle of the mirror 4003, as in the present embodiment, reduces a loss of the light intensity obtained in one frame period and
therefore increases light-usage efficiency, accuracy, the gradation of the display image.

Further, the present embodiment is configured to reduce the tilt angle of the mirror to no more than ±8 degrees, making it possible to reduce the difference in potentials (noted as "potential difference" hereinafter), to be applied between the mirror 4003 and address electrodes (i.e., the address electrodes 4008b and 4008a) to start up and drive the mirror 4003 of the spatial light modulator 5100, to no higher than 5 volts, and more desirably, no higher than 3.3 volts.

That is, there is a relationship between the voltage, which is to be applied between the mirror 4003 and address electrodes, and the deflection angles of the mirror 4003 between the respective deflection states, and therefore, the spatial light modulator 5100, which is enabled for a low-voltage drive, attains a high light-usage efficiency, high accuracy, high-grade gradation image display.

Further, the miniaturization of the mirror 4003 and, accordingly, that of the mirror array 5110, are accompanied by the capability of driving the mirror 4003 with a lower applied voltage.

<Embodiment 3>

The following is a description, in detail, of the preferred embodiment of the present invention with reference to the accompanying drawings.

The following describes various embodiments, with the configurations and operations of the projection apparatuses exemplified above taken into consideration. Note that the same reference symbols are assigned to the same constituent components as the above-described configurations, and an overlapping description will not be provided.

In the case of the single-panel projection apparatus (IxSLM; comprising a single SLM), exemplified in the above described Fig. 21, in the case of the present embodiment, one frame of input digital video data 5700 (i.e., a frame 6700-1) is constituted by a plurality of sub-frames 6701, 6702 and 6703 in a time series corresponding to the respective colors R, G and B, and binary data 6704 or non-binary data 6705 is generated for each subfield as described above, as exemplified in Fig. 30A.

Meanwhile, in the case of the above described multi-panel projection apparatus (3xSLM; comprising three SLMs) 5020, 5030 and 5040, a plurality of subfields 6700-2 (i.e., equivalent to subfields 6701, 6702 and 6703) corresponding to the respective colors R, G and B are simultaneously outputted to the respective spatial light modulators 5100, and the spatial light modulation for the respective colors are carried out simultaneously during the display period of one frame (i.e., a frame 6700-1) as exemplified in Fig. 30B.

Also in this case, the above described binary data 6704 or non-binary data 6705 is
generated for each subfield 6700-2 of each respective color.

The present embodiment is configured such that the video image analysis unit 5550 of the control unit 5500 detects, from the input digital video data 5700, the timing of a change of the signal waveforms of the binary data 6704 or non-binary data 6705, generates a light source profile control signal 6800, used to control the ON/OFF of the red laser light source 5211, green laser light source 5212 and blue laser light source 5213 of the variable light source 5210, and inputs the signal to the light source control unit 5560 by way of the sequencer 5540.

This configuration implements the ON/OFF control (which is described later) of the variable light source 5210 in sync with the timing of a change in the signal waveforms of the binary data 6704 or non-binary data 6705 of the input digital video data 5700.

<Embodiment 3-I>

A sequencer 5540 of the control unit 5500 exemplified in Fig.23A includes the function of receiving, as input, control signals, including a mirror control profile 6710 and a mirror control profile 6720, such as binary data 6704 or non-binary data 6705, which are outputted to a spatial light modulator 5100 from a SLM controller 5530, generating a light source profile control signal 5800 used to make a light source control unit 5560 control the emission of the variable light source 5210, such as light source pulse patterns 6801 through 6811 (which are described later), and outputting the generated signals 5800 to the light source control unit 5560.

Note that, while the variable light source 5210 is constituted by the red laser light source 5211, green laser light source 5212 and blue laser light source 5213 in Fig. 23A; the light source pulse patterns 6801 through 6817 (described later) exemplify the case of the variable light source 5210 constituted by a single light source capable of emitting light containing all wavelengths corresponding to the colors red (R), green (G) and blue (B).

In the case of the present embodiment, an image signal to be displayed is inputted, as input digital video data 5700, to a display apparatus, and the image signal is stored in the frame memory 5520 for each frame. The SLM controller 5530 generates drive signals, such as mirror control profiles 6710 and 6720, from the input digital video data 5700 stored in the frame memory 5520. The spatial light modulator 5100 is driven with the drive signal.

Meanwhile, the drive signal generated by the SLM controller 5530 is also inputted to the sequencer 5540 controlling the operation of the system. The sequencer 5540 transmits, to the light source control unit 5560, the light source profile control signal 5800 in accordance with the drive signal input from the SLM controller 5530, so that the light source control unit 5560 controls the light source drive circuit 5570 in regards to the timing
and light intensity of light emission from the variable light source 5210. The variable light source 5210 emit the illumination light 5600 in response to the timing and light intensity driven by the light source drive circuit 5570.

Note that, here, the light source profile control signal 5800 has been described as a configuration that is generated by the sequencer 5540; alternately, it may be generated, as described above, by the light source control unit 5560 shown in Fig. 23A.

The present embodiment makes it possible to continuously adjust the intensity of emission of the variable light source 5210 while the spatial light modulator 5100 is driven, that is, during the display of an image onto the screen 5900. It also makes it possible to change the brightness of a pixel to be displayed, thereby enabling a control of the gradation characteristic of the display video image. Further, the present embodiment is configured to adjust the emission intensity of the variable light source 5210 using a drive signal used for driving the spatial light modulator 5100, eliminating extraneous emission of the variable light source 5210, thereby reducing the heat generated and the power consumed.

<Embodiment 3-2>

Fig. 36A exemplifies a waveform of a mirror control profile 6720 that is a control signal output from a SLM controller 5530 to a spatial light modulator 5100 and an example of the waveform of a light source pulse pattern 6801 generated by a light source control unit 5560 from a light source profile control signal 5800 corresponding to the aforementioned mirror control profile 6720.

In this case, one frame of the mirror control profile 6720 is constituted by the combination of a mirror ON/OFF control 6721 on the frame head side and a mirror oscillation control 6722 on the tail end side and is used for controlling the tilting operation of the mirror 4003 corresponding to the gray scale of the present frame.

That is, the mirror ON/OFF control 6721 controls the mirror 4003 in either of the ON and OFF states, and the mirror oscillation control 6722 controls the mirror 4003 in an oscillation state, in which the mirror 4003 oscillates between the ON state and the OFF state.

The present embodiment is configured such that the light source control unit 5560 controls the frequencies of the pulse emission of the variable light source 5210 in accordance with the signal (i.e., mirror control profile 6720) driving the spatial light modulator 5100. The spatial light modulator 5100 performs a display of the illumination light 5600 through a spatial light modulation by means of a large number of mirrors 4003 corresponding to the pixels to be displayed and the tilting operation of the mirrors 4003.

Note that for the mirror oscillation control 6722, the pulse emission frequency fp
of the variable light source 5210 emitting the illumination light 5600 is preferably either higher (in the case of the light source pulse pattern 6801 shown in Fig. 36A) by ten times, or more, than the oscillation frequency \( f_m \) of the oscillation control for the mirror 4003, or lower (in the case of the light source pulse pattern 6802 shown in Fig. 36B) by one tenth, or less, than the frequency \( f_m \). The reason is that if the oscillation frequency \( f_m \) of the mirror 4003 and the pulse emission frequency \( f_p \) of the variable light source 5210 are close to each other, a humming occurs, which may hamper a correct display of gray scales by means of the mirror oscillation control 6722.

Fig. 36C is a chart exemplifying the above described light source pulse pattern 6801, which is shown by enlarging the part corresponding to the mirror oscillation control 6722.

The mirror oscillation control 6722 oscillates at an oscillation cycle \( t_{osc} \) (1/\( f_m \)), and, in contrast the light source pulse pattern 6801, performs pulse emission at a pulse emission frequency \( f_p \) (1/(\( t_p+ti \))) with [emission pulse width \( t_p \)+emission pulse interval \( ti \)] as one cycle. In this case, the condition is: \( f_p > (f_m \times 10) \)

That is, in the example of Fig. 36C, about 32 pulses of emission is carried out during the oscillation cycle of the mirror oscillation control 6722.

The present embodiment is configured to change the frequencies of the pulse emission of the variable light source 5210, thereby making it possible to adjust the intensity of the illumination light 5600 emitted.

Fig. 37 exemplifies the case of a light source pulse pattern 6803 performing a chirp modulation, in which the pulse emission frequencies \( f_p \) of the variable light source 5210 are continuously changed from a high frequency to a low frequency while the spatial light modulator 5100 is driven.

The continuous changing of the pulse emission frequencies \( f_p \), as exemplified by the light source pulse pattern 6803, makes it possible to extend the number gray scales in the darker part of an image and thereby allowing the details in the darker part of the image to be displayed without saturating the brighter parts of the image.

Fig. 38 exemplifies the case in which the spatial light modulator 5100 is driven with a mirror control profile 6710, comprised of binary data 6704 generated by the SLM controller 5530 and in which the pulse emission frequencies \( f_p \) of the variable light source 5210 are changed during a period corresponding to the LSB of the binary data 6704.

Fig. 38 exemplifies the case of lowering the pulse emission frequency \( f_p \) by increasing an emission pulse interval \( ti \), while keeping the emission pulse width \( t_p \) fixed in the section of the LSB.
The configuration makes it possible to adjust the light intensity of the light source by changing the pulse emission frequencies $f_p$ of the variable light source 5210 in the LSB period, that is, the minimum period for driving the mirror 4003, and therefore to increase the number of bits of gray scales.

Fig. 39 exemplifies the case of a light source pulse pattern 6805 in which the spatial light modulator 5100 is driven with a mirror control profile 6710, i includes the binary data 6704 generated by the SLM controller 5530, and in which the pulse emission frequency $f_p$ of the variable light source 5210 is changed to half during the period of the LSB of the mirror control profile 6710.

As described above, the changing of the pulse emission frequency $f_p$ of the light source pulse pattern 6805 to half during the LSB period of the mirror control profile 6710 to make the light intensity of the variable light source 5210 halved unique language makes it possible to increase the drive time of the mirror 4003 to two times the LSB period. That is, a use of common light source intensity obtains the same light intensity of the illumination light as the light intensity obtained during the LSB period.

In this case, the period of drive time of the mirror 4003 can be increased to two times the LSB period, and therefore, the control of the spatial light modulator 5100 can be simplified. Alternatively, it is possible to increase the number of bits of gray scales.

Figs. 40A and 40B exemplify the case of changing the emission pulse widths $t_p$ of the pulse emission of the variable light source 5210 in accord with a signal driving the spatial light modulator 5100.

That is, the control is such as to relatively increase the emission pulse width $t_p$ like the light source pulse pattern 6806 exemplified in Fig.40A, or relatively decrease the emission pulse width $t_p$ like the light source pulse pattern 6807 exemplified in Fig.40B, depending on the mirror control profile 6720 constituted by the mirror ON/OFF control 6721 and mirror oscillation control 6722.

As described above, increasing of the emission pulse width $t_p$ while keeping the pulse emission frequency $f_p$ constant ($t_p + t_i = \text{constant}$) makes it possible to increase the emission intensity of the illumination light 5600 emitted from the variable light source 5210.

The present embodiment is configured to change the emission pulse widths $t_p$ of the pulse emission of the variable light source 5210 with the pulse emission frequency $f_p$ kept constant, thereby making it possible to adjust the emission intensity of the illumination light 5600, such as a laser light, emitted from the variable light source 5210.
<Embodiment 3-4>

Figs. 41A and 41B exemplify the case of changing the emission light intensities of the emission pulse of the variable light source 5210 in accordance with a mirror control profile 6720 driving the spatial light modulator 5100.

That is, the light source pulse pattern 6808 exemplified in Fig.41A controls, in sync with the mirror control profile 6720, the emission intensity by using the emission pulse width tp, emission pulse interval ti and emission intensity Ph1.

Further, the light source pulse pattern 6809 exemplified in Fig.41B controls, in sync with the mirror control profile 6720, the emission intensity by using an emission intensity Ph2 (< emission intensity Ph1) with the emission pulse width tp and emission pulse interval ti held constant.

The present embodiment is configured to change the emission light intensities of the emission pulse, thereby making it possible to adjust the emission intensity of the variable light source 5210, such as a laser.

<Embodiment 3-5>

Fig. 42 exemplifies the case of changing the emission light intensities using any of the following parameters: the pulse emission frequency, emission pulse width, and emission intensity of a pulse or a discretionary combination of any plural parameters from among the aforementioned parameters. 637 has an extra sentence fragment here.

That is, the light source pulse pattern 6810 shown in Fig. 42 exemplifies the case of changing the pulse emission frequency fp, emission pulse width tp, emission intensity Ph3 and emission intensity Ph4, in sync with the mirror control profile 6720.

That is, the light source pulse pattern 6810 performs a control such that, in the display period of one frame, first, the pulse emission frequency fp is gradually increased while the emission intensity Ph3 and emission pulse width tp are kept constant and then, in the latter part of the frame, the emission pulse width tp is increased, of the section of mirror ON/OFF control 6721.

Further, in the section of mirror oscillation control 6722, the emission intensity is increased to the emission intensity Ph4 (which is larger than the emission intensity Ph3) and the emission pulse width tp is also increased to a value that is equal to the width of the oscillating section 6722.

Controlling the light source pulse pattern 6810 makes it possible to expand the gray scales in, for example, a darker part of a video display, enabling a display of details in a darker part of the image without saturating the brighter parts of the video image.
The present embodiment enables control of the gray of a displayed image, by changing the parameters of the pulse emission of the variable light source 5210, such as pulse emission frequency fp, emission pulse width tp, and emission light intensities Ph3 and Ph4 of the pulse emission of the variable light source 5210.

Embodiment 3-6

Fig. 43 exemplifies the control data for making a variable light source 5210 perform pulse emission only during the period in which the entire pixels of a spatial light modulator 5100 are driven and suppressing the pulse emission of the variable light source 5210 during the period in which the entire pixels of the spatial light modulator 5100 are not driven.

That is, the light source pulse pattern 6811 shown in Fig. 43 is generated in sync with the mirror control profile 6720, which makes the variable light source 5210 perform pulse emission during the period of driving the mirror 4003 by means of the mirror control profile 6720 and suppresses the pulse emission during the switch-off period t_{c-x} between frames.

The present embodiment is configured to make the variable light source 5210 emit light only when the spatial light modulator 5100 is driven, and therefore the power consumption of the projection apparatus and the heat generation of the variable light source 5210 can be suppressed.

Embodiment 3-7

Fig. 44 is a chart exemplifying control data for projecting a color display, by means of a color sequence control using a control unit 5500 configured as exemplified in Fig. 23A, in a single-panel projection apparatus comprising a single spatial light modulator exemplified in the above described Fig. 21.

As exemplified in Fig. 23A, the light source control unit 5560 generates a control signal for driving the light sources of the respective colors R, G and B, on the basis of the light source profile control signal 5800 inputted from the sequencer 5540, and the light source drive circuit 5570 causes the light sources of the respective colors R, G and B to perform pulse emission.

The display period of one frame (i.e., frame 6700-1) is further divided, in a time series, to the subfields 6701, 6702 and 6703, corresponding to the respective colors G, R and B.

Then, the pulse emission of the green laser light source 5212 is controlled in accordance with a light source pulse pattern 6812 in the green (G) subfield 6701; the pulse emission of the red laser light source 5211 is controlled in accordance with a light source
pulse pattern 6813 in the red (R) subfield 6703; and the pulse emission of the blue laser light source 5213 is controlled in accordance with a light source pulse pattern 6814 in the blue (B) subfield 6702 very slight difference.

As described above, the light source drive circuit 5570 performs a control so as to adjust the emission light intensities for the red laser light source 5211, green laser light source 5212 and blue laser light source 5213 of the respective colors R, G and B in accordance with the mirror control profile 6720 generated by the SLM controller 5530.

The present embodiment makes it possible to expand the gradation very slight difference of the respective colors R, G and B in a color display on a color sequential projection apparatus.

<Embodiment 3-8>

Fig. 45 is a chart showing the waveforms of control signals of a projection apparatus according to the present embodiment 3-8.

The drive signal (i.e., a mirror control profile 6720 shown in Fig. 45) generated by the SLM controller 5530 drives a plurality of spatial light modulators 5100 accommodated in a device package (not shown here).

The light source control unit 5560 generates a light source profile control signal 5800 corresponding to the mirror control profile 6720, which is the signal driving the respective spatial light modulators 5100, and inputs the generated profile 6720 to the light source drive circuit 5570, which in turn adjusts the intensity of the laser lights (i.e., the illumination lights 5600) emitted respectively from the red laser light source 5211, green laser light source 5212 and blue laser light source 5213.

The control unit implemented in the projection apparatus, according to the present embodiment 3-8, is an exemplary modification of the control unit exemplified in Fig. 23A, in which one SLM controller 5530 driving a plurality of spatial light modulators 5100 makes it possible to irradiate an illumination light 5600 in the optimal light intensity for each respective spatial light modulator 5100 without a need to includes a light source control unit 5560 or a light source drive circuit 5570 for each of the spatial light modulators 5100. This configuration simplifies the circuit configuration of the control unit 5500.

As exemplified in Fig. 45, the light source control unit 5560 and light source drive circuit 5570 drive the red laser light source 5211, green laser light source 5212 and blue laser light source 5213 so as to adjust the emission intensities of individual lasers (i.e., the illumination light 5600) of the respective colors R, G and B in sync with the respective SLM drive signal (i.e., the mirror control profile 6720) that are generated by the SLM
controller 5530.

In this case, a color sequence control is employed for the two colors B and R sharing one spatial light modulator 5100.

That is, one frame is constituted by a plurality of subfields 6701, 6702 and 6703, and the same light source pulse pattern 6815 is repeated in the respective subfields for one spatial light modulator 5100 corresponding to green (G).

Meanwhile, the pulse emissions of the red laser light source 5211 and blue laser light source 5213, sharing one spatial light modulator 5100, are controlled so as to use the subfields, i.e., subfields 6701 through 6703, alternately in a time series as indicated by the light source pulse patterns 6816 and 6817, respectively.

The present embodiment makes it possible to increase the gradation levels for the respective colors R, G and B.

<Embodiment 4>

The following is a description, in detail, of the preferred embodiment of the present invention with reference to the accompanying drawings.

The following description provides various embodiments, with the configurations and operations of the projection apparatuses described above taken into consideration. Note that the same reference symbols are assigned to the same constituent component as that included in the above-described configurations, and an overlapping description is not provided here.

Incidentally, a spatial light modulator 5100 comprising a mirror device used in a projection apparatus according to the present embodiment is configured to perform a linear gradation display, unlike a conventional display apparatus such as a CRT.

Therefore, as exemplified in Fig. 46, when a γ collection, such as an input data γ curve 7700a, is applied to a piece of input digital video data 5700 at the transmission source (i.e., where the imaging is carried out), assuming a display in the CRT, a projection apparatus comprising a display device other than the CRT is required to restore the characteristics of a gradation display back to the original state (e.g., a conversion line 7700L for performing a linear conversion of a brightness signal in terms of an input data signal) by means of a correction, such as a γ correction curve 7700b and/or to perform various γ corrections in accordance with the characteristics of the projection apparatuses 5010, 5020, 5030 and 5040.

In such a case, a mathematical operation for the input digital video data 5700, as it is performed in a conventional display device, causes the circuit scale of the control unit 5500 to increase, leading to a higher production cost.
The present embodiment is accordingly configured such that the above described video image analysis unit 5550 changes the emission pattern of the illumination light 5600 emitted from a variable light source 5210 to the profile, as indicated by a \( \gamma \) correction light intensity variation 7800a, so as to follow the above noted \( \gamma \) correction curve 7700b, as exemplified in Fig. 47. Thereby, a linear gradation display, as indicated by the conversion line 7700L, is attained by negating the influence of the input data \( \gamma \) curve 7700a performed at the transmission source, without requiring a mathematical operation of the input digital video data 5700.

Note that this configuration makes it possible to not only restore the linearity by negating the influence of the input data \( \gamma \) curve 7700a but also to change, intentionally nonlinearly, the emission intensities of the variable light source 5210 within one frame, thereby enabling various and highly precise gradation displays in excess of the original gradation control capability of the spatial light modulator 5100.

As an example, a video image output (i.e., the input digital video data 5700) contains various scenes such as a dark scene, a bright scene, a generally bluish scene and a generally reddish scene such as a sunset. The projection apparatus according to the present embodiment is configured to control the gradation of the emission output of the variable light source 5210 most optimally depending on the particular scene (with actual control carried out in units of frame), thereby making it possible to attain higher quality video images.

Incidentally, when a \( \gamma \) correction of the input digital video data 5700 (i.e., the input data \( \gamma \) curve 7700a) is implemented by means of a temporal change in emission intensities of the variable light source 5210, as described above, a precise emission control of the variable light source 5210 is difficult if an ON/OFF control of the mirror 4003, through a pulse width modulation (PWM) using binary data 7704 included in the input digital video data 5700, is carried out.

Accordingly, the SLM controller 5530 according to the present embodiment is configured to carry out an ON/OFF control of the mirror 4003 using non-binary data 7705 obtained by converting binary data 7704, as exemplified in Figs. 48, 49, 50 and 51.

That is, Fig. 48 exemplifies the case of generating non-binary data 7705, which is a bit string having an equal weighting factor for each digit, from the binary data 7704 that is constituted by, for example, 8-bit "10101010", and a control is carried out for turning ON the mirror 4003 only for the period in which the bit string continues.

Note that Fig. 48 exemplifies the case of converting the non-binary data 7705 so that the bit string is packed forward within the display period of one frame, controlling the mirror 4003 to be turned ON for a predetermined period, in accordance with the bit string
number from the beginning of a frame display period.

Likewise, Fig. 49 exemplifies the case of converting 8-bit "01011010" binary data 7704 into non-binary data 7705, a forward-packed bit string.

Further, Fig. 50 exemplifies the case of converting the binary data 7704, exemplified in Fig. 48, into a bit string of non-binary data 7705 with the digits packed backward. In this case, the mirror 4003 is controlled so as to be turned ON only in the period of time corresponding to the bit string number starting from the middle of a frame display period until the end.

Likewise, Fig. 51 exemplifies the case of converting binary data 7704, exemplified in Fig. 49, into a bit string of non-binary data 7705, with the digits packed backward and controlling the ON/OFF of the mirror 4003.

When the ON/OFF is controlled by the non-binary data 7705 as described above, the ON period of the mirror 4003 becomes continuous, and therefore it is easier to control the emission intensity of the variable light source 5210 in sync with the aforementioned ON period.

Fig. 52 exemplifies the case of dividing the brightness input of 8-bit non-binary data 7705 into, for example, four steps, i.e., 64, 128, 192 and 255, as shown in the upper rows of Fig. 52, and obtaining a $\gamma$ correction curve 7700c, as shown in the lower row of the drawing, through a four-step control of the output intensity of the variable light source 5210 in response to each of the aforementioned levels, as indicated by a light source pulse pattern 7801 shown in the middle row of the drawing.

For simplicity, Fig. 52 exemplifies the case of performing a control in four steps. A further minute grouping of the non-binary data 7705 makes it possible to obtain a smoother curve than the $\gamma$ correction curve 7700c.

Note that the example of Fig. 52 shows that the correction amount of the $\gamma$ correction curve 7700c is in shortage on the brighter side when compared with the conversion line 7700L correction curve flattens out in comparison with the conversion line as the brightness of the image increases. Therefore, the emission pattern of the variable light source may be controlled so as to cause the $\gamma$ correction curve 7700c to more closely approach the conversion curve 7700L by increasing the emission light intensity of the light source pulse from an emission intensity H0 to an emission intensity H1 on the tail end of the display period of one frame.

Fig. 52 exemplifies the case of performing a $\gamma$ correction by changing the emission intensity while the variable light source 5210 continuously emits light, as indicated by the light source pulse pattern 7801. Alternately, the control may be performed by means of
an intermittent pulse emission. Figs. 53A, 53B, 53C and 53D exemplify a control by means of an intermittent pulse emission. A light source pulse pattern 7803 exemplified in Fig. 53A generates emission pulses having an emission pulse width $t_p$ intermittently in intervals of emission pulse intervals $t_i$ and increases the number of emission pulses per unit of time by gradually decreasing the emission pulse interval $t_i$ between the beginning and end of the display period of one frame, thereby attaining an effect similar to the continuous light source pulse pattern 7801 described in Fig. 52.

The light source pulse pattern 7804 exemplified in Fig. 53B shows the gradual increase of the emission pulse width $t_p$ between the beginning and end of the display period of one frame.

The light source pulse pattern 7805 exemplified in Fig. 53C shows the gradual decrease of the emission pulse intervals $t_i$ and the gradual increase of the emission pulse width $t_p$ between the beginning and end of the display period of one frame.

The light source pulse pattern 7806 exemplified in Fig. 53D shows the gradual increase of both the emission pulse width $t_p$ and emission intensity $H_2$ between the beginning and end of the display period of one frame.

Figs. 54A and 54B exemplify the case of attaining a $\gamma$ correction curve $7700e$ by performing $\gamma$ correction to increase the correction effect on the lower brightness values by means of a light source pulse pattern 7807.

That is, the light source pulse pattern 7807 shown in Fig. 54A controls the emission pattern of the variable light source 5210 so as to densely generate a plurality of emission pulses having a constant emission pulse width $t_p$ densely (that is, the emission pulse interval is small) near the beginning of the display period of one frame, and to gradually decrease the number of pulses (that is, the emission pulse interval $t_i$ gradually increases) towards the end of the display period.

As exemplified in Fig. 54B, this control makes it possible to attain a convex $\gamma$ correction curve $7700e$ to the top and left of the conversion line 7700L and which, accordingly, provides a large correction effect, i.e., increasing brightness, on the values/data/input with lower brightness values.

Figs. 55A and 55B exemplify the case of a $\gamma$ correction which takes into consideration the visual perception of humans by controlling the variable light source 5210 with a light source pulse pattern 7808. That is, the human eye is known to possess higher sensitivity to the values in the middle of the brightness range. Accordingly, a $\gamma$ correction is performed by controlling the variable light source 5210 with the light source pulse pattern 7808 to densely emit pulses having the same emission pulse width $t_p$ (i.e., making the
emission pulse interval \( t_i \) small) at the center of the display period of one frame and gradually decreasing the density of the emission pulse on either side, as exemplified in Fig. 55A.

This control attains a \( \gamma \) correction using a \( \gamma \) correction curve 7700f that is below the conversion line 7700L on the lower brightness side in the lower brightness values and above the line on the higher brightness side in the higher brightness values. This correction makes it possible to obtain a modulated and clear projection image, as seen by the human eye.

Next is an example of expanding the number of display gray scales by performing a modulation control of the accumulated maximum light intensity in the display period of one frame corresponding to the variable light source 5210 of each color, so as to obtain a desired output light intensity corresponding to the pixel data indicating the maximum brightness.

The maximum gray scale output provided by a spatial light modulator 5100 comprising a mirror device is determined by the operation speed of the ON/OFF control of a mirror (more specifically, it is affected by other factors such as a single-panel comprisal versus a multi-panel comprisal and the number of sub-frame divisions).

For example, if an 8-bit gray scale output is the maximum according to the operation speed of the mirror 4003, a 256-step gray scale, i.e., "0" through "255", can be outputted. If a single color gradation is displayed, the gradation is 256 steps; the gradation recognition capability of human being exceeds these steps. Thus, the display will not be viewed as a smooth gradation, but as stepwise borders. It is believed that to match the gradation recognition capacity of the human eye, a 12-bit scale is required.

In practice, however, there are few scenes that utilize the entire gray scale of "0" through "255". For example, in a movie, only "0" through "128" may be outputted, or even only the values for the darker gradations. The visual recognition capability of human being is greater in discerning the difference between gradations in darker areas of a display than that in brighter areas of a display, and therefore a person tends to recognize even a minute difference in the brightness of a dark scene as a line.

The present embodiment is accordingly configured to perform a modulation control of an accumulated maximum light intensity in the display period of one frame corresponding to the spatial light modulator 5100 of each color, so that a desired output light intensity corresponding to the maximum brightness pixel data is obtained. This control makes it possible to express brightness through a whole range of gradations, from the brightest part (i.e., the pixel) to the total absence of light (i.e., "0" brightness) of a scene (i.e., frame) by the maximum gray scale output of a mirror, thereby displaying a
higher resolution video image, especially in a dark scene.

The top half of Fig. 56 shows the case of making the variable light sources 5210 (i.e., the red 5211, green 5212, and blue laser light source 5213) emit light continuously at a constant emission intensity, H10, in the gradation display control of each color in, for example, the multi-panel projection apparatuses 5020, 5030 and 5040, and turning ON/OFF the mirrors 4003 in accordance with the mirror control profiles 7706a, 7707a and 7708a in the display control of each color, whereas the variable mirror control profiles 7706a, 7707a and 7708a (for red, green and blue) by means of the PWM. Thereby, a gradation a higher resolution display is attained.

When performing a gray scale control by means of the ON/OFF control of the mirror 4003 by the conventional method, in some cases a smooth gradation cannot be expressed because the expression depends on the gradation expression—graduated expression of the data width of the input digital video data 5700. Further, the light sources for each color are in a constant emission state, independent of the gradation change of the colors, wasting emission energy.

In contrast, the present embodiment is configured to maintain the mirror 4003 of a pixel, which indicates the maximum brightness, continuously in the ON state (in accordance with the mirror control profiles 7706a, 7707a and 7708a) and to set the variable light sources 5210 (i.e., the red 5211, green 5212, and blue laser light source 5213), which output the illumination light 5600, at emission intensities H11 (for red), H12 (for green) and H13 (for blue), which correspond to the gray scale data indicating the maximum brightness, in the gray scale control of each color, as exemplified in the bottom half of Fig. 56. Thereby the gradation can be expressed by the maximum gray scale output (that is, a continuous ON state in one frame period) of the mirror 4003, displaying a higher resolution and higher quality video image, especially in a dark scene.

Further, the brightness of the colors R, G and B are attained by the increase/decrease in the intensity of the illumination light 5600 output from the corresponding variable light sources 5210 (i.e., the red 5211, green 5212, and blue laser light source 5213), saving energy, reducing an unnecessary light component, and improving the contrast in the video image.

Note that, while the above described Fig. 56 exemplifies the case of controlling the variable light sources 5210 to be continuously turned on at the emission intensities H11, H12 and H13, in the gray scale control of the respective colors, the variable light sources 5210 may be controlled with an intermittent emission pulse, as shown in Fig. 57.

In Fig. 57, the mirror 4003 of a pixel indicating the maximum brightness is maintained at a continuous ON in one frame period, as represented by the mirror control profiles 7706a, 7707a and 7708a in the display control of each color, whereas the variable light sources 5210 (i.e., the red 5211, green 5212, and blue laser light source 5213) emit light intermittently in accordance with the respective mirror control profiles 7706a, 7707a and 7708a, maintaining a high brightness without wasting energy, improving the contrast in the video image.
light sources 5210 are configured to emit pulses in accordance with the emission pulse width \( t_p \) and emission pulse interval \( t_i \), as represented by light source pulse patterns 7809b (for red), 7810b (for green) and 7811b (for blue).

In this event, the number of emission pulses is controlled so that the total intensity of the emission pulse is equivalent to the gray scale data of a pixel indicating the maximum brightness.

Also in this case, the gradation can be expressed by the maximum gray scale output (that is, a continuous ON state in one frame period) of the mirror 4003, producing a higher quality and higher resolution video image, especially in a dark scene.

Further, the brightness of the colors R, G and B are attained by the increase/decrease in the intensity of the corresponding variable light sources 5210 (i.e., the red 5211, green 5212, and blue laser light source 5213), saving energy, reducing an unnecessary light component, and improving the contrast in the video image.

Fig. 58 exemplifies the case of performing a gray scale control when the gray scale control exemplified in the above described Figs. 56 and 57 is applied to a single-panel projection apparatus.

In this case, the display period of one frame is divided into a plurality of subfields 5701, 5702 and 5703 corresponding to the respective colors R, G, and B, and a color display is attained by a color sequence method.

In the case of the conventional method, the ON/OFF control for the mirror 4003 is performed, by means of a PWM, in accordance with the mirror control profiles 7706 (for red), 7707 (for green) and 7708 (for blue) in the respective subfields, and the variable light sources 5210 perform a continuous emission at a constant intensity level in accordance with the light source pulse patterns 7809, 7810 and 7811, thereby performing a gray scale control, as shown in the top half of Fig. 58. In this case, a gray scale expression depends on the data width of input digital video data 5700, and therefore there is a possibility that a smooth gradation expression cannot be attained.

In contrast, as shown in the bottom half of Fig. 58, the present embodiment is configured to perform a control so that the mirror 4003 of a pixel indicating the maximum brightness is controlled to the ON state in the entire display period of one frame (i.e., the entire subfields) in accordance with the mirror control profiles 7706a, 7707a and 7708a, and so that the intensity of the variable light sources 5210 are set at intensity equivalent to the gray scale data of a pixel indicating the maximum brightness (i.e., the emission intensities H11 (for red), H12 (for green) and H13 (for blue)), and thereby the gray scale can be expressed by the maximum gray scale output (that is, a continuous ON state during
the period of one frame) of the mirror 4003, thus smoothing out and beautifying the video image especially in a dark scene.

Fig. 59 shows the case of attaining an intensity equivalent to the above described emission intensities H11, H12 and H13 by adjusting the emission pulse width tp and emission pulse interval ti of the emission pulse by means of an intermittent pulse emission of the variable light sources 5210 in the respective subfields of red, green and blue. Also in this case, an effect similar to the case of the above-described Fig. 58 is obtained.

Fig. 60 shows a capability of a grayscale control with a wide dynamic range than the case of making the emission intensity of the variable light source 5210 constant by combining the ON/OFF control of the mirror 4003 and the emission intensity control of the variable light source 5210 in the above described various control examples.

That is, if the emission intensity level of the variable light source 5210 is constant at the emission intensity H20, with a gray scale expression in 256 steps, that is, "0" through "255", in accordance with, for example, input digital video data 5700 only being possible in the range between the full ON and full OFF of the mirror 4003 and a pixel indicating the maximum brightness being a half light intensity, i.e., "0" through "127"; then a 128-step gray scale, i.e., "0" through "127", can only be expressed, as shown on the upper part of Fig. 60.

In contrast, when the emission intensity of the variable light source 5210 is controlled, the maintaining of the emission intensity H21 of the variable light source 5210 at one half of the emission intensity H20, as in the present embodiment, makes it possible to attain a 256-step grayscale expression, i.e., "0" through "255", in the range between the full ON and full OFF of the mirror 4003, as shown on the lower part of Fig. 60.

That is, the width of the grayscale expression can be represented more minutely in excess of the designation range of the input digital video data 5700, thus improving the image quality.

Next is a description of an example of countermeasures to a color break. In the case of a multi-panel projection apparatus comprising a plurality of spatial light modulators 5100, as in the above described projection apparatuses 5020, 5030 and 5040, there is a concern that, if the output time for each color is different, a state in which only a certain color is output is created, resulting in the occurrence of a color break, in which the individual colors R, G and B are singularly visible to some people.

Accordingly, the present embodiment is configured to equip the SLM controller 5530 controlling the spatial light modulators 5100 with the function of controlling the mirror 4003 of the spatial light modulators 5100 to either condition of the changeover
between the ON state and OFF state and the intermediate output state, in which the mirror 4003 oscillates between the ON and OFF states.

Further, if the brightness output value to be modulated is no smaller than the brightness output of a case in which the intermediate output state is continued in the entire display period of one frame for each color, the modulation is performed in the combination between the ON state and intermediate output state of the mirror 4003 for the display period of one frame for each color.

Fig. 61 exemplifies the control for such a countermeasure to a color break. A mirror control profile 7711 drawn at the center of Fig. 61 indicates the case of a brightness output carrying out a mirror oscillation control 7710b in the entire display period of one frame for each color.

Further, the present embodiment is configured to continue to output light in the entire display period of one frame by the combination between a mirror ON/OFF control 7710a and the mirror oscillation control 7710b as indicated by the mirror control profile 7710 on the top side of Fig. 61 in the case in which the brightness output is no less than the mirror control profile 7711.

In contrast, in the case in which the brightness output is no more than the mirror control profile 7711, a required brightness output is attained by controlling a continuation time period of the mirror oscillation control 7710b during the display period of one frame as shown on the lower side of Fig. 61.

The control exemplified in Fig. 61 makes it easy to align the output time for each color, thereby reducing a possibility of the occurrence of a color break in the projection apparatuses 5020, 5030 and 5040, each of which includes a plurality of spatial light modulators 5100.

Note that, if a grayscale control is carried out by controlling the intensity by setting the emission pulse width tp and emission pulse interval ti of the variable light source 5210, as in the above described Figs. 57, 59, et cetera, the light source control unit 5560 is also capable of performing a control so as to increase the maximum brightness of the variable light source 5210 by selectively narrowing the emission pulse interval ti within a specific unit time during a one-frame period for a frame of a specific condition of the input digital video data 5700 when the output of the illumination light 5600 is modulated by varying the emission pulse interval ti (i.e., the emission interval cycle) of the pulse emission of the variable light source 5210.

As such, the taking advantage of so-called peak brightness of the variable light source 5210 widens the dynamic range of a video image output, thereby making it possible
to obtain a further powerful video image.

That is, the configuration is for increasing the peak brightness of the variable light source 5210 by putting it in over-drive only when displaying a scene (i.e., a frame) in which, for example, only a small part of a screen is very bright, or the like scene, as described above because a continuous setup of the maximum brightness will adversely affects the life, et cetera, of the variable light source 5210.

<Embodyment 5>

A mirror device can be further miniaturized by reducing the mirror size of a mirror element. As an example, a miniaturized mirror device is constituted by comprising a plurality of mirror elements each consisting of approximate square mirrors of which one side is between about 4μm and 10μm. The mirror in this case has an aperture ratio of about 80% or larger and the reflectance of about 80% or higher. Further, the individual mirror elements are configured such that the gap between adjacent mirrors is set at 0.5μm to 1μm, with the pitch between the adjacent mirrors set at 4μm to 10μm, in order to prevent a pair of reflection light of the adjacent mirrors from interfering with each other. Provided that the structure of an elastic hinge is such as to prevent an interference with the adjacent mirror, the gap between the mirrors may be smaller, such as 0.1μm to 0.5μm. If the gap between mirrors is as such, the aperture ratio of the reflection surface of the mirror will be improved to 90% or higher. Furthermore, the energy of the light led through the gap between the mirrors and emitted onto a device substrate will also be decreased.

Then, the diagonally measured size of a mirror array for use in a full high definition (Full HD) television (TV) can be miniaturized to 10.16 mm to 22.098 mm (0.4 inches to 0.87 inches) by arraying a plurality of mirror elements described above.

When about 1 mm, respectively, for a land and the like, which are used for the circuit wiring driving each mirror element, are secured in the mirror array in which the mirror size is miniaturized as described above, the size of the device substrate is approximately as follows.

For a 6μm pixel pitch and 4: 3 XGA screen, the mirror array is about 7.62 mm (0.30 inches) and the devise substrate is about 10.16 mm (0.4 inches).

For a 7μm pixel pitch and 4: 3 XGA screen, the mirror array is about 8.89 mm (0.35 inches) and the devise substrate is about 11.43mm (0.45 inches).

For a 7μm pixel pitch and 16: 9 Full HD screen, the mirror array is about 15.24 mm (0.6 inches) and the devise substrate is about 17.78 mm (0.70 inches).

For a 9μm pixel pitch and 16: 9 Full HD screen, the mirror array is about 19.81 mm (0.78 inches) and the devise substrate is about 22.098 mm (0.87 inches).
Enabling a miniaturization of the device substrate in association with the miniaturization of the mirror device reduces the volume of the device substrate. Therefore, an increase in the volume of the device substrate due to thermal expansion is reduced from the device substrate of a 0.95-inch mirror array conventionally used.

In a mirror device, it is possible to prevent undesirable light from being projected by deflecting a mirror to a large deflection angle, for example, between minus 13 degrees and plus 13 degrees. For example, it is possible to change over between the state (i.e., the ON state), in which the reflection light is incident to a projection lens, and the state (i.e., the OFF state) in which the reflection light is not incident to the projection lens. This operation makes it possible to improve the contrast of an image to be projected.

Note that the deflection angle is defined as "0" degrees when the mirror is horizontal, the angle in clockwise direction (CW) is defined as plus (+) and that in counterclockwise direction is defined as minus (-), as reference of the deflection angle of a mirror in the present specification document.

Meanwhile, when using a light flux, such as a laser light source, which has a small diffusion angle of light from the light source and which is approximately parallel, the numerical aperture NA of an illumination light flux can be reduced on the basis of the relationship of etendue, and therefore a mirror size can be reduced. As a result, it is possible to obtain a configuration avoiding the mutual interference between the projection light path and illumination light path, and therefore the deflection angle of the mirror can be reduced to ±10 degrees or smaller. Thus, the changeover between the ON state and OFF state can be carried out by making the deflection angle of the mirror small. Moreover, the adopting of such a deflection angle of the mirror minimizes a decrease in contrast.

Furthermore, reducing the deflection angle to ±10 degrees or smaller makes it possible to lower the drive voltage due to the decrease in distance between the address electrode and mirror on a device substrate.

As an example, when the deflection angle of the mirror in the ON state is +13 degrees and the deflection angle thereof in the OFF state is -13 degrees, with a drive voltage required for deflecting the mirror being 16 volts, a reduction in the deflection angle to ±6 degrees, respectively, decreases the distance between the mirror and address electrode to a half. Here, the electrostatic force (i.e., a coulomb force) functioning between the address electrode and mirror when deflecting the mirror is inversely proportional to the second power of the distance between the address electrode and mirror. Therefore, a drive voltage applied to the address electrode will be one quarter of the voltage, that is, 4 volts, when the deflection angle of the mirror used to be ±13. As such, the reduction of the deflection angle of the mirror to ±10 or smaller makes it possible to lower the drive voltage
which is to be applied to the address electrode and which is required to deflect the mirror.

The drive voltage applied to the address electrode is lowered by miniaturizing the mirror size to about 4μm to 10μm and accordingly decreasing the drive voltage to be applied to the address electrode. This configuration makes it possible to thin the circuit-wiring pattern of the control circuit controlling the mirror. The circuit-wiring pattern can be thinned from, for example, 0.25μm to 0.13μm. Then, the deflection of the mirror of which the deflection angle is reduced to ±10 degrees or smaller can be controlled by applying a drive voltage of 5 volts or lower to the address electrode. As a result, the voltage applied to the address electrode can be lowered, as compared to the conventional technique, and thereby the voltage resistance of a transistor constituting the address electrode can be lowered.

Meanwhile, it is also possible to control the intensity of reflection light towards the projection light path by causing the mirror to perform a free oscillation between the deflection angle of the ON state and the OFF state. Controlling the intensity of a light source can improve a gradation.

As an example, let it be assumed that the deflection angle of the ON state is +13 degrees, and the deflection angle in the OFF state is -13 degrees. The ON state and OFF state is frequently changed over by the mirror performing a free oscillation between the deflection angle of the ON state and that of the OFF state. As a result, a lower light intensity can be made to be incident to the projection lens than the intensity when the mirror is maintained in a continuous ON state, in a given period of time. Therefore, the intensity of a projection light can be adjusted by controlling the number of free oscillations and the deflection angle when performing the free oscillation, and thereby, a freely gradated video image can be projected. Note that the mirror can also be put into a free oscillation at other angles, such as ±8 degrees, ±4 degrees, et cetera.

Further, extraneous light irradiated onto the mirror device can be reduced by synchronizing the free oscillation of a mirror with the timing of the emission of a light source. As a result, the heat generation by the light can be effectively reduced.

Next is a description of a laser light source for irradiating the light onto a mirror device.

The laser light source for irradiating light onto a mirror device preferably has a numerical aperture NA of 0.07 to 0.14 and emits the laser light at no less than 3 watts.

The numerical aperture NA has a large effect on the usage efficiency of light and the resolution of a projection optical system. The numerical apertures NA of an illumination light flux and of a projection light flux, in the case where a conventional light
source, for example a mercury lamp, is used, is between about 0.18 and 0.24. In contrast, the numerical aperture NA in the case of employing a laser light source can be configured to be the same as (for example, about 0.22 for a 13-degree deflection angle of a mirror) or smaller than the case of the mercury lamp, depending on the deflection angle of the mirror. For example, the NA is 0.14 for an 8-degree deflection angle and the 0.07 for a 4-degree deflection angle.

Further, when using a laser light source, the optical system can be set so as to form a light flux with a numerical aperture of 0.07 to 0.14 in comprehension of a resolution taking into consideration the resolution and a decrease in a modulation transfer function (MTF). As a result, the usage efficiency of light can be improved when using a laser light source versus a mercury lamp. Note that a laser light source rated at about 3 watts to 5 watts is employed for a rear projection system or other similar system, and a high-output laser light source rated at tens watts is employed for a theater-use projection apparatus.

Yet another reason for using a laser light source is a possibility of reducing the problem of etendue by the capability of irradiation with a single wavelength, high directivity and approximately parallel light flux, unlike a mercury lamp and the like. Therefore, the brightness of light can be increased by increasing the intensity, per unit area, of the laser light irradiated onto a mirror device, and therefore the brightness of light will not be reduced even if the mirror array of the mirror device is miniaturized.

Furthermore, a laser light source can be configured to includes an illumination intensity variable circuit and emit an intermediate intensity between the ON light and OFF light. Configuring as such makes it possible to change the intensities of the laser light source. Therefore, the controlling of the laser light source makes it possible to adjust the light intensity to be modulated and reflected by a mirror element in accordance with an image signal. Particularly, the laser light source is preferred to possess an emission state in which an intensity that is 50%, or lower, of the maximum intensity (i.e., the ON light).

Further, a laser light source can be made to perform pulse emission for a predetermined period of time by equipping it with a circuit used for performing the pulse emission of the ON light and OFF light alternately.

For example, the intensity of light can be adjusted in accordance with an image signal (i.e., in accordance with the brightness and/or color (or hue) of the entire projection image) by elongating the interval of the OFF light or elongating that of the ON light, such a control is enabled by making the laser light source perform the pulse emission. Further, the utilizing of the pulse emission makes it possible to turn off the laser light source appropriately when the colors of an image are changed over. Such a configuration enables a reduction in the incidence of light to the mirror device other than is necessary. As a result,
it is possible to alleviate a temperature rise due to an extraneous irradiation of light onto the mirror device even a little. Note that dimming of a laser light makes it possible to make the dynamic range of an image variable and darken the entirety of a screen in accordance with a dark image. Considering this, it is preferred to configure the laser light allowing to be turned off at least one time during the display of one frame.

Further, a single laser light source may be constituted by a plurality of sub-laser light sources. Configuring as such and adjusting the number of sub-laser light sources to emit enable an adjustment of the intensity. Note that such a plurality of sub-laser light sources may includes some number of sub-laser light sources, each of which emits a laser light in a desired single wavelength with the tolerance of a few nanometers.

When a mirror device is irradiated with a laser light by such a laser light source, however, the light enters the device substrate as a result of the absorption of the light on a mirror surface and the transmission thereof through the gap between the mirrors. Then, the light is absorbed in the device substrate. As a result, heat is accumulated in the mirror device. The heat causes the thermal expansions of the individual constituent components of the mirror device, shifting the position of a mirror and possibly causing the mirror device to fail to function normally.

What is accordingly provided is a packaging for the mirror device capable of protecting the above described mirror device from a damage and dust, which cause an operation failure, absorbing or transmitting the light diffusely reflected by the mirror device and radiating heat effectively.

Further, if a material of which the coefficient of linear expansion is significantly different from those of other constituent components and circuit wiring pattern, which constitute the mirror device, is used for the package of the mirror device, the package may break or the adhesively-attached components may come apart from each other due to the difference in the coefficients. Therefore, the package uses, for packaging the mirror device, a material of which the melting point is lower than those of the materials used for the constituent components and wiring, which constitute the mirror device, and of which the coefficient is approximately the same. The material for the package includes, for example, transparent glass, silicon, ceramics and a metallic material.

A description of the configuration of a package according to a preferred embodiment 5-1 is provided.

Figs. 62A, 62B, 62C, 62D, 62E show an assembly body 2100 that packages a mirror device 2000 using glass.
Mostly identical except where noted Fig. 62A is a front cross-sectional diagram of the assembly body 2100 that packages a mirror device 2000 using glass.

The assembly body 2100 includes a package substrate 2004 constituted by a glass material, a cooling/radiation member (heat sink) 2013, an intermediate member 2009, a thermal conduction member 2003, a mirror device 2000 and a cover glass 2010. Here, the "package" represents the formation constituted by the constituent components excluding the mirror device 2000. As an example, the formation constituted by the package substrate 2004 (which is constituted by a glass material), cooling/radiation member (heat sink) 2013, intermediate member 2009, thermal conduction member 2003 and cover glass 2010, which are shown in Fig. 62A, are called the package.

The following is a description of each constituent member of the assembly body 2100 shown in Fig. 62A.

[Package Substrate]

The package substrate 2004 constituted by a glass material is joined to the cooling/radiation member 2013 used for radiating the conducted heat, to the thermal conduction member 2003 to which heat is conducted, and to the intermediate member 2009 used for creating a sealed space together with the cover glass 2010.

A circuit wiring pattern 2005, which is used for forming an electrical conduction to the device substrate 2001 of the mirror device 2000, and a radiation circuit wiring pattern 2014 (refer to Fig. 62B), which is used for radiating the heat in inside of the package to outside thereof, are equipped on the upper surface of the package substrate 2004. A large number of circuit wiring patterns 2005 is thusly placed (i.e., wired) on the upper surface of the package substrate 2004. As a result, the pitch between the individual wiring is narrowed. Therefore, a ground-use wiring is preferably placed between individual wirings to prevent noise between the wirings. Moreover, an insulation layer containing silicon (Si) or the like is preferably coated on the upper surface of the package substrate 2004, and the circuit wiring patterns 2005 is preferably placed on the coated surface.

Incidentally, the "inside of the package" noted in the present specification document represents a space sealing the mirror device 2000. As an example, the space in which the mirror device 2000 is sealed by the package substrate 2004, cover glass 2010 and intermediate member 2009 is called an "inside of the package" in Fig. 62A.

Further, a light shield layer 2006 used for absorbing extraneous light, which has transmitted the upper surface of the package substrate 2004, is placed on the bottom surface of the transparent package substrate 2004 that is made of a glass material. It is easy to radiate heat to the outside by equipping the light shield layer 2006, which is capable of
absorbing extraneous light and which has good thermal conductivity, on the bottom surface of the package substrate 2004 as described above.

Further, a cooling/radiation member (heat sink) 2013 comprising a radiation plate equipped with a fan and a metallic radiation member can possibly be joined onto the bottom surface of the package substrate 2004 in order to radiate the heat conducted from the package substrate 2004 to the outside efficiently.

Note that the wider the surface area of the package substrate 2004, the further the radiation can be improved.

Further, a glass material for the package substrate 2004 is preferred to use a material with better thermal conductivity. For example, soda ash glass with the thermal conductivity being about 0.55 to 0.75 W/mK, and Pyrex (a registered trademark; used to be manufactured by Corning, Inc.; now by World Kitchen, LLC) exceeding 1 W/mK, are available.

Further, the package substrate 2004 may be made of, silicon, ceramics, metal or a composite body of these materials, in addition to being made of glass.

[**Circuit Wiring Pattern and Radiation Circuit Wiring Pattern**]

The circuit-wiring pattern 2005 is the wiring of a control circuit for controlling the mirror device 2000 and is electrically connected to the device substrate 2001.

The radiation circuit-wiring pattern 2014 fills the role of radiating the heat inside of the package to the outside.

The radiation circuit wiring pattern 2014 having large wiring widths is placed across inside and outside of the package on the package substrate 2004. Such a configuration makes it possible to radiate the heat in the inside of the package to the outside by way of the radiation circuit wiring pattern 2014. The heat can also be radiated by way of the circuit wiring pattern 2005 having a large number of small-width wirings.

Considering radiation, a metallic material constituting the radiation circuit wiring pattern 2014 preferably uses tungsten (W), aluminum (Al), gold (Au), silver (Ag), cupper (Cu), silicon (Si) or magnesium (Mg), with 150 W/mK or higher thermal conductivity. Incidentally, these metallic materials can be used as thermal conductive members.

Further, the radiation circuit wiring pattern 2014 will serve a double purpose, i.e., radiation and electrical connection, which aims at removing noise from the device substrate 2001.

When driving the mirror device 2000 comprising mirror elements of one million to four million pixels, or more, in high-level gray scale such as 10 bits, there is a very large
number of data. Therefore, a high-speed data transfer is required. The resistance value on a circuit wiring and the floating capacity of a capacitor greatly affect the data transfer. Considering this, the circuit wiring pattern 2005 preferably uses a material with a small resistance value in the temperature range 0°C through 100°C, for example, aluminum (2.5 to 3.55*10⁻⁸ Ωm), tungsten (4.9 to 7.3*10⁻⁸ Ωm), gold (2.05 to 2.88*10⁻⁸ Ωm) and copper (1.55 to 2.23*10⁻⁸ Ωm).

[Cooling/Radiation Member]

The cooling/radiation member (heat sink) 2013 fills the role of externally radiating the heat conducted from the package substrate 2004 and the like.

The cooling/radiation member 2013 is constituted by, for example, a radiation plate equipped with one or a plurality of fans or a metallic radiation member. The metallic radiation member may be attached directly to the bottom surface of the package substrate 2004 or may be attached to another member made of a material of which a coefficient of linear expansion is approximately the same as that of the package substrate 2004. Moreover, the cooling/radiation member 2013 may be thermally connected to the package substrate 2004 by way of a Via by penetrating with a metallic Via or embedding it.

Further, a metallic cooling/radiation member 2013, made as a black light shield layer, may be equipped on the bottom surface of the package substrate 2004. Such a configuration serves dual functions as light shield and radiation.

[Intermediate Member (Support Member)]

The intermediate member 2009 is placed on the top surface of the package substrate 2004 and fills the role of supporting the cover glass 2010 for providing a sealed space between the package substrate 2004 and cover glass 2010, or the role as a member for joining the respective constituent components.

Dust may sometimes be attached to the product in the production process of the mirror device 2000 or that of the projection apparatus comprising it. If the dust or the like attached to the top or bottom surface of the cover glass 2010 is projected, the quality of the projection image will be damaged. Therefore, when a sealed space is provided between the package substrate 2004 and cover glass 2010, the intermediate member is preferred to be designed in such a manner so that the distance between the top surface of the mirror of the mirror device 2000 and the cover glass 2010 is no less than several times a depth of focus of a projection optical system. For example, the intermediate member is preferred to be designed such that the distance between the top surface of the mirror of the mirror device 2000 and cover glass 2010 is no less than 0.5 mm.

Moreover, configuring the thickness of the cover glass 2010 to be 1 mm to 3 mm
makes it possible to make a projected dust attached to the surface of the cover glass inconspicuous should the dust be projected.

The intermediate member 2009 is constituted by a support member 2007 for determining the height of the cover glass 2010 and by a seal material 2008 made of fritted glass (i.e., granulated glass), epoxy resin, or a low melting point metallic material such as solder. Note that the support part 2007 may use fritted glass or the same material as that of the seal member 2008. Further, the package substrate 2004 may be configured as a cavity form and as a formation by integrating the package substrate 2004 with the intermediate member 2009.

The cover glass 2010 is joined to the package substrate 2004, which is made from a glass material, by welding with the fritted glass (i.e., granulated glass) which is the seal member 2009, or with epoxy resin or a low-melting point metallic material such as solder, which is the seal member 2008. For example, the fritted glass is coated, as the seal member 2008, on the joinder surface between the package substrate 2004 and support part 2007. Then, they are put into a furnace such as an electric furnace. Then, the joinder surface is sandwiched from the top and bottom with a hot heater or the like and is welded, and thereby the joining is accomplished.

In particular, the seal member 2008 is preferred to use glass with a low-melting point, i.e., the glass transition temperature being no higher than 400°C, or a metallic material with a melting point being no higher than 400°C. The reason is that an aluminum circuit wiring and the like are formed on the device substrate 2001 in a semiconductor process, and that the constituent components of the device substrate 2001 is unable to withstand the temperature of no lower than 400°C for an extended period of time.

For example, the mirror of a mirror element is made of an aluminum layer of the thickness of about 1500 angstroms to 3000 angstroms and is supported by an elastic hinge of 200 angstroms to 700 angstroms thick. The elastic hinge also uses aluminum or the like. Therefore, the mirror and elastic hinge alike are unable to withstand a temperature of no lower than 400°C for an extended period of time, likewise the aluminum circuit wiring. If a temperature of no lower than 400°C continues for an extended period of time, the heat will cause the internal stress of the elastic hinge to be changed because the gap between the individual mirrors of the mirror array 2002 is very narrow, e.g., 0.1μm to 0.5μm. As a result, the positions of the mirror may be changed to possibly lose the function of the mirror device.

Further preferably, the seal member 2008 uses a low-melting point glass with the glass transition temperature no higher than 300°C or a metallic material with the melting point no higher than 300°C. The usage of such a low-melting point material makes it easy
to carry out welding.

Low-melting point glass includes seal member made of, for example, fritted glass. While the fritted glass allows different melting points and thermal expansion, depending on the material; generally used in many cases include barium oxide (BaO)-series and lead oxide (PbO)-series lead glass with good fluidity and sealing property.

Further, glass not including lead, that is, unleaded glass, with a glass transition temperature between 300°C and 400°C has been developed in recent years. The unleaded glass includes a material obtained, for example, by adding TeO₂ or P₂O₅ to, a V₂O₅ - ZnO - BaO component-series material. The coefficient of linear expansion of this material, i.e., about 6- to 7 × 10⁻⁶ /K, has good fluidity and sealing property.

Several materials with a melting point between about 200°C and 400°C are available as a low-melting point metallic material. For example, an Au 80-Sn 20 alloy has a melting point between about 260°C and 320°C. In addition, an alloy such as Sn 80-Ag 20 that is a tin series high-temperature solder has a melting point between 220°C and 370°C, and likewise, Sn 95-Cu 5 has a melting point between 230°C and 370°C. Further additionally, indium (In) has a melting point about 157°C.

The use of the seal member 2008 made of the above described low melting point material makes it easy to carry out welding.

The intermediate member 2009 is preferred to use a material possessing a coefficient of linear expansion approximately the same as that of a non-alkali glass such as the material used for the package substrate 2004 and that of a silicon substrate used for the device substrate 2001, or a material possessing a coefficient of linear expansion between the aforementioned those coefficients of linear expansion.

Meanwhile, the package substrate 2004 may be configured to have a cavity structure comprising the support parts 2007 that constitute walls on four sides. Then, a use of a material, which is similar to that of the package substrate 2004, for the support parts 2007 makes it possible to reduce the constituent components of the package, which require a consideration for the coefficient of linear expansion.

In such a case, the device substrate 2001 is placed by providing, with a concave part, the center part of the package substrate 2004, in which the device substrate is placed by applying etching. Further, the protrusion parts on four corners, on which the device substrate 2001 is placed, can be used as the support parts 2007.

Furthermore, the package substrate 2004 may be constituted by the same silicon material as that of the device substrate 2001. In such a case, the package substrate 2004 is opaque and has the same coefficient of linear expansion as the device substrate 2001 does.
The use of a silicon material such makes it easy to make the package substrate a cavity structure. Further, the center part of the package substrate 2004 made of a silicon material can be etched in the semiconductor process. Further, a cavity structure can be formed by depositing a silicon material or the like on the package substrate 2004 made of a silicon material. The silicon material may use an 8-inch- to 10-inch silicon wafer for use in a semiconductor process. Although the package substrate 2004 may be constituted by an inexpensive glass material, the use of such a silicon material makes it easy to handle for forming a three-dimensional cavity. Furthermore, the package substrate 2004 may use a ceramic material when forming a three-dimensional form using a mold. Moreover, the package substrate 2004 may use a metallic material.

The package according to the present embodiment is configured to join the cover glass 2010 with the package substrate 2004, which includes the miniaturized mirror device, by using the seal member 2008. Further, the seal member 2008 for the joiner parts uses a material most suitable in terms of the coefficient of linear expansion and melting point, thereby enabling the most optimal package.

[Thermal Conduction Member]

The thermal conduction member 2003 is joined to the device substrate 2001 and package substrate 2004. Further, the thermal conduction member 2003 fills the role of receiving heat, and the like, generated by the light irradiated on the device substrate 2001 following its passing the gap between mirrors of the mirror device 2000 and conducting the heat to the radiation circuit wiring pattern 2014 and package substrate 2004, thereby mediating for externally radiating the heat.

Referring to Fig. 62A, the light absorbed in the surface of the mirror and the light passing through the gap between mirrors and absorbed by the device substrate 2001 are turned into heat. Then, the heat is conducted to, and radiated from, the top surface of the package substrate 2004 that is joined with the thermal conduction member 2003 by way of the thermal conduction member 2003 that is joined to the bottom surface of the device substrate 2001. In this case, the thermal conduction member 2003 can also fill the role of the radiation circuit wiring pattern 2014.

The thermal conduction member 2003 uses a material possessing a good thermal conductivity to the device substrate 2001 and package substrate 2004. It is particularly preferred to use a material containing a substance (e.g., tungsten, silicon, aluminum, gold, silver and magnesium) with the thermal conductivity of no less than 150 W/mK. Note that the silicon (Si) that is the primary element constituting the device substrate 2001 possesses the thermal conductivity of 168 W/mK.

Furthermore, the thermal conduction member 2003 is preferred to select a material
also in consideration of a coefficient of linear expansion. For example, at the ambient temperature (i.e., 20 °C), tungsten possesses the coefficient of linear expansion of 4.5*10^-6/K, while tantrum possesses that of 6.3*10^-6/K. Further, a tungsten suicide, which is produced by the reaction between tungsten and silicon (Si), and a tantrum suicide, which is produced by the reaction between tantrum and Si, possess the coefficients of linear expansion close to that of the material used for the device substrate 2001, which contains Si possessing the coefficients of linear expansion being 2.6*10^-6/K, or close to the coefficient of linear expansion of the package substrate 2004 made of a silicon material or glass material. Therefore they are suitable to the thermal conduction member 2003.

[Mirror Device]

The mirror device 2000 is primarily constituted by the device substrate 2001 and mirror array 2002. Further, the mirror device 2000 is placed on the thermal conduction member 2003 joined with the package substrate 2004 or directly thereon.

In Fig. 62A, the bottom surface of the device substrate 2001 of the mirror device 2000 is joined with the thermal conduction member 2003, and the thermal conduction member 2003 joined with the mirror device 2000 is placed on the package substrate 2004. Then, an electrode pad equipped on the top surface of the device substrate 2001 is connected, by a wire 2012, to an electrode equipped in the circuit wiring pattern 2005 on the top surface of the package substrate 2004.

For example, the material for the wire 2012 is preferred to be a high-thermal conductive material, such as gold, so that the heat of the device substrate 2001 can also be radiated through the wire 2012.

Further, the mirror array 2002 constituted by arraying a plurality of mirror elements, in two dimensions, on the device substrate 2001 fills the role of reflecting the light emitted from a light source, and then transmitting through the cover glass, and of controlling the direction of the reflection light.

The heat of the light absorbed in the individual mirrors of the mirror array 2002 is conducted to the device substrate 2001 by way of the structures such as elastic hinge and post, which constitute the mirror element. Then, the heat is conducted from the device substrate 2001 to the thermal conduction member 2003, and then radiated to outside of the package from the package substrate 2004 and other members. Therefore, the elastic hinge and post are preferred to use a material possessing high thermal conductivity.

For example, the elastic hinge, which is formed to be a few hundred angstroms thick and a few micrometers wide, is preferred to use a material containing any of Al, W and Si, which possess good thermal conductivity, in order to prevent a deformation due to
the heat. As the good thermal conductivity material, particularly a silicon material possessing thermal conductivity of 168 W/mK, an aluminum material of about 236 W/mK and the like are appropriate.

Here, a silicon material is available in several crystallization states such as amorphous silicon, poly-silicon and single crystal silicon, from which the most optimal material is preferably to be selected in consideration of a property such as a modulus of elasticity.

Further, in consideration of thermal conduction, other members linked to the elastic hinge are preferred to use a material possessing thermal conductivity being at least 150 W/mK.

Therefore, it is possible to conduct the heat of the light absorbed in the mirror and the heat generated by the operation of the mirror element effectively to the device substrate 2001 by selecting the material described above for the elastic hinge or the member linked thereto. Accordingly, this configuration is capable of radiating heat from the device substrate 2001 to the outside by way of the thermal conduction member 2003 and the related components.

[Cover Glass]

The cover glass 2010 is designed to be smaller than the package substrate 2004 so as to cover the upper side of the mirror device 2000, and is joined to the package substrate 2004 using the intermediate member 2009. The cover glass 2010 mainly fills the roles of protecting the mirror device 2000 from external dust, shielding extraneous incident light so as to prevent the extraneous incident light from entering the mirror device 2000 and generating heat within the package, and of preventing the light reflected by the mirror array 2002 from reflecting diffusely within the package.

An anti-reflection (AR) coating 2011 is applied to the top and bottom surfaces of the cover glass 2010 and thereby the light reflected by the top surface of the cover glass 2010 is not reflected toward the projection lens. Further, the AR coating 2011 prevents the light reflected by the mirror array 2002 from being further reflected by the bottom surface of the cover glass 2010 and thereby a diffuse reflection of the light is prevented.

Further, either one of the top and bottom surfaces of the cover glass 2010, or both surfaces thereof, are partially equipped with the light shield layer 2006 for preventing extraneous light from entering the mirror device 2000. In Fig. 62A, the light shield layer 2006 is equipped on the bottom surface of the AR coating 2011, which is applied to the bottom surface of the cover glass 2010.

While a cover glass is placed in the form of nearly touching a liquid crystal layer
in a liquid crystal device; in a mirror device, a cover glass is preferred to be placed by maintaining the distance of, for example, 1 mm to 5 mm between the mirror and the bottom surface of the cover glass. Such a setup makes it possible to allow a certain degree of freedom for the roughness of the cover glass surface. For example, the roughness, about 0.15μm to 0.3μm/20mm, of the bottom surface of the cover glass is permissible. Further, the cover glass surface may be polished to about 0.05μm to 0.15μm/20mm.

[Anti-Reflection (AR) Coating]

An anti-reflection (AR) coating 2011 is applied to either one of the top and bottom surfaces of the cover glass 2010, or both surfaces thereof, for preventing a reflection on the surface of the cover glass 2010 and preventing the light reflected by the mirror array 2002 from diffusely reflecting internally within the package.

The AR coating 2011 can be applied, for example, by coating magnesium fluoride (MgF2) on a glass surface, or by applying a processed glass material as a nano-structure. This can produce the reflectance of an incident light to be no higher than 0.4%.

A coating on a glass surface applies a multi-coating so as to eliminate dependence on various wavelengths and the incident angle. Note that a multi-coating corresponding to wide wavelength range is also viable.

When processing a nano-structure, fine particles are layered with a gelatinous material and then metallic particles are thermally removed, and thereby a fine form can be formed. Note that the adopting of the method for processing a nano-structure makes it possible to make the layer respond to a wide wavelength range easier than the multi-coating layering an inorganic material is.

The application of such AR coating 2011 reduces the reflection light intensity oriented to the projection lens from the cover glass 2010, thereby improving a contrast. Further, a large volume of light is incident to the mirror array 2002. Considering this fact, the AR coating 2011 is preferred to be applied so as to lower the reflection of the wavelength of the incident light.

Meanwhile, the intensities of light incident to the device substrate 2001 or package substrate 2004 of the mirror device are changed depending on the AR coating 2011 and the aperture ratio and reflectance of the mirror of a mirror element.

For example, when using a mirror, of which the aperture ratio is 80% and the reflectance is 80%, with the mirror reflecting 1% by means of the AR coating, then about 58% of the incident light is reflected by the mirror, and the remaining 42% of the light enters the device substrate or package substrate.

When using a mirror, of which the aperture ratio is 90% and the reflectance is 85%,
with the mirror reflecting 0.4% by means of the AR coating, then about 73% of the incident
light is reflected by the mirror, and the remaining 27% of the light enters the device
substrate or package substrate.

Based on the above, a package can possibly be designed to attain an intensity of
light incident to the device substrate of package substrate between 27% to 42%.

In a projection apparatus comprising the mirror device 2000 of which the mirror
size is, for example, 11μm, the illumination lights of the respective colors, that is, red (R),
green (G) and blue (B), are modulated by the mirror array 2002 corresponding to image
signals to project a color image. In such a projection apparatus, some apparatus makes the
image brighter by enhancing the intensity of green light (G) even by unbalancing the other
colors respective colors of R, G and B. In such a case, the image can be made brighter
effectively by providing the most optimal AR coating 2011 for the green light.

In the meantime, a multi-panel projection apparatus comprising a plurality of the
mirror devices 2000 corresponding to a plurality of illumination lights such as R, G and B
is preferred to be equipped with AR coatings 2011, in multi-coating or single layer coating,
which are most optimal to the respective illumination lights.

Further, if a light source used for a projection apparatus is another light source
such as a mercury lamp and the like, the numerical aperture NA of the light is larger than
that of a laser light source and the light contains many wavelengths as green light. In such a
case, the deflection angle of a mirror of the mirror device 2000 is set, for example, at ±13
degrees. When there is this degree of difference in angles of the deflection angle between
the incident light and reflection light on the basis of the deflection angle of the mirror, the
dependence on the incident angle is reduced by applying a multi-coating by considering the
optical path lengths of the incident light and reflection light passing through the cover
glass.

In contrast, in the case of a laser light source, the numerical aperture NA is smaller
than that of a mercury lamp and the light has a single wavelength, and therefore the
deflection angle of the mirror of the mirror device 2000 can be reduced to the range of ±4
degrees and ±8 degrees. Therefore, the angular difference between the incident light and
reflection light can be reduced from the case of using the mercury lamp. As a result, the
optical path lengths of the incident light and reflection light passing through the cover
glass can be shortened from the case of using the mercury lamp. Therefore, a sufficient
effect can be obtained by applying a single layer coating of the thickness of 1/4 wavelength
of the incident light so as to optimize it with the wavelength of the incident light.

Furthermore, when the deflection angles of a mirror in the ON state and OFF state
are respectively ±13 degrees, the total deflection angle of the mirror is 26-degree. Here, if
the deflection angle is reduced to the range of ±4 degrees and ±8 degrees, the total deflection angle is reduced to the range of ±8 degrees and ±16 degrees. This configuration makes it possible to reduce the difference in light transmission between the incident light and reflection light passing through the AR coating 2011 provided on the cover glass.

5 [Light Shield Layer]

The light shield layer 2006 fills the role of absorbing the extraneous light irradiated onto the mirror device 2000 and the undesirable light reflected by it, thereby alleviating a temperature rise within the package.

In the configuration of Fig. 62A, the light shield layer 2006 is equipped on the bottom surface of the package substrate 2004. Further, the light shield layer absorbs a portion of the light passing inside of the package, thereby improving the radiation efficiency to the outside thereof.

The light shield layer 2006 is constituted by, for example, a black film layer containing carbon, or by a multiple layer comprising a black film layer and a metallic layer. Alternatively, a layer to well pass light may be formed by applying a film coating with the AR coating 2011.

15 [Cover Glass and Package Substrate]

The material for the cover glass 2010 and package substrate 2004 can use glass. Any of non-alkali glass, which is used for a thin-film transistor (TFT) liquid crystal, et cetera, and in which an alkali component is limited to 1% or less, soda ash glass, used for a supertwist nematic (STN) liquid crystal, et cetera, and high strain point glass used for a plasma display, et cetera, may be used. A circuit and glass, however, are practically in touch with each other in a liquid crystal, et cetera, and therefore a protective film made of SiC>2 needs to be provided on a glass surface for preventing the elution of an alkali component from the glass if the soda ash glass is used.

As an example, Laid-Open Japanese Patent Application Publication No. 2006-301 153 has disclosed that a material possessing the coefficient of linear expansion of $10^\times 10^{-6}$ /K is used for a support member of a diffraction grating type device filled in a protective member. In contrast, the present embodiment is configured to use a material possessing a coefficient of linear expansion smaller than $10^\times 10^{-6}$ /K in order to widen a limit range of the temperatures of environment in which the mirror device is used. Although there are various types of non-alkali glass, the coefficients of linear expansion of many types fall in 4.6- to 4.8$\times 10^{-6}$ /K, with some of them falling in 3.7- to 3.8$\times 10^{-6}$ /K. Meanwhile, common soda ash glass and high strain point glass fall in 7.8- to 8.5$\times 10^{-6}$ /K. Furthermore, Laid-Open Japanese Patent Application Publication No. H11-116271 has
disclosed a fritted glass of which the coefficient of linear expansion falls in about 7.2- to 9*10^{-6}/K. Among the above described, the glass to be used for the cover glass 2010 and package substrate 2004 is preferred to possess the coefficient of linear expansion between 3.5-8.5*10^{-6}/K.

Further, the device substrate 2001 of the mirror device 2000 is cut from a wafer made of a single crystal silicon material. The coefficient of linear expansion of silicon (Si) that is the main component of the device substrate 2001 is 2.6*10^{-6}/K at normal temperature (20°C). Here, if non-alkali glass possessing the coefficient of linear expansion of 3.5- to 4.8*10^{-6}/K is used for the cover glass 2010 and package substrate 2004, the difference in coefficients of linear expansion between them and device substrate 2001 is small. Furthermore, if the coefficient of linear expansion of the intermediate member 2009 is also the same as that of the cover glass 2010 and package substrate 2004, it is preferable since a sufficient permissible stress exists against the deformation of the member due to temperature. Therefore, it is preferable to use the material(s) possessing approximately the same coefficient of linear expansion for the cover glass 2010 and package substrate 2004, and it is further preferable to use a material possessing a coefficient of linear expansion of no higher than 5*10^{-6}/K.

Further, it is also possible to equalize the thermal influence on the glass on the top and bottom by configuring both the thickness of the cover glass 2010 and that of the package substrate 2004, which is made of glass, between 1 mm and 3 mm.

[Space Inside of Package]

The space inside of the package may be filled with a gas, or vacuum. If the space is filled with a high thermal conductivity gas, the radiation efficiency is improved since the heat is easily transferred to the individual constituent components of the package. Heat transfers (to the individual constituent components of the package) are improved by filling the space with, for example, an inert gas such as a nitrogen gas. Note that the thermal conductivity of the nitrogen gas is 2.4*10^{-2} Wm/K that of a helium gas is 14.2*10^{-2} Wra/K, and that of a xenon gas is 0.52*10^{-2} Wm/K.

Fig. 62B is a top view diagram of the assembly body 2100 shown in Fig. 62A, with the cover glass 2010 and intermediate member 2009 removed.

The mirror array 2002 is placed on the device substrate 2001. Further, the device substrate 2001 is connected, via the wire 2012, to the circuit wiring pattern 2005 placed on the package substrate 2004.

The thermal conduction member 2003 (not shown in this drawing) is placed on the bottom surface of the device substrate 2001, and the configuration is such that the heat is
conducted from the thermal conduction member 2003 to the package substrate 2004 and radiation circuit wiring pattern 2014, and is radiated to outside of the package.

Fig. 62C is a top view diagram of the assembly body 2100 shown in Fig. 62A.

The comprising of the cover glass 2010 and intermediate member 2009 on the upper side of the assembly body 2100 (cf. Fig. 62B) enables the light shield layer, which is applied to the bottom surface of the cover glass 2010, to absorb the light irradiated onto regions other than the mirror array 2002. The configuration further makes it possible to radiate the heat inside of the package from the radiation circuit wiring pattern 2014 extending from the inside to outside of the package.

Figs. 62D and 62E are bottom view diagrams of the assembly body 2100 shown in Fig. 62A. Incidentally, the delineation of the cooling/radiation member (heat sink) 2013, light shield layer 2006 and circuit wiring pattern 2005 is omitted here for drawing the form of the thermal conduction member 2003.

The form of the thermal conduction member 2003 is arbitrary and so is the position of the device substrate 2001. The form and placement of the thermal conduction member 2003, however, need to consider the change in shapes due to thermal expansion, since the thermal conduction member 2003 is closely placed with the device substrate 2001.

As an example, Fig. 62D exemplifies the case of placing the columnar thermal conduction member 2003 at the center of the bottom surface of the device substrate 2001.

Adding heat to such a columnar thermal conduction member 2003 generates thermal expansion so that the thermal conduction member 2003 expands in the form of a concentric column. This phenomenon causes the positions of the device substrate 2001 placed on the thermal conduction member 2003 to change, further creating a change of the positions of a mirror of the mirror array 2002. The configuration, however, is contrived in such manner that columnar thermal conduction member 2003 deforms at the center of the device substrate 2001 and therefore a shift in the optical axis at the center of the screen can be limited to a minimum. Further, the device substrate 2001 is stabilized by placing the thermal conduction member 2003 at the center of gravity position of the device substrate 2001, which is the center thereof.

In Fig. 62E on the other hand, a rectangular-shaped thermal conduction member 2003 is placed in line with the bottom surface of the device substrate 2001. Such a configuration makes the other side of the device substrate 2001 a free end. Therefore, if the device substrate 2001 and package substrate 2004 are expanded by the heat, an influence caused by different degrees of expansion between the device substrate 2001 and package substrate 2004 on either of them can be alleviated. This fact widens a degree of freedom in
selecting a glass material and broadens the temperature range of the environment in which the device substrate is used.

Note that one piece of the thermal conduction member 2003 is preferred to be placed for a part of one piece of the device substrate 2001. The reason is that a placement of a plurality creates a need to consider the degrees of deformation of those thermal conduction members 2003.

<Embodiment 5-2>

A package according to an embodiment 5-2 is a modified embodiment of that of the embodiment 5-1.

The package according to the embodiment 5-2 has a separate package substrate, or the package substrate has an opening part, which is the difference from the package of the embodiment 5-1. Further, the package improves radiation efficiency by placing the opening part of the package substrate so that the opening part is under the mirror device. It is configured to generate a sealed space by joining the package substrate 2004, which has an opening part including the circuit wiring pattern 2005, and the bottom part of the device substrate 2001 by means of welding a seal member 2008 (e.g., a solder) of an intermediate member, and thereby the inside of the package is isolated from the outside. The other comprisals of the embodiment 5-2 are similar to the embodiment 5-1 and therefore the description is not provided here.

Further, a thermal conduction member is connected to the bottom surface of the device substrate of the mirror device, and thereby heat can be externally radiated from the device substrate by way of the thermal conduction member. Note that the comprisal may exclude the thermal conduction member.

Furthermore, the radiation efficiency can also be improved by comprising a cooling/radiation member (heat sink) equipped with fins in the opening part of the package substrate.

Figs. 63A and 63B show an assembly body 2200 that packages a mirror device 2000 by using a package substrate 2004 having an opening part, as a preferred embodiment 5-2.

Fig. 63A is the front cross-sectional diagram of the assembly body 2200 that packages the mirror device 2000 by using the package substrate 2004 having an opening part.

In the assembly body 2200 shown in Fig. 63A, the package substrate 2004 has an opening part, and a thermal conduction member 2003 joined to the mirror device at the center of the opening part is placed. The present embodiment is configured to join the top
surface of the thermal conduction member 2003 to a device substrate 2001 and join the
bottom surface of the thermal conduction member 2003 to a cooling/radiation member
(heat sink) 2013. Configuring as such makes it possible to externally radiate the heat from
the device substrate 2001 directly without an intervention of the package substrate.

The present embodiment includes a space between the opening part of the package
substrate 2004 and the thermal conduction member 2003. It is also possible to radiate from
such a space by way of the thermal conduction member 2003 and cooling/radiation member
(heat sink) 2013. An alternative configuration may be such that a space is not provided
between the thermal conduction member 2003 and the opening part of the package
substrate 2004, that is, the opening part of the package substrate 2004 is joined by the
thermal conduction member 2003.

The present embodiment is further configured such that a light shield layer 2006 is
overlapped on the top surface of the package substrate 2004 including a circuit wiring
pattern 2005. The equipping of the light shield layer 2006 on the top surface of the package
substrate 2004 enables an instant absorption of the light that is incident to inside of the
package and not reflected by the mirror array 2002. As a result, a diffuse reflection of light
can be suppressed. Further, the heat accumulation efficiency of the circuit wiring pattern
2005 existing under the light shield layer 2006 is improved and the radiation to the outside
of the package is improved.

The light shield layer 2006 is made of, for example, a black material containing
carbon. Further, an insulation layer (not shown in a drawing herein) is preferred to be
placed between the circuit wiring pattern 2005 and light shield layer 2006.

Fig. 63B is the bottom plain view diagram of the assembly body 2200 shown in Fig.
63A. Note that the drawing omits the cooling/radiation member (heat sink) 2013, light
shield layer 2006 and circuit wiring pattern 2005 for showing the opening part of the

The columnar opening part exists at the center of the package substrate 2004, and
the columnar thermal conduction member 2003, which has a similar figure to the opening
part and which is connected to the bottom surface of the device substrate 2001, is formed at
the center of the opening part. Note that the forms of the opening part and thermal
conduction member 2003 are not limited as described above.

In Fig. 63B, the package substrate 2004 does not contact with the thermal
conduction member 2003 so that there is a space between them. Further, the top surface of
the thermal conduction member 2003 is connected to the bottom surface of the device
substrate 2001, and the bottom surface of the thermal conduction member 2003 is
connected to the cooling/radiation member (heat sink) 2013 (not shown here).
Configuring as such makes the thermal conduction member 2003 exposed to outside of the package, thereby making it possible to radiate the heat received from the device substrate 2001 without an intervention of the package substrate.

Further, it is easy for the device substrate 2001 to absorb light by being equipped with the light shield layer (not shown here). As a result, the heat accumulation in the device substrate 2001 is improved; and the thermal conduction from the device substrate 2001 to the thermal conduction member 2003 is improved by a larger difference in temperatures between the device substrate 2001 and thermal conduction member 2003.

As described above, the use of the package as shown in Figs. 63A and 63B enables an improvement in the radiation efficiency.

<Embodiment 5-3>

A package according to an embodiment 5-3 is a further modified embodiment of that of the embodiment 5-1.

The package according to the embodiment 5-3 differs from the package of the embodiment 5-1 where the former includes a substrate which is made of a silicon material, a metallic material or a ceramic material and which has a cavity. It is further configured to form an electrical connection between a device substrate and a cover glass by equipping it with a circuit wiring pattern. The other comprisals of the embodiment 5-3 are similar to those of the package according to the embodiment 5-1, and therefore the description is not provided here.

Fig. 64 is a front cross-sectional diagram of an assembly body 2300 which includes a package substrate 2019 and which packages a mirror device 2000 so as to be electrically connected to a device substrate 2001 by equipping a cover glass 2010 with a circuit wiring pattern 2005.

The assembly body 2300 shown in Fig. 64 is configured to equip a light shield layer 2006 on the top surface of the cover glass 2010 and equip the circuit wiring pattern 2005 on the bottom surface of the cover glass 2010.

The light shield layer 2006 equipped on the top surface of the cover glass 2010 pre-limits the region of light irradiated onto the mirror device 2000. The limiting of the light incident to inside of the package makes it difficult to accumulate the heat generated by the incident light.

Further, the circuit wiring pattern 2005 extends from inside of the package to outside thereof and is connected to a circuit substrate on the outside of the package. On the other hand, the circuit wiring pattern 2005 is electrically connected to an intermediate member 2009 possessing good electrical conductivity, e.g., a seal member 2008 such as
solder, which is equipped on the device substrate 2001 inside of the package. Configuring as such enables the control circuit as included in a circuit board 2015 to electrically connect the mirror device 2000 by way of the circuit wiring pattern 2005.

Further, different from the embodiment 5-1, the light shield layer 2006 is provided on the top surface of the package substrate 2019, while a light shield layer 2006 is not provided on the bottom surface of the package substrate 2019.

Alternatively, the circuit board 2015 may be provided with an opening part, and the cover glass may be retained as a flange by inserting the package substrate 2019 into the opening part.

<Embodiment 5-4>

A package according to an embodiment 5-4 is a package storing a control circuit for controlling a plurality of mirror devices, or one or a plurality of mirror devices.

A plurality of mirror devices and the control circuit are placed directly on a package substrate. The package substrate is, for example, glass substrate, silicon substrate, metallic substrate or ceramic substrate.

When a device substrate is placed on a package substrate, the package substrate and cover glass, which are formed in an approximate similar form to the outer shape of a mirror device, are generally placed. When a device substrate is placed in a package constituted by a package substrate made of glass and by a cover glass made of glass, or a plurality of device substrate is placed on a single package substrate, however, a preferred configuration is such that the outer shape of the package substrate is not parallel to that of the device substrate so as to cause the incident light to enter from the direction of a side of the package substrate. In the case of using, for example, a square mirror element, the placement is such that each side of the mirror element forms a 45-degree angle with a side of the package substrate so as to make the side of the package substrate parallel to the deflection axis of the mirror element. The positioning and assembly of the device substrate and optical elements can be easily carried out by placing them in such a manner that any of the sides of the optical elements placed on the package substrate is not parallel to the side of the package substrate. Particularly, when a plurality of mirror devices is placed inside of a single package, the illumination lights corresponding to the respective mirror devices may be made to be incident from the directions of different sides or from the same direction. Such a placement enables an improvement in the freedom of layout for individual constituent components within a projection apparatus.

Based on the above description, the preferred placement of a light source is such that a plurality of mirror devices does not have a side in parallel to the outer circumference.
of a single package substrate and also such that the optical axis of the incident light is perpendicular to any of the sides of the package substrate in the plane direction of the mirror array.

Note that an alternative configuration may be such that a thermal conduction member 2003 as noted in the embodiment 5-1 is joined to a plurality of mirror devices and/or the control circuit so as to enable radiation by way of the package substrate.

As an example, Figs. 65A, 65B and 65C show an assembly body that packages a plurality of mirror devices and a control circuit used for controlling the mirror devices in one package shown in the embodiment 5-1.

Fig. 65A is a front cross-sectional diagram of an assembly body 2400 that packages two mirror devices 2030 and 2040 and a control circuit 2017 in one package substrate 2004.

The assembly body 2400 includes the package substrate 2004 made of a silicon material, and includes two mirror devices 2030 and 2040 and a control circuit 2017 on the package substrate 2004.

Further, a circuit wiring pattern 2005 is configured to collect the circuit wiring pattern 2005 only in one direction, that is, only in the left direction in the example shown in Fig. 65A.

Then, a part of the top and bottom surfaces, respectively, of a cover glass 2010 are provided with light shield layers 2006 so as to not irradiate any region other than the mirror arrays 2032 and 2042 of the respective mirror devices 2030 and 2040.

The other constituent components of the embodiment 5-4 are the same as those of the embodiment 5-1 and therefore the descriptions are not provided here. Note that the package as shown in Fig. 65A, is capable of further accommodating many mirror devices, control circuits and the like.

When a plurality of mirror devices is placed in one package as described above, it is easy to align the heights from the top surface of the package substrate 2004 and the intervals between mirror devices. For example, the plurality of mirror devices 2030 and 2040 can be placed on the same package substrate 2004 in the same process, with the placement performed against the same positioning part as reference. Therefore, the placements of the plural mirror devices are easy. Furthermore, the positional relationship with a synthesis optical system used for synthesizing the reflection lights from individual mirror devices can also be carried out easily.

Further, a video image projected by a projection apparatus comprising such an assembly body 2400 suffers little degradation of resolution because the pixels of the
respective mirror devices 2030 and 2030 will overlap with each other. Furthermore, the colors reflected by the respective mirror devices 2030 and 2040 are observed with a less amount of blur.

Further, the equipping of the control circuit 2017 inside of the package makes it possible to place the circuit wiring pattern 2005, which includes a very large number of lines, of the control circuit 2017 on a single package substrate. This produces a result of greatly reducing the floating capacity and the like of the circuit wiring pattern 2005. Furthermore, the control circuit 2017 controlled in higher speed than a video signal can be placed at a position equally distanced from the respective mirror devices 2030 and 2040, and the differences in the resistance values and floating capacity of the respective circuit wiring patterns 2005 connected to the individual mirror devices 2030 and 2040 are reduced. This enables the use of a mirror device comprising many mirror elements and a mirror device for which a data processing volume is large and which is capable of control in higher number of gray scales. This accordingly enables an image in a high level of gradation and high resolution. Further, the shortening of the circuit wirings to the respective mirror devices makes it easy to synchronize the timing, for controlling the mirror devices, between the respective mirror devices.

Furthermore, the thermal environments of the plural mirror devices placed on a single package substrate are the same and thereby the positional shifts due to thermal expansion of mirror elements of the respective mirror devices become approximately the same. Therefore, the projection conditions can be made to be identical. Further, the controls for the respective mirror devices can also be handled as the same environment so that the control conditions such as an analogical control for the mirror and the voltage value of memory can be made the same for the mirror devices.

Fig. 65B is a top view diagram of the assembly body 2400 shown in Fig. 65A, with the cover glass and the intermediate member removed.

The circuit wiring pattern 2005 is placed on the package substrate 2004, and the circuit wiring pattern 2005 is directly connected to the device substrates 2031 and 2041 of the respective mirror devices, and to the control circuit 2017.

The circuit wiring pattern 2005 is configured to collect the pattern only in one direction, that is, only in the left direction in Fig. 65B. Alternatively, the circuit wiring pattern 2005 may be configured to place evenly in the left and right directions depending on the number of wirings.

Further, a positioning pattern 2016 is provided for positioning the two mirror devices 2030 and 2040 or control circuit 2017 on the package substrate 2004. In Fig. 65B, the positioning pattern 2016 is formed by using the circuit wiring pattern 2005. Then, the
positional relationship among mirror devices 2030 and 2040 and control circuit 2017 can be determined in high precision by measuring the positioning pattern 2016 provided on the package substrate 2004 optically with a charge-coupled device (CCD) camera, etcetera.

Furthermore, a collation of the placement of the positioning pattern with the mirror device and control circuit can be carried out by using, for example, a marker provided on the mirror of the mirror device, or taking the circuit wiring pattern equipped on the outer circumference of the device substrate, or a land, as reference. Assuming the width of the circuit wiring pattern 2005 and positioning pattern 2016 is 0.1 μm, a positioning can be performed in the accuracy of one half of the width of the wiring or higher, that is, 0.05 μm or better.

Incidentally, while the positioning pattern 2016 is formed by using the circuit wiring pattern 2005 in the configuration of Fig. 65B, a positioning pattern may be formed by using a material different from that of the circuit wiring pattern 2005. Such a positioning can also be provided in the case of using a substrate made of a glass or ceramic material as a package substrate 2004. Further, the positioning pattern 2016 may also function as the circuit wiring pattern 2005 and/or radiation circuit wiring pattern.

As yet another positioning method, it is possible to provide an uneven part (i.e., a concave-convex part) for positioning the device substrates 2031 and 2041 in relation to the package substrate 2004 by applying an etchant to the package substrate 2004, made of a silicon material, in the semiconductor process.

Further, the mirror devices 2030 and 2040 may be placed in a concave part provided at the center part of the package substrate 2004.

Fig. 65C is a top view diagram of the assembly body 2400 shown in Fig. 65A.

Equipping a cover glass 2010 and an intermediate member 2009 on the assembly body 2400 shown in Fig. 65A (note—neither 2010 or 2009 are shown in Fig. 65B, only Fig. 65A) enables light shield layers 2006, which are respectively provided on the top and bottom surfaces of the cover glass 2010, to absorb the light irradiated onto parts other than the respective mirror arrays 2032 and 2042.

The circuit wiring pattern 2005 connected, respectively, to the mirror devices 2030 and 2040 extends from inside of the package to outside thereof and fills the role of conducting the heat inside of the package and radiating it to the outside.

[Projection Apparatus]

Next is a description of a projection apparatus comprising a light modulation device packaged as described above. The light modulation device is, for example, a mirror device.
The projection apparatus according to the present embodiment includes a laser light source, an illumination optical system, a light modulation device, a package and a projection lens.

The laser light source is preferably the laser light source as described above.

The illumination optical system fills the role of enlarging the light flux emitted from the laser light source.

The light modulation device fills the role of modulating the light flux enlarged by the illumination optical system. The light modulation device is constituted by a light modulation array of which the diagonal size is 10.41mm to 22.098mm (0.41 inches to 0.87 inches) and in which, for example, no less than two million pixels of light modulation elements are arrayed in two dimensions, with the pitch between individual light modulation elements 4.6μm to 10μm, on a device substrate. The light modulation device is, for example, a mirror device, and the light modulation element is, for example, a mirror element. The mirror element contains aluminum. The device substrate is, for example, a silicon substrate.

The package protects the light modulation device. The package includes a support substrate for supporting the device substrate of the light modulation device, a transparent cover glass and an intermediate member for joining the support substrate and cover glass together.

The support substrate is, for example, a glass substrate, a silicon substrate or a metallic substrate, as described above.

Other constituent members are preferably configured by using the materials noted above as much as possible. Particularly, a package configured by using glass selects an appropriate material so as to minimize the difference in coefficients of linear expansion between the glass and a material for the light modulation device. Configuring as such makes it possible to prevent a breakage or a mutual peeling off due to the difference in thermal expansion between the light modulation device and package.

The projection lens fills the role of projecting the light modulated by the light modulation device.

The designing of a projection apparatus using the constituent components described above makes it possible to display a high resolution, bright image.

Note that the heat retained by the light modulation device can be reduced by controlling the intensity of a laser light irradiated onto the light modulation device. For example, the changing of the intensity of a laser light source changes the intensity to be modulated by the light modulation device that is used for modulating light in accordance
with an image signal. Here, there is a possibility that the entire screen is dark or the average brightness of the screen is low, depending on the image signal. In such a case, the heat stored in the light modulation device can be reduced by modulating light by lowering the intensity of the illumination light to 50% or 25%.

Further, when the entire screen is bluish and the modulation performed by the light modulation array corresponding to the red laser light source is finished early in a multi-panel projection apparatus comprising light modulation devices corresponding to the respective light sources of red (R), green (G) and blue (B), the red laser light source is turned OFF early by shortening the sub-frame corresponding to red. As such, it is possible to eliminate the extraneous illumination onto the light modulation device corresponding to the red laser light source and accordingly reduce the heat retained by the light modulation device due to an extraneous illumination.

Next is a description of a projection apparatus employing a mirror device as the light modulation device.

First, the resolution of an image projected by the projection apparatus is determined by the size of a mirror, the F-number of a projection lens, the numerical aperture NA of a light source, the coherency of a light flux, et cetera.

When using a laser light source, a bright image can be projected by maintaining the resolution with the numerical aperture NA of an illumination light flux as 0.1 to 0.04 because a degradation in the high frequency component of the spatial frequency of a laser light is small. Further, it is possible to maintain the resolution of a projection image even with the F-number of the projection lens increased to between 5 and 12, a larger than that of the case of using a mercury lamp or the like.

Then, a useless space between the illumination light flux and projection light flux can be reduced by determining the deflection angle of the mirror device by matching the F-number of the illumination light flux and projection light flux, and also designing a layout so as to close the distance between the illumination light flux and projection light flux. If the deflection angle of the mirror is designated at $\theta$, the numerical aperture is let as $\text{NA} = \sin \theta$, and the F-number is let at $\text{F-number} = 1/2*\text{NA}$, and thereby an approximation is possible. With this approximation equation, an appropriate F-numbers will be changed in association with the deflection angle $\theta$ of a mirror and the numerical aperture $\text{NA}$.

When the deflection angle $\theta$ of a mirror is $\pm 4$ degrees, the NA of an obtainable light flux is 0.070, and the preferable F-number for a projection lens can possibly be 7.2.

When the deflection angle $\theta$ of a mirror is $\pm 5$ degrees, the NA of an obtainable light flux is 0.087, and the preferable F-number for a projection lens can possibly be 5.7.
When the deflection angle $\theta$ of a mirror is $\pm 7$ degrees, the NA of an obtainable light flux is 0.122, and the preferable F-number for a projection lens can possibly be 4.1.

When the deflection angle $\theta$ of a mirror is $\pm 9$ degrees, the NA of an obtainable light flux is 0.156, and the preferable F-number for a projection lens can possibly be 3.2.

When the deflection angle $\theta$ of a mirror is $\pm 13$ degrees, the NA of an obtainable light flux is 0.225, and the preferable F-number for a projection lens can possibly be 2.2.

Based on the approximation result, when the F-number for a projection lens is determined to be 2.2 for an illumination light flux of which the numerical aperture NA emitted by, for example, a mercury lamp is 0.225, the deflection angle of a mirror element is preferred to be designated at $\pm 13$ degrees. Therefore, in a rear projection system using a mercury lamp, the numerical aperture NA is between 0.17 and 0.21, and the F-number for a projection lens to be used is designated between 2.4 and 2.8, and therefore a mirror device in which the deflection angle of a mirror element is between $\pm 10$ degrees and $\pm 13$ degrees.

Meanwhile, when using an illumination light flux of which the numerical aperture emitted from a laser light source is between 0.10 and 0.04, the F-number of a projection lens can be increased to between 5 and 12, larger than when using a mercury lamp, and the deflection angle of mirror can be reduced to between $\pm 2.3$ degrees and $\pm 5.7$ degrees.

When an aberration of light is not considered, the relationship between an appropriate F-number for a projection lens and the deflection angle of a mirror can be obtained from the pixel pitch of a mirror element and the above described relational expression of resolution.

Furthermore, a laser light is a light with a uniform phase, and therefore a clear diffracted light is generated, as compared with the light emitted from a mercury lamp. Therefore, it is possible to make it difficult for a projection lens to project the diffracted light by setting the deflection angle $\theta$ of mirror at larger than the appropriate deflection angle $\theta$ of mirror approximated in accordance with the numerical aperture NA of the light flux of a laser light source and the F-number of a projection lens. Considering this, the incidence of the diffracted light into the projection lens can be suppressed by setting the deflection angle of mirror larger than $\pm 4$, when the numerical aperture NA of the illumination light from the laser light source is 0.070, and the F-number of the projection lens at 7.14. As a result, the contrast of the projection image is improved.

Therefore, the projection apparatus according to the present embodiment using a laser light source is configured to set the deflection angle of mirror between $\pm 7$ degrees and $\pm 5$ degrees, even if the pitch between the mirrors is between 4.6$\mu$m and 10$\mu$m. Alternatively, the deflection angle $\theta$ of mirror may be set at $\pm 4$ degrees, and only the NA of
the illumination light flux may reduced.

Next is a description of a suitable projection lens when a mirror device is further miniaturized.

If a mirror device with a diagonal size of 0.95 inches is used for a rear projection system with about 65-inch screen size, the required projection magnification ratio is about 68. If a mirror array with a diagonal size of 0.55 inches is used, the required projection magnification ratio is about 118. As such, the projection magnification increases in association with the miniaturization of the mirror array. This ushers in the problem of color aberration caused by a projection lens.

The focal distance of the lens needs to be shortened to increase the projection magnification. Accordingly, the F-number for the projection lens is set at 5 or higher by using a laser light source. With this, it is possible to use a projection lens with the F-number at 2 times, and the focal distance at a half, as included in a configuration of a mercury lamp and a focal distance is 15 mm with the F-number at about 2.4 for the projection lens—is this in reference to a comprisal with laser or mercury. The usage of a projection lens with a large F-number makes it possible to reduce the outer size of the projection lens. This in turn reduces the image size with which a light flux passes through the illumination optical system, thereby making it possible to suppress a color aberration caused by the projection lens.

Therefore, in the case of using a laser light source with a mirror device miniaturized to between 0.4 inches and 0.87 inches, the deflection angle of mirror can be reduced to between ±7 degrees and ±5 degrees, and the F-number for a projection lens can be increased. Alternatively, the setting of the numerical aperture NA of an illumination light flux between 0.1 and 0.04 with the deflection angle of mirror maintained at ±13 degrees makes it possible to reflect the OFF light to a large distance from the projection lens, improving the contrast of the projection image.

As described above, the projection magnification of a projection lens can be set at 75x to 120x by reducing the numerical aperture NA of the light flux emitted from a laser light source, using a miniaturized mirror device (diagonal size of 0.4 inches to 0.87 inches) with which the deflection angle of mirror is reduced to between ±7 degrees and ±5, and thereby the F-number for a projection lens is increased.

Meanwhile, when a mirror device is moved forward or backward relative to the optical axis of projection, a distance with which an image blur (i.e., out of focus) of a projected image is permissible is called a focal depth. When an image is projected with a permissible blur in a degree of the mirror size by an optical setup of the same focal distance, projection magnification and mirror size, a depth of focus is approximated as
follows:

\[ \text{Depth of focus } Z = 2 \times (\text{permissible blur}) \times \text{(F-number)} \]

Here, the depth of focus is proportional to the F-number of a projection lens. That is, the permissible distance of the shift in positions of a placed mirror device, relative to the optical axis of projection, increases with F-number. This factor is represented by the relationship between a permissible circle of confusion and a depth of focus.

As an example, where the F-number of a projection lens is "8" and the permissible blur is equivalent to a 1µm mirror size in the above described approximation equation, the depth of focus is:

\[ Z = 2 \times 10 \times 8 = 160 [\mu\text{m}] \]

Further, where a mirror size is 5µm and an F-number is 2.4, the depth of focus is 24µm. Here, considering the errors of a projection lens and other components of the optical system, the depth of focus is preferred to be no larger than 20µm or several micrometers or less. With this in mind, when the top or bottom surface of a package substrate is taken as reference, the difference in heights of the reflection on the surface of mirrors placed respectively on both ends of a mirror array is preferred to be no more than 20µm. This part slightly different

Further, a blurred image of dust, et cetera, perched on the surface of a cover glass can be made invisible by providing a distance between the top surface of a mirror and the bottom surface of the cover glass with a distance of no less than the value of the depth of focus. It is therefore preferred to provide the distance between the top surface of the mirror and the bottom surface of the cover glass with a distance of at least 20 times, or more, of the mirror size.

Note that a projection apparatus may be a single-panel projection apparatus, sequentially illuminating the lights of colors R, G and B on a single light modulation device, or a multi-panel projection apparatus, modulating the lights of the respective colors at a plurality of light modulation devices corresponding to the plurality of color light sources. Here, the light modulation device may be a mirror device.

The following exemplifies a multi-panel projection apparatus according to the present embodiment. Note that the projection apparatus employs a mirror device as a light modulation device. The multi-panel projection apparatus includes a plurality of light sources, a plurality of mirror devices, a prism and a projection lens. The light source may preferably be a laser light source.

As an example, if the numerical aperture NA of the illumination light flux emitted from the laser light source of the projection apparatus is between about 0.1 and 0.07, the
diameter of the illumination light flux is thin and the depth of focus is long. This fact makes it possible to increase a degree of freedom in the incident path of the illumination light flux from the light source to the incidence surface on which the laser light enters a prism within the projection apparatus. This also makes it possible to increase a degree of freedom in designing a layout of the optical system within the projection apparatus. Further, the optical path length of the illumination light path between each laser of the laser light sources to the prism or light modulation element can be modified.

Further, it may be possible to employ a light source comprising a semi-ON state (in addition to an ON state and an OFF state), in which the light source outputs an incident light with does not project an image or the light source outputs no incident light although it is being driven. Note that such a control for causing a light source to be in the ON state, semi-ON state and OFF state can be carried out with the configuration shown in the above described Fig. 23A or with the above described exemplary modification of the aforementioned configuration.

Furthermore, the light source is configured by equipping a plurality of sub-light sources respectively having a plurality of wavelengths. Each sub-light source can possibly be controlled independently. As an example, only a laser light source having a specific wavelength is turned off or the light intensity is reduced for the source. Further, pulse emission, which is difficult in the case of using a mercury lamp, can be carried out.

The prism synthesizes the reflection lights from a plurality of light modulation devices, e.g., a plurality of mirror devices. It is preferred to make the incident light enter from a direction approximately orthogonal to a surface used for synthesizing the reflection light of the prism.

When synthesizing the reflection light from different mirror arrays within a prism, a dichroic filter, which passes or reflects only a predetermined wavelength, can be placed on the synthesis plane of the prism. The dichroic filter is capable of selecting only a predetermined wavelength, thereby acting as a color filter. Further, when using a laser light source emitting a polarized light, a polarization beam splitter prism capable of light separation and synthesis, using the differences in polarizing directions, can be used.

Figs. 66A, 66B, 66C and 66D show the configuration of a two-panel projection apparatus 2500 comprising the assembly body 2400, shown in the above described Figs. 65A through 65C, which is obtained by one package accommodating two mirror devices 2030 and 2040.

The two-panel projection apparatus 2500 does not project only one color of three colors R, G and B in sequence, nor does it project the R, G and B colors continuously and simultaneously, as in the case of a three-panel projection apparatus. A two-panel
projection apparatus projects an image by continuously projecting, for example, a green light source possessing high visibility, a red light source, and a blue light source in sequence.

The two-panel projection apparatus 2500 is capable of changing over colors in high speed by means of pulse emission in 180 kHz to 720 kHz by comprising laser light sources, thereby making it possible to obscure flickers caused by changing over among the light sources of the respective colors. It may be alternatively configured to use a light emitting diode (LED) light source in place of the laser light source.

Note that the present configuration using laser light sources emitting the colors red (R), green (G) and blue (B), is arbitrary. Laser lights of colors cyan (C), magenta (M) and yellow (Y) may be also used. Further an R light closer to the wavelength of G, in place of a pure R, a G light closer to the wavelength of R or B, in place of a pure G, and a B light closer to the wavelength of G, in place of a pure B may be used. Further, laser lights of four wavelengths or more, obtained by combining the aforementioned colors, may be used.

Further, a projection method of continuously projecting the brightest color and changing over among the other colors in sequence on the basis of the image signals can also be adopted. Such a projection method can also be applied to a configuration that makes R, G and B lights correspond to the respective mirror devices, as in the three-panel projection method.

Fig. 66A is a front view diagram of a two-panel projection apparatus 2500; Fig. 66B is a rear view diagram of the two-panel projection apparatus 2500; Fig. 66C is a side view diagram of the two-panel projection apparatus 2500; and Fig. 66D is a top view diagram of the two-panel projection apparatus 2500.

The following is a description of the optical comprisal and principle of projection of the two-panel projection apparatus 2500 shown in Figs. 66A through 66D.

The projection apparatus 2500 shown in Figs. 66A through 66D includes a green laser light source 2051, a red laser light source 2052, a blue laser light source 2053, illumination optical systems 2054a and 2054b, two triangular prisms 2056 and 2059, 1/4 wavelength plates 2057a and 2057b, two mirror devices 2030 and 2040 accommodated in a single package, a circuit board 2058, a light guide prism 2064 and a projection lens 2070.

The two triangular prisms 2056 and 2059 are joined together to constitute one polarization beam splitter prism 2060. Further, the joined part (i.e., a surface of synthesis) between the two triangular prisms 2056 and 2059 is provided with a polarization beam splitter film 2055 or coating. The polarization beam splitter prism 2060 primarily fills the
role of synthesizing the light reflected by the two mirror devices 2030 and 2040.

The polarization beam splitter film 2055 is a filter for transmitting only an S-polarized light and reflecting P-polarized light.

A slope face of the right-angle triangle cone light guide prism 2064 is adhesively attached to the front surface (i.e., an incidence surface 2060b) of the polarization beam splitter prism 2060, with the bottom of the light guide prism 2064 facing upward. The green laser light source 2051, the illumination optical system 2054a corresponding to the green laser light source 2051, the red laser light source 2052, the blue laser light source 2053, and the illumination optical system 2054d corresponding to the red laser light source 2052 and blue laser light source 2053 are equipped beyond the bottom surface of the light guide prism 2064, with the respective optical axes of the green laser light source 2051, red laser light source 2052, blue laser light source 2053 being aligned perpendicularly to the bottom surface of the light guide prism 2064.

Here, the light guide prism 2064 is equipped for causing the respective lights of the green laser light source 2051, red laser light source 2052 and blue laser light source 2053 to enter perpendicularly to the polarization beam splitter prism 2060. Such a light guide prism 2064 makes it possible to reduce the amount of the reflection light caused by the polarization beam splitter prism 2060 when the laser light enters the polarization beam splitter prism 2060.

Further, 1/4 wavelength plates 2057a and 2057b are equipped on the bottom surface of the polarization beam splitter prism 2060 on which a light shield layer 2063 is applied in regions other than the areas where the light is irradiated on the individual mirror devices 2030 and 2040. Because of this, the light shield layer 2063 is also applied between the mirror device 2030 and mirror device 2040. Note that the 1/4 wavelength plates 2057a and 2057b may alternatively be equipped on the cover glass of the package.

Furthermore, a light shield layer 2063 is equipped also on the rear surface (i.e., an opposite surface 2060c that is opposite to the incidence surface 2060b) of the polarization beam splitter prism 2060.

Further, the two mirror devices 2030 and 2040, which are accommodated in a single package, are equipped under the 1/4 wavelength plates 2057a and 2057b. That is, the configuration is such that the two mirror devices are sealed by the bottom surface 2060a (i.e., the principal surface) of the optical member constituted by the light guide prism 2064, polarization beam splitter prism 2060 and 1/4 wavelength plates 2057a and 2057b. Furthermore, the cover glass of the package is joined to the polarization beam splitter prism 2060 by way of a thermal conduction member 2062. This joinder makes it possible to radiate heat from the cover glass of the package to the polarization beam splitter prism.
by way of the thermal conduction member 2062. Note that the thermal conduction member 2062 has also the function as spacer. Alternatively, the thermal conduction member 2062 may be constituted by a material possessing approximately the same coefficient of thermal expansion as that of the cover glass of the package. Further, the circuit boards 2058 comprising a control circuit(s) for controlling the individual mirror devices 2030 and 2040 equipped respectively on both sides of the package.

Then, the mirror devices 2030 and 2040 are respectively placed to form a 45-degree angle relative to the four sides of the outer circumference of the package on the same horizontal plane. That is, the placement the mirror devices 2030 and 2040 is such that the deflecting direction of each mirror element of the mirror devices 2030 and 2040 is approximately orthogonal to the slope face forming the polarization beam splitter prism 2060 and to the plane on which the reflection lights are synthesized. In terms of positioning the mirror devices 2030 and 2040 in relation to the polarization beam splitter prism 2060, a high precision positioning of the two mirror devices 2030 and 2040 within the package by means of the positioning pattern 2016 is very important.

Incidentally, the illumination optical systems 2054a and 2054b each includes a convex lens, a concave lens and other components, and the projection lens 2070 includes a plurality of lenses and other components.

The following is the principle of projection of the projection apparatus 2500 shown in Figs. 66A through 66D.

In the projection apparatus 2500, the individual laser lights 2065, 2066 and 2067 are incident from the front direction and are reflected by the two mirror devices 2030 and 2040 toward the rear direction, and then an image is projected by way of the projection lens 2070 located in the rear.

Next is a description of the projection principle starting from the incidence of the individual laser lights 2065, 2066 and 2067 to the reflection of the respective laser lights 2065, 2066 and 2067 at the two mirror devices 2030 and 2040 toward the rear direction, with reference to the front view diagram of the two-panel projection apparatus shown in Fig. 66A.

The respective laser lights 2065, 2066 and 2067 emitted from the S-polarized green laser light source 2051, and the P-polarized red laser light source 2052 and blue laser light source 2053 are made to be incident to the polarization beam splitter prism 2060 from the incidence surface 2060b by way of the illumination optical systems 2054a and 2054b respectively corresponding to the laser lights 2065, and 2066 and 2067, and by way of the light guide prism 2064. Then, having transmitted through the polarization beam splitter prism 2060, the S-polarized green laser light 2065 and the P-polarized red and blue laser
lights 2066 and 2067 are incident to the 1/4 wavelength plates 2057a and 2057b, which are placed on the bottom surface of the polarization beam splitter prism 2060. Having passed through the 1/4 wavelength plates 2057a and 2057b, the individual laser lights 2065, 2066 and 2067 respectively change the polarization by the amount of 1/4 wavelengths to become a circular polarized light state.

Then, having passed through the 1/4 wavelength plates 2057a and 2057b, the circular polarized green laser light 2065 and the circular polarized red and blue laser lights 2066 and 2067 respectively incident to the two mirror devices 2030 and 2040 that are accommodated in a single package. The individual laser lights 2065, 2066 and 2067 are modulated and reflected by the correspondingly respective mirror devices so that the rotation directions of the circular polarization are reversed.

Here, the red laser light 2066 and blue laser light 2067 are incident to the mirror device 2040; the assumption is that the mirror device 2040 is configured to perform modulation on the basis of a video image signal corresponding to either wavelength.

Note that at least respective portions of individual light fluxes of the red laser light 2066 and blue laser light 2067 overlap with each other and mix in the illumination light paths between the red laser light source 2052 and mirror device 2040 and between the blue laser light source 2053 and mirror device 2040, and the mixed light is incident to the mirror device 2040.

Further in this event, an alternative configuration may be such that the incidence angle of the green laser light 2065, incident to the mirror device 2030, is different from that of the red laser light 2066 and blue laser light 2067, which are incident to the mirror device 2040. In such a case, each mirror device causing the above described deflection angle to be decreased to a minimum angle, which is determined by the frequency of the light as the target of modulation, makes it possible to reduce the power consumption of the mirror device and enhance the contrast of a projection image. The deflection angle may be decreased when deflecting light of a shorter wavelength versus with light of a longer wavelength.

Next is a description of the projection principle starting from the reflection of individual laser lights 2065, and 2066 and 2067 to the projection of an image with reference to the rear view diagram of the two-panel projection apparatus shown in Fig. 66B.

The ON light 2068 of the circular polarized green laser and the mixed ON light 2069 of the circular polarized red and blue lasers, which are reflected by the respective mirror devices 2030 and 2040, passes through the 1/4 wavelength plates 2057a and 2057b again and enter the polarization beam splitter prism 2060. In this event, the polarization of
the green laser ON light 2068 and that of the mixed red and blue laser ON light 2069 are respectively changed by the amount of 1/4 wavelengths to become a linear polarized state with 90-degree different polarization axes. That is, the green laser ON light 2068 is changed to a P-polarized light, while the mixed red and blue laser ON light 2069 is changed to an S-polarized light.

Then, the green laser ON light 2068 and the mixed red and blue laser ON light 2069 are respectively reflected by the outer side surface (i.e., a reflection surface) of the polarization beam splitter prism 2060, and the P-polarized green laser ON light 2068 is reflected again by the polarization beam splitter film 2055. Meanwhile, the S-polarized mixed red and blue laser ON light 2069 passes through the polarization beam splitter film 2055. Then, the green laser ON light 2068 and red and blue laser mixed ON light 2069 are incident to the projection lens 2070, and thereby a color image is projected. Note that the optical axes of the respective lights incident to the projection lens 2070 from the polarization beam splitter prism 2060 are desired to be orthogonal to the ejection surface of the polarization beam splitter prism 2060. Alternatively, there is also a viable configuration that does not use the 1/4 wavelength plates 2057a and 2057b.

With the configuration and the principle of projection as described above, an image can be projected in the two-panel projection apparatus 2500 comprising the assembly body 2400 that packages the two mirror devices 2030 and 2040, which are accommodated in a single package. Note that the assembly body 2400 in this configuration is a mirror device in a broad sense.

Fig. 66C is a side view diagram of the two-panel projection apparatus 2500.

The green laser light 2065 emitted from the green laser light source 2051 orthogonally enters the light guide prism 2064 via the illumination optical system 2054a. In this event, the reflection of the laser light 2065 can be minimized by the laser light 2065 orthogonally entering the light guide prism 2064.

Then, having passed through the light guide prism 2064, the laser light 2065 passes through the polarization beam splitter prism 2060 and 1/4 wavelength plates 2057a and 2057b, which are joined to the light guide prism 2064, and then enters the mirror array 2032 of the mirror device 2030.

In this event, having been reflected by the cover glass, the laser light 2065 is absorbed by a light shield layer 2063 applied to a surface (i.e., an opposite surface 2060c) opposite to the incidence surface 2060b before entering the mirror array 2032 of the mirror device 2030.

The mirror array 2032 reflects the laser light 2065 with the deflection angle of a
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mirror that puts the reflected light in any of the states, i.e., an ON light state in which the entirety of the reflection light is incident to the projection lens 2070, an intermediate light state in which a portion of the reflection light is incident to the projection lens 2070 and an OFF light state in which no portion of the reflection light is incident to the projection lens 2070.

The reflection light of a laser light (i.e., ON light) 2071, from which the ON light state is selected, is reflected by the mirror array 2032 and will be incident to the projection lens 2070.

Meanwhile, a portion of the reflection light of a laser light (i.e., intermediate light) 2072, from which the intermediate state is selected, is reflected by the mirror array 2032 and will be incident to the projection lens 2070.

Further, the reflection light of a laser light (i.e., OFF light) 2073, from which the OFF light state is selected, is reflected by the mirror array 2032 toward the light shield layer 2063, in which the reflection light is absorbed.

With this configuration, the laser light enters the projection lens 2070 at the maximum light intensity of the ON light, at an intermediate intensity between the ON light and OFF light of the intermediate light, and at the zero intensity of the OFF light. This configuration makes it possible to project an image in a high level of gradation. Note that the intermediate light state produces a reflection light reflected by a mirror of which the deflection angle is regulated between the ON light state and OFF light state.

Meanwhile, making the mirror perform a free oscillation causes it to cycle three deflection angles producing the ON light, the intermediate light and the OFF light, respectively. Here, the controlling of the number of free oscillations makes it possible to adjust the light intensity and obtain an image in higher level of gradation.

Fig. 66D is a top view diagram of the two-panel projection apparatus 2500.

The mirror devices 2030 and 2040 are placed in the package with them respectively forming an approximately 45-degree angle, on the same horizontal plane, in relation to the four sides of the outer circumference of the package as shown in Fig. 66D, and thereby the light in the OFF light state can be absorbed by the light shield layer 2063 without allowing the light to be reflected by the slope face of the polarization beam splitter prism 2060 and the contrast of an image is improved.

Further, the mirror devices 2030 and 2040 are placed in the package with them respectively forming an approximately 45-degree angle, on the same horizontal plane, in relation to the package. Therefore, each of the four sides forming the contour of the mirror device is orthogonal to a respectively corresponding side of the four sides forming the
Further, the heat generated inside of the package is conducted to the polarization beam splitter prism 2060 by way of the thermal conduction member 2062 and is radiated to the outside therefrom. As such, the conduction of the heat generated in the mirror device to the polarization beam splitter prism 2060 improves the radiation efficiency. Further, the heat generated by absorbing light is radiated to the outside instantly because the light shield layer 2063 is exposed to the outside.

When a mirror element reflects the incident light toward a projection lens 2070 at an intermediate light intensity (i.e., an intermediate state) that is the intensity between the ON light and OFF light states, an effective reflection plane needs to be conventionally taken widely in the longitudinal direction of the slope face of a prism.

In contrast, the projection apparatus 2500 is enabled to provide a wide effective reflection plane in the thickness direction of the polarization beam splitter prism 2060 even when the mirror element as described above has the intermediate state. With this configuration, a total reflection condition with which the reflection light from the mirror element is reflected by the slope face of the polarization beam splitter prism 2060 can be alleviated. End of similar section 727, p. 72:23.

Fig. 67 is a diagram showing an exemplary modification of a projection apparatus 2500 according to the present embodiment.

The projection apparatus 2501 exemplified in Fig. 67 includes polarization elements 2077 (i.e., polarization elements 2077a and 2077b) in place of the 1/4 wavelength plates 2057 (i.e., the 1/4 wavelength plates 2057a and 2057b). Otherwise the configuration is similar to that of the projection apparatus 2500. The polarization elements 2077 are each optical elements, transmitting only specific polarized light. For example, the polarization element 2077a has the property of transmitting P-polarized light, while the polarization element 2077b has the property of transmitting S-polarized light.

Like the projection apparatus described above, projection apparatus 2501 also makes it possible to eliminate, from a projection light path, diffused light in which the polarizing direction is disturbed, from the reflection light reflected by the mirror devices 2030 and 2040.

Figs. 68A and 68B are diagrams showing another exemplary modification of the projection apparatus according to the present embodiment. Fig. 68A is a top view diagram of a projection apparatus 2502. Fig. 68B is a side view diagram of the projection apparatus 2502.

The projection apparatus 2502 is configured to guide the laser lights of individual
colors to the polarization beam splitter prism 2060 with two light guide prisms 2064a and 2064b, as exemplified in Figs. 68A and 68B, and two incidence surfaces (i.e., incidence surfaces 2060d and 2060e) are includes. Note that both of the incidence surfaces 2060d and 2060e are oriented to cross the polarization beam splitter film 2055 (i.e., a synthesis surface) of the polarization beam splitter prism 2060 in an approximately orthogonal direction.

The projection apparatus 2502 includes light shield layers 2063a and 2063b corresponding to the two light guide prisms 2064a and 2064b. The light guide prism 2064a and the corresponding light shield layer 2063a is placed with a shift to one direction offset in relation to the polarization beam splitter film 2055 that on the synthesis surface of the polarization beam splitter prism 2060 not sure if this is right. The light guide prism 2064b and the corresponding light shield layer 2063b are placed with a shift to the other direction in relation to the polarization beam splitter film 2055 in the joinder part of the polarization beam splitter prism 2060. This configuration prevents the laser lights guided by the respective guide prisms from interfering with one another. The projection apparatus 2502 of the present exemplary modification also makes it possible to obtain a benefit similar to that of the projection apparatus 2500.

If a fixed position of the assembly body 2400 is designated by the position of the polarization beam splitter film, that is, the position of the joinder surface of the two triangular prisms 2056 and 2059, in the projection apparatus put forth in Figs. 66A, 66B, 66C, 66D and 67, a shift in the positions of a projected image caused by the two mirror devices will not occur even if the assembly body 2400 expands a little due to a temperature rise in the apparatus, shifting the positions of the device substrates 2031 and 2041 relative to the projection optical member, because the projected image is in the direction compensating the aforementioned shift of the mirror device.

<Embodiment 6>

Fig. 69 is a top view diagram of the mirror array of a spatial light modulator. Each square enclosed by thick solid lines is equivalent to the mirror 4003 of one mirror element. The spatial light modulator 5100 is constituted by arraying, crosswise in two dimensions on a device substrate 4004, a plurality of mirror elements each comprising address electrodes (not shown here), elastic hinge (not shown here), and a mirror 4003 supported by the elastic hinge.

Note that the example shown in Fig. 69 looks as if adjacent mirror elements 4001 are placed without a gap between them. In actuality, the mirror elements 4001 are arrayed crosswise at predetermined intervals on the device substrate 4004.

The mirror 4003 of one mirror element 4001 is controlled by applying a voltage to
the address electrode provided on the device substrate 4004.

Further, the pitch (i.e., the interval) between adjacent mirrors 4003 is preferably between 4µm and 10µm, taking into consideration the number of pixels required for various levels required, from a 2Kx4K super hi-vision TV to a non-full hi-vision TV. Here, the "pitch" is the distance between the respective deflection axes of adjacent mirrors 4003. More preferably, the pitch between the respective deflection axes of adjacent mirrors 4003 may be between 4µm and 7µm. Note that the form of the mirror 4003 or the pitch between the mirrors 4003 is not limited as such.

The drawing indicates the deflection axis 4005, about which a mirror 4003 is deflected, by dotted line. The light emitted from a light source 4002 possessing a coherent characteristic is made to enter the mirror 4003 so as to be in the orthogonal or diagonal direction in relation to the deflection axis 4005. The light source 4002 possessing a coherent characteristic may be, for example, a laser light source.

The following is a description of the configuration and operation of the mirror element 4001 of a spatial light modulator 5100 shown in Fig. 69, with reference to a cross-sectional diagram on a diagonal line of the mirror element 4001 there is no line in Fig. 69 other than the deflection axis, a line which is perpendicular to the deflection axis 4005.

As described previously in Fig. 27B, the individual memory cells 4010a and 4010b are controlled by signals from the COLUMN line 1, COLUMN line 2 and ROW line, and thereby the deflection angles of the mirror 4003 of each mirror element 4001 can be controlled, enabling the modulation and reflection of the incident light.

Next is a description of the deflecting operation of the mirror 4003 of the mirror element 4001 shown in Fig. 69 with reference to Figs. 8B through 8D.

Fig. 8B is a diagram delineating the state reflecting an incident light toward a projection optical system by deflecting the mirror of a mirror element.

Giving a signal (0, 1) to the memory cells 4010a and 4010b (which are not shown here) described in Fig. 27B applies a voltage of "0" volts to the address electrode 4008a of Fig. 8B and applies a voltage of Ve volts to the address electrode 4008b. As a result, the mirror 4003 is deflected from a deflection angle of "0" degrees, i.e., the horizontal state, to that of +13 degrees attracted by a coulomb force in the direction of the address electrode 4008b to which the voltage of Ve volts is applied. This causes the incident light to be reflected by the mirror 4003 toward the projection optical system (which is called the ON light state).

Note that the present specification document defines the deflection angles of the mirror 4003 as "+" (positive) for clockwise (CW) direction and ".-" (negative) for
counterclockwise (CCW) direction, with "0" degrees as the initial state of the mirror 4003. Further, an insulation layer 4006 is provided on the device substrate 4004, and a hinge electrode 4009 connected to the elastic hinge 4007 is grounded through the insulation layer 4006.

It also defines that a signal (0, 1) is a state in which a signal "0" is inputted to COLUMN line 1, and a signal "1" is inputted to COLUMN line 2. The signals inputted to COLUMN line 1 and COLUMN line 2 are indicated as aforementioned in the following description.

Fig. 8C is a diagram delineating the state in which an incident light is not reflected toward a projection optical system by deflecting the mirror of a mirror element.

Giving a signal (1, 0) to the memory cells 4010a and 4010b (which are not shown here) described in Fig. 27B applies a voltage of Ve "Va" volts to the address electrode 4008a, and "0" volts to the address electrode 4008b. As a result, the mirror 4003 is deflected from a deflection angle of "0" degrees, i.e., the horizontal state, to that of -13 degrees attracted by a coulomb force in the direction of the address electrode 4008a to which the voltage of Ve volts is applied. This causes the incident light to be reflected by the mirror 4003 to elsewhere other than the light path toward the projection optical system (which is called the OFF light state).

Fig. 8D is a diagram delineating the state in which reflecting and not reflecting an incident light toward a projection optical system are repeated by free-oscillating the mirror of a mirror element.

In either of the states shown in Figs. 8B and 8C, in which the mirror 4003 is pre-deflected, giving a signal (0, 0) to the memory cells 4010a and 4010b (which are not shown here) applies a voltage of "0" volts to the address electrodes 4008a and 4008b. As a result, the coulomb force, which has been generated between the mirror 4003 and the address electrode 4008a or 4008b, is eliminated so that the mirror 4003 performs a free oscillation within the range of the deflection angles ±13 degrees in accordance with the property of the elastic hinge 4007. The incident light is reflected toward the projection optical system only within the range of a deflection angle to produce the ON light in association with the free oscillation of the mirror 4003. The mirror 4003 repeats the free oscillations, changing over frequently between the ON light state and OFF light state. Controlling the number of changeovers makes it possible to finely adjust the intensity of light reflected toward the projection optical system (which is called a free oscillation state).

The total intensity of light reflected by means of the free oscillation toward the projection optical system is certainly lower than the intensity when the mirror 4003 is continuously in the ON light state and higher than the intensity when it is continuously in
the OFF light state. That is, it is possible to make an intermediate intensity between those
of the ON light state and OFF light state. Therefore, a higher gradation image can be projected than with the conventional technique by finely adjusting the intensity as described above.

Although not shown in the drawing, an alternative configuration may be such that only a portion of light is made to enter the projection optical system by reflecting an incident light in the initial state of a mirror 4003. Configuring as such, a reflection light enters the projection optical system in higher intensity than that when the mirror 4003 is continuously in the OFF light state and lower intensity than that when the mirror 4003 is continuously in the ON light state (which is called an intermediate light state).

Note that the mirror device with the oscillation state and intermediate light state is more preferable than the conventional mirror device capable of only two states, i.e., the ON light state and OFF light state. Unique paragraph

Fig. 70A shows a cross-section of a mirror element that is configured to be equipped with only one address electrode and one drive circuit as another embodiment of a mirror element.

The mirror element 4011 shown in Fig. 70A includes an insulation layer 4006 on a device substrate 4004 including one drive circuit for deflecting a mirror 4003. Further, an elastic hinge 4007 is equipped on the insulation layer 4006. The elastic hinge 4007 supports one mirror 4003, and one address electrode 4013, which is connected to the drive circuit, is equipped under the mirror 4003.

Note that the area sizes of the address electrode 4013 exposed above the device substrate 4004 are configured to be different between the left side and right side of the deflection axis of the elastic hinge 4007, or mirror 4003, with the area size of the exposed part of the address electrode 4013 on the left side of the elastic hinge 4007 being larger than the area size on the right side, in Fig. 70A.

Here, the mirror 4003 is deflected by the electrical control of one address electrode 4013 and drive circuit. Further, the deflected mirror 4003 is retained at a specific deflection angle by contacting with stopper 4012a or 4012b, which are equipped in the vicinity of the exposed parts on the left and right sides of the address electrode 4013.

Further, a hinge electrode 4009 connected to the elastic hinge 4007 is grounded through the insulation layer 4006. Such is the comprisal of the mirror element 4011.

Incidentally, the present specification document calls the part, which is exposed above the device substrate 4004, of the address electrode 4013 of Fig. 70A as electrode part, in specific, calls the left part as "first electrode part" and the right part as "second electrode
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part, with the deflection axis of the elastic hinge 4007 or mirror 4003 referred to as the border.

As such, the applying of a voltage by configuring the address electrode 4013 to be asymmetrical, that is, the left side is different from the right side, e.g., the area sizes, in relation to the deflection axis of the elastic hinge 4007 or mirror 4003 generates the difference in coulomb force between (a) and (b), where (a): a coulomb force generated between the first electrode part and mirror 4003, and (b): a coulomb force generated between the second electrode part and mirror 4003. The mirror 4003 can be deflected by differentiating the coulomb force between the left and right sides of the deflection axis of the elastic hinge 4007 or mirror 4003.

Meanwhile, Fig. 70B is an outline diagram of a cross-section of the mirror element 4011 shown in Fig. 70A. Requiring only one address electrode 4013 makes it possible to reduce the two memory cells 4010a and 4010b, which correspond to the two address electrodes 4008a and 4008b in the configuration of Fig. 27B, to one memory cell 4014. This in turn makes it possible to reduce the number of wirings for controlling the deflection of the mirror 4003.

Other comprisals are similar to the configuration described for Fig. 27B and therefore the description is not provided here.

Next is a description, in detail, of a single address electrode 4013 controlling the deflection of a mirror with reference to Figs. 71A, 71B, 71C and 72.

Mirror elements 401 1a and 401 1b respectively shown in Figs. 71A and 71B each is configured such that the respective area sizes of the first and second electrode parts of one address electrode 4013 on the left and right sides, sandwiching the deflection axis 4015 of the mirror 4003, are different from each other (i.e., asymmetrical).

Fig. 71A shows a top view diagram, and a cross-sectional diagram, both of a mirror element 401 1a structured such that the area size S1 of a first electrode part of one address electrode 4013a and the area size S2 of a second electrode part thereof are in the relationship of S1>S2, and such that the connection part between the first and second electrode parts exists in the same structural layer as the layer in which the first and second electrode parts exist.

In contrast, Fig. 71B shows a top view diagram, and a cross-sectional diagram, both of a mirror element 401 1b structured such that the area size S1 of a first electrode part of one address electrode 4013b and the area size S2 of a second electrode part thereof are in the relationship of S1>S2, and such that the connection part between the first and second electrode parts exists in a structural layer different from the layer in which the first and
second electrode parts exist.

Next is a description of the control for the deflecting operation of a mirror in the mirror element 4011a or 4011b, each respectively shown in Fig. 71A or 71B.

Fig. 72 is a diagram showing a data input to the mirror elements 4011a or 4011b, the voltage application to the address electrodes 4013a or 4013b, and the deflection angles of the mirror 4003, in a time series.

Referring to Fig. 72, the "data input" is to the mirror element 4011a or 4011b, which is controlled in two states, i.e., HI and LOW, with the HI representing a data input, that is, projecting an image and LOW representing no data input, that is, not projecting an image.

Next, the vertical axis of the "address voltage" of Fig. 72 represents the voltage values applied to the address electrode 4013a or 4013b of the mirror element 4011a or 4011b, and the voltage values applied to the address electrode 4013a or 4013b is, for example, "4" volts and "0" volts.

The vertical axis of the "mirror angle" of Fig. 72 represents the deflection angle of the mirror 4003, defining the deflection angle of the mirror 4003 in the state in which it is parallel to the device substrate 4004 to be "0" degrees. Further, with the first electrode part of the address electrode 4013a or 4013b defined as the ON light state side, the maximum deflection angle of the mirror 4003 in the ON light state is set at -13 degrees. On the other hand, with the second electrode part of the address electrode 4013a or 4013b defined as the OFF light state side, the maximum deflection angle of the mirror 4003 in the OFF light state is set at +13 degrees. Therefore, the mirror 4003 deflects within a range in which the maximum deflection angles of the ON light state and OFF light state are ±13. Further, the horizontal axis of Fig. 72 represents elapsed time t.

When the deflecting operation of the mirror 4003 is performed in the configuration of Figs. 71A and 71B, a voltage is applied to the address electrode 4013a or 4013b at the timing on the basis of the passage of time due to a data input and a data rewrite.

Referring to Fig. 72, no data is input between the time t0 and t1, and the mirror 4003 is accordingly in the initial state. That is, the deflection angle of the mirror 4003 is "0" degrees in the state, in which no voltage is applied to the address electrode 4013a or 4013b.

At the time t1, a voltage of 4 volts is applied to the address electrode 4013a or 4013b, causing the mirror 4003 to be attracted by a coulomb force generated between the mirror 4003 and address electrode 4013a or 4013b toward the first electrode part having a large area size so that the mirror 4003 shifts from the 0-degree deflection angle at the time
t1 to a -13-degree deflection angle at the time t2. Then, the mirror 4003 is retained on the stopper 4012a on the first electrode part side.

The phenomenon in which the mirror 4003 is attracted to the first electrode part, with a larger area size (than that of the second electrode part), of the address electrode 4013a or 4013b, is explained by the coulomb force F being expressed by the following equation (1):

\[ F = \frac{1}{4\pi \varepsilon r^2} \left( \frac{l}{\varepsilon} \right) q_1 q_2 \quad ... \ (1) \]

where "r" is the distance between the address electrode 4013a or 4013b and mirror 4003, "\varepsilon" is permittivity, "q1" and "q2" are the amount of charge retained by the address electrode 4013a or 4013b and mirror 4003.

The distance G1 between the mirror 4003 and the first electrode part and the distance G2 between the mirror 4003 and the second electrode part, when the mirror 4003 is in the initial state, are the same, and the first electrode part has a larger area than the second electrode part does, and therefore the first electrode part can retain a larger amount of charge. As a result, a larger coulomb force is generated for the first electrode part.

Between the time t2 and t3, continuously applying a voltage of 4 volts to the address electrode 4013a or 4013b in accordance with the period in response to the data input causes the mirror 4003 to be retained on the stopper 4012a on the first electrode part side.

Then, at the time t3, stopping the data input applies a voltage of "0" volts to the address electrode 4013a or 4013b. As a result, the coulomb force generated between the address electrode 4013a or 4013b and mirror 4003 is cancelled. This causes the mirror 4003 retained on the first electrode part side to be shifted to a free oscillation due to the restoring force of the elastic hinge 4007.

Further, the deflection angle of the mirror 4003 becomes \( \theta < 0 \) degrees, and when a voltage of 4 volts is applied to the address electrode 4013a or 4013b at the time t4 when a coulomb force F1, that is generated between the mirror 4003 and first electrode part, and a coulomb force F2, which is generated between the mirror 4003 and second electrode part, constitutes the relationship of F1 < F2, and thereby the mirror 4003 is attracted to the second electrode part. Further, the mirror 4003 is retained onto the stopper 4012b of the second electrode part at the time t5.

The reason for the above is that the second power of distance r has a larger effect on the coulomb force represented by the expression (1) than the charge q1 and q2. Therefore, with an appropriate adjustment of the area sizes of the first and second electrode parts, a coulomb force F acts more strongly to the smaller distance G2 of the distance.
between the address electrode 4013a or 4013b and mirror 4003, despite that the area S2 of the second electrode part is smaller than the area S1 of the first electrode part. As a result, the mirror 4003 can be deflected to the second electrode part.

Note that the transition time of the mirror 4003 between the time t3 and t4 is preferred to be performed in about 4.5μsec in order to obtain a high grade of gradation. Further, a control can possibly be performed in such a manner to turn off the illumination light synchronously with a transition of the mirror 4003 so as to not let the illumination light be reflected and incident to the projection light path during a data rewrite, that is, during the transition of the mirror 4003, between the time t3 and t4.

Continuously applying a voltage to the address electrode 4013a or 4013b between the time t5 and t6 causes the mirror 4003 to be continuously retained to the stopper 4012b of the second electrode part. In this event, no data is input and therefore no image is projected.

Then, at the time t6, a new data input is carried out. The voltage of 4 volts, which has been applied to the address electrode 4013a or 4013b, is changed over to "0" volts at the time t6 in accordance with the data input. This operation cancels the coulomb force generated between the mirror 4003 retained onto the second electrode part and the address electrode 4013a or 4013b likewise the case of the time t3 so that the mirror 4003 shifts to a free oscillation state due to the restoring force of the elastic hinge 4007.

 Further, a voltage of 4 volts is again applied to the address electrode 4013a or 4013b at the time t7 when a coulomb force F1, which is generated between the mirror 4003 and first electrode part, and a coulomb force F2, which is generated between the mirror 4003 and second electrode part, constitutes the relationship of F1>F2 when the deflection angle of the mirror 4003 becomes 0>0 degrees, and thereby the mirror 4003 is attracted to the first electrode part, and then the mirror 4003 is retained onto the second electrode part at the time t8.

This principle is understood from the description of the action of a coulomb force between the above described time t3 and t5. Also in this event, the transition time of the mirror 4003 between the time t3 and t4 is preferred to be performed in about 4.5μsec, and the control is performed in such a manner to turn off the illumination light synchronously with a transition of the mirror 4003 so as to not let the illumination light be reflected and incident to the projection light path during the transition of the mirror 4003.

Then, continuously applying a voltage of 4 volts to the address electrode 4013a or 4013b between the time t8 and t9 causes the mirror 4003 to be continuously retained to the stopper 4012a of the first electrode part. In this event, data is continuously input and images are projected.
Then, the voltage applied to the address electrode 4013a or 4013b is changed from 4 volts to "0" volts as the data input is stopped at the time t9. This operation puts the mirror 4003 into the free oscillation state. Then, at the time t10, a voltage is applied to the address electrode 4013a or 4013b in a similar principle as the time from t3 to t5, from the time t6 to t8, and thereby the mirror 4003 can be retained onto the stopper 4012b of the second electrode part at the time t11.

A repetition of the similar operation enables the control for deflecting the mirror 4003.

Next is a description of the control for returning, to the initial state, the mirror 4003 retained onto the stopper 4012a of the first electrode part or onto the stopper 4012b of the second electrode part.

In order to return to the initial state, the mirror 4003 retained onto the stopper 4012a of the first electrode part or onto the stopper 4012b of the second electrode part in the state in which a voltage is applied to the address electrode 4013a or 4013b, an appropriate pulse voltage is applied.

As an example, the mirror 4003 is shifted to a free oscillation state by changing the voltage applied to the address electrode 4013a or 4013b to "0" volts in the state in which the mirror 4003 is retained onto the stopper 4012a of the first electrode part or onto the stopper 4012b of the second electrode part. In the state of the mirror performing a free oscillation, the mirror 4003 can be returned to the initial state by temporarily applying an appropriate voltage to the address electrode 4013a or 4013b, thereby generating a coulomb force pulling the mirror 4003 back toward the first electrode part or the second electrode part, either of which the mirror 4003 has been retained onto, that is, the coulomb force generating an acceleration in a direction reverse to the heading of the mirror 4003 when the distance between the address electrode 4013a or 4013b and the mirror 4003 is an appropriate length as the mirror 4003 tilts from the first electrode part side to the second electrode part side, or vice versa.

As described above, a control can be carried out to return the mirror 4003 from the state, in which the mirror 4003 is retained onto the stopper 4012a of the first electrode part or onto the stopper 4012b of the second electrode part, to the initial state by applying a pulse voltage to the address electrodes 4013a or 4013b.

Considering the principle of the coulomb force between the mirror and address electrode 4013a or 4013b as described above, the applying of a voltage to the address electrode 4013a or 4013b at an appropriate distance between the mirror 4003 and address electrode 4013a or 4013b also makes it possible to retain the mirror 4003 at the deflection angle of the ON light state by returning the mirror 4003 from the ON light state, or at the
deflection angle of the OFF light state by returning the mirror 4003 from the OFF light state.

Note that the control of the mirror 4003 of the mirror elements 4011a and 4011b shown in Fig. 72 is widely applicable to a mirror element that is configured to have a single address electrode and to be asymmetrical about the deflection axis of the elastic hinge or mirror.

As described above, the mirror can be deflected to the deflection angle of the ON light state or OFF light state, or put in the free oscillation state, with a single address electrode of a mirror element.

Fig. 71C shows a top view diagram, and a cross-sectional diagram, both of a mirror element 4011c structured such that the area size S1 of a first electrode part of one address electrode and the area size S2 of a second electrode part thereof are in the relationship of S1=S2, and such that the distance G\(_1\) between a mirror 4003 and the first electrode part and the distance G\(_2\) between the mirror 4003 and the second electrode part are in the relationship of G\(_1\)<G\(_2\).

That is, the configuration of Fig. 71C is such that, for the address electrode 4013, the height of the first electrode part is different from that of the second electrode part and such that the distance G\(_1\) between the first electrode part and mirror 4003 and the distance G\(_2\) between the second electrode part and mirror 4003 is in the relationship of G\(_1\)<G\(_2\). It is further such that the address electrode 4013c is electrically connected to the first electrode part and second electrode part on the same layer as the address electrode 4013 exists.

In the case of the mirror element 4011c as shown in Fig. 71C, the size of the coulomb force generated between the mirror 4003 and address electrode 4013c in the first electrode part is different from that generated between the mirror 4003 and address electrode 4013c in the second electrode part because the distances between the mirror 4003 and address electrode 4013 are different in the first electrode part and the second electrode part. Therefore, the deflection of the mirror 4003 can be controlled by carrying out a control similar to the case of the above described Fig. 72.

Note that the deflection angle of the mirror 4003 is retained by using the stoppers 4012a and 4012b in Figs. 71A, 71B and 71C, the deflection angle of the mirror 4003, however, can be established by configuring an appropriate height of the address electrode 4013c to also fill the roles of the stoppers 4012a and 4012b.

Further, while the present embodiment is configured to set the control voltages at 4-volt and 0-volt applied to the address electrode 4013a, 4013b or 4013c, such control voltages, however, are arbitrary and other appropriate voltages may be used to control the
Furthermore, the mirror can be controlled with multi-step voltages to be applied to the address electrode 4013a, 4013b or 4013c. As an example, if the distance between the mirror 4003 and address electrode 4013a, 4013b or 4013c, increasing a coulomb force, the mirror 4003 can be controlled with a lower voltage than that when the mirror 4003 is in the initial state.

Next is a description of each constituent part that constitutes a mirror element. The mirror is formed with a highly reflective metallic material, such as aluminum (Al) or a multi-layer film of a dielectric material. The entirety or a part of the elastic hinge (e.g., the base part, neck part or intermediate part) is constituted by a metallic material possessing a restoring force. The material for the elastic hinge uses, for example, silicon (Si), such as amorphous silicon (a-Si) or single crystal silicon, which is an elastic body. The address electrode is configured to have the same electric potential, by using, for example, aluminum (Al), copper (Cu), or tungsten (W) as a conductor.

The insulation layer uses silicon dioxide (SiO₂) and silicon carbide (SiC). The device substrate uses a silicon material.

Note that materials and forms of each constituent part of a spatial light modulator may be changed to suit a different purpose.

Next is a description of the circuit configuration of a spatial light modulator used for processing input signals. The outline of the circuit configuration of a spatial light modulator used for processing input signals is similar to the circuit shown in the previously described Fig. 27A.

The spatial light modulator shown in the previously described Fig. 27A includes a timing controller 5141, a selector 5142, a ROW line decoder 5130, a plurality of column drivers 5120, and a mirror element array (memory array) 5110 arraying a plurality of memory cells in a two-dimension array comprising M columns by N rows inside of a device substrate.

The memory cell may be includes of, for example, a complementary metal oxide semiconductor (CMOS) circuit in which a wiring process rule exists.

In the previously described Fig. 27A, the timing controller 5141 controls the selector 5142 and ROW line decoder 5130 in accordance with a signal input from an external drive circuit (not shown in the drawing). The selector 5142 transfers an n-bit signal, which is transferred from the external drive circuit by way of an n-bit data bus line, to at least one column driver 5120 in accordance with the control of the timing controller 5141. The column driver 5120 outputs the n-bit signal transferred from the selector 5142 to
each COLUMN line of the connected memory array, thereby driving the respective COLUMN lines placed on the device substrate of each mirror element. Further, the ROW line decoder 5130 drives an arbitrary ROW line of the memory array in accordance with the control of the timing controller 5141.

With the above described configuration in mind, first, the image data of a signal corresponding to a desired display period of time is transferred from the external drive circuit by way of the n-bit data bus line. Then, these pieces of n-bit image data are sequentially transferred to the desired column drivers 5120 by way of the selector 5142. Upon completion of the transfer of the pieces of new image data to all column drivers 5120, the ROW line decoder 5130 drives a desired ROW line in accordance with the command of the timing controller 5141. Then, a voltage applied to a predetermined memory cell is controlled by the image data from the column driver 5120 and the driving of the ROW line, according to the control mechanism.

Fig.73 illustrates an example of a system diagram of this invention. In this example, a 10 bit signal input is split into two parts, for example, upper 8 bits and lower 2 bits. The upper 8 bits are sent to the 1st state controller, the lower 2 bits are sent to the 2nd state controller, and the sync signal is sent to the timing controller 5141. Then, the 2nd state controller converts binary data, which is the lower 2 bits, into non-binary data. Such a configuration makes it possible to control a mixture of 1st state and 2nd state binary data and non-binary data. Further, if such a control is applied to a single-panel projection apparatus, the 2nd state is set at no less than 180 Hz, and the lights of the respective colors are sequentially projected. In this event, sub-frames determined by the 2nd state can be assigned to the lights of the respective colors R, G and B. Further, an image can alternatively be projected in six colors by adding cyan, magenta and yellow.

Note that the sync signal is generated by a signal splitter. The timing controller 5141 in Fig. 73 it's 4016 controls the selector 5142 in Fig. 73 it's 4017 in accordance with the sync signal and changes over between making the 1st state controller control the spatial light modulator 5100 and making the 2nd state controller control the spatial light modulator 5100.

The human eye is most sensitive to wavelengths perceived as green light. Therefore, a 14-bit gray scale may be used only for green, and the 12-bit may be used for other colors.

Furthermore, there is a case in which an illumination light of white obtained by superimposing red, green and blue is illuminated. In such a case, the white may be assigned to the 1st state.

The following provides a description of a projection apparatus comprising the
spatial light modulator as described above.

A single-panel projection apparatus comprising a single spatial light modulator described above includes the apparatus as shown in the previously described Fig. 21. The configuration and operation are already provided and therefore they are not provided here.

In the thusly configured single-panel projection apparatus, a period (i.e., one frame) of displaying one image is divided into sub-frames, and the light of any of the color lights, R, G and B is irradiated onto the spatial light modulator within each sub-frame period. Further, the images corresponding to the lights reflected to the projection light path are projected onto a screen in sequence by the mirror element of the spatial light modulator reflecting the selectively irradiated light.

Fig. 74 is an illustrative diagram showing the configuration of a multi-panel projection apparatus 4040 comprising three spatial light modulators 5100r, 5100g and 5100b. Note that a light source in this configuration is constituted by combining a plurality of light sources of colors (i.e., wavelengths), each of which possesses a coherent characteristic.

In the multi-panel projection apparatus 4040, the light of the respective colors output from the light source 4041 passes through a condenser lens 4042. Having passed through the condenser lens 4042, only the specific wavelengths of light are respectively reflected by two dichroic mirrors 4043 and 4044, while the lights of other wavelengths pass through the mirrors. Thereby the light is separated into the lights of the respective colors R, G and B.

In the case of Fig. 74, the assumption is that the first dichroic mirror 4043 reflects only the red light and the second dichroic mirror 4044 reflects only the green color, leaving the remaining blue light to be reflected by a mirror 4045.

The lights of the separated colors red (R), green (G) and blue (B) are incident to the spatial light modulators 5100r, 5100g and 5100b, respectively corresponding to R, G and B. Then, the lights of the respective colors are selectively reflected by the individual mirror elements comprising the respective spatial light modulators 5100r, 5100g and 5100b toward a projection optical system 4046. The lights of the respective colors are then projected onto a screen 4047 by way of the projection optical system 4046, e.g., a projection lens.

In such a configured multi-panel projection apparatus 4040, the lights R, G and B are selectively reflected by the mirror elements of the respective spatial light modulators 5100r, 5100g and 5100b, corresponding to the respective lights in one frame period, and thereby the lights of the three colors can be projected continuously onto the screen 4047.
Therefore, the multi-panel projection apparatus 4040 is capable of projecting the light from the light source 4041 using the entirety of one frame period, causing no color break.

Next, another multi-panel projection apparatus comprising a plurality of spatial light modulators, including the type as shown in the previously described Fig. 22B, will be described. The configuration and the principle of projection of the projection apparatus shown in the previously described Fig. 22B are similar to the above description, and therefore the description is not provided here. Note that a light source in this configuration is constituted by combining a plurality of light sources of different colors (i.e., wavelengths), each of which possesses a coherent characteristic.

There is also a projection apparatus, configured as shown in the previously described Fig. 22A, as another multi-panel projection apparatus configured to make the number of reflections of each color light in the light path equal to one another. Don’t know what this is saying The comprisal and projection principle of the projection apparatus shown in the previously described Fig. 22A are similar to the above described, and therefore the description is not provided here. Incidentally, a light source in this configuration is constituted by combining a plurality of light sources of colors (i.e., wavelengths), each of which possesses a coherent characteristic.

Furthermore, a projection apparatus comprising a total internal reflection (TIR) prism and Koester prism includes a type shown previously in Fig. 22C. The configuration and the principle of the projection apparatus are similar to the above description and therefore are not provided here. Incidentally, a light source in this configuration is constituted by combining a plurality of light sources of colors (i.e., wavelengths), each of which possesses a coherent characteristic. The reason for making each laser light incident orthogonally to each respective prism surface is to reduce, as much as possible, the loss of light due to the reflection on the prism surface when the light enters the prism.

The use of a light source possessing a coherent characteristic as the light source in each of the projection apparatuses described above enables an image projection using an optical component with a larger F-number (allowing small expansion of a light flux) than the case of using a conventional discharge lamp as the light source.

A projection apparatus comprising a laser light source as a light source possessing a coherent characteristic enables, for example, an optical design with a light flux of f/10, making it possible to set the deflection angle of the mirror of a spatial light modulator at about ±3 degrees CW in relation to the initial state of the mirror.

Meanwhile, if a conventional discharge lamp is used, the directivity of light is lower than a laser light and therefore the illumination cannot be designed to be bright unless larger optical components are used in consideration of the usage efficiency of light.
This is generally called etendue.

What follows is a description of the setup of the deflection angle of the mirror element of a mirror device when a light source possessing a coherent characteristic represented by a laser light source is used for solving the problem of etendue described above. Note that a mirror device can be miniaturized and the deflection angle of the mirror can be reduced, as described above, when a light source possessing a coherent characteristic is used.

Fig. 75 illustrates the relationship between the deflection of a mirror and the reflecting direction of an illumination light in the configuration of Fig. 69.

When the mirror 4003 is tilted CW, the deflection angle of the mirror 4003 is in the ON light state (i.e., an ON angle), in which the illumination light is reflected to an optical axis 4122 of the ON light, that is, the entirety of light enters the projection optical system.

When the mirror 4003 is in the initial state, the deflection angle of the mirror 4003 is in an intermediate light state, in which the illumination light 4121 is reflected to an optical axis 4123 of the intermediate light, that is, a portion of light enters the projection optical system.

When the mirror 4003 is tilted CCW, the deflection angle of the mirror 4003 is in the OFF light state (i.e., an OFF angle), in which the illumination light is reflected to an optical axis 4124 of the OFF light, that is, no light enters the projection optical system.

The present embodiment aims at allowing none of the OFF light to enter the projection optical system more securely, and therefore sets the deflection angle of the mirror 4003 to be larger than a conventional angle that is theoretically led to the OFF light state. The increasing of the mirror deflection angle than the conventional makes it possible to place the OFF light further distanced from the projection optical system and accordingly prevent diffracted light or scattered light generated by the OFF light from entering the projection optical system. As a result, the image quality and contrast of the projected image are improved.

Fig. 76 is illustrative diagram showing diffracted light generated when the light is reflected by a mirror of a spatial light modulator.

As shown in the figure, the diffracted light is generated as a result of irradiating light onto a mirror, and the diffracted light 4110 spreads, that is, the primary diffracted light 4111, the secondary diffracted light 4112, the tertiary diffracted light 4113, and so on, in directions perpendicular to the four sides of the mirror 4003 shown at the center. In this event, the light intensity decreases gradually with the primary diffracted light 4111, secondary diffracted light 4112, tertiary diffracted light 4113, and so on. In the case of
using a laser light source, the coherence is improved by the uniformity of the wavelength of a laser light, distinguishing the diffracted light 4110. Note that the diffracted light 4110 also possesses an expansion to the depth direction of the mirror 4003 in three dimensions.

The spatial light modulator 5100 Fig. 69 can be configured to set the diagonal direction of the mirror 4003 as the deflection axis thereof, thereby making it possible to prevent the diffracted light 4110 of light from entering the projection optical system. This configuration prevents extraneous light, that is, the diffracted light 4110, from entering the projection optical system, thereby improving the contrast of a projected image.

Meanwhile, the resolution of a projected image at a projection apparatus is determined by parameters, such as the size of a mirror, the F-number of a projection lens, the numerical aperture NA of a light source, the coherence of a light flux. Therefore, the most optimal deflection angle of the mirror 4003 needs to be set in consideration of these factors.

Where "θ" is the maximum deflection angle of a mirror and "±α" is the maximum spread angle of a reflected light flux from the optical axis, the relationship between the deflection angle θ and the maximum spread angle ±α of a reflected light flux from the optical axis is:

θ = α

Further, the numerical aperture NA equivalent to the radius of a reflected light flux is:

NA = n sin α

where "n" is a refractive index. Further, an appropriate F-number for a projection lens can be approximated as:

F = 1/2*NA

Considering the above described conditions, the deflection angle of the mirror is theoretically set so that the respective light fluxes of the illumination light, ON light, intermediate light and OFF light are not overlapping with one another. The setting of such a deflection angle enables an improvement in the contrast.

Next is a description of the conventional theoretical setting of the deflection angle of mirror with reference to Fig. 77.

Fig. 77 is an illustrative cross-sectional diagram delineating a situation in which an f/2.4 light flux, which is emitted from a discharge lamp light source, is reflected by a conventional spatial light modulator for which the deflection angles of the ON light state and OFF light state of a mirror are set at ±12 degrees, respectively.
Conventionally, with the deflection angle of a mirror in the ON state being set at +12 degrees, an angle of 24 degrees is provided between the optical axis 4122a of the ON light and the optical axis 4121a of the illumination light so that the ON light enters a projection optical system 4125 without theoretically overlapping with the illumination light output from a discharge lamp light source 4002a.

That is, the maximum expansion angle from the optical axis 4121a of the light flux of the illumination light (emitted from a light source 4002) possessing a coherent characteristic is ±12 degrees when the deflection angle \( \theta \) of the mirror 4003 is 12 degrees. Further, the maximum expansion angle from the optical axis 4122a reflected by the mirror 4003 is also ±12 degrees, from the above description, and therefore a provision of at least 24 degrees between the optical axis 4121a of the illumination light and the optical axis 4122a of the flux of the reflected light makes it possible, to theoretically prevent the light fluxes from overlapping with each other.

Further, with the deflection angle of the mirror 4003 in the initial state being set at "0" degrees, an angle of -24 degrees is provided between the optical axis 4123a of the light reflected by the mirror 4003 in the initial state and the optical axis 4122a of the ON light so that the reflected light does not theoretically overlap with the ON light and so that no light enters the projection optical system 4125.

Meanwhile, the conventional spatial light modulator is structured such that the deflection angle of a mirror rotates (i.e., swings) in equal swinging angles CW and CCW about the initial state of the mirror as the center, and therefore the deflection angle of mirror in the OFF state is -12 degrees in relation to the deflection angle, i.e., +12 degrees, of mirror in the ON state.

At the angle in the OFF state, an angle of -48 degrees is provided between the optical axis 4124a of the OFF light and the optical axis 4122a of the ON light so that not only does the light flux of the OFF light overlap with the light flux of the ON light theoretically, but also that of the OFF light does not overlap with the light flux reflected by the mirror 4003 in the initial state. Configuring as such prevents the diffraction light or scattered light generated by the mirror from entering the projection optical system 4125, while the usage efficiency of f/2.4 light output from the discharge lamp light source is theoretically optimized.

The present embodiment, however, does not need to consider an optimization of the usage efficiency any deeper than the case of using the discharge lamp light source, as a result of using the light source 4002 possessing a coherent characteristic, such as a laser light source.

The reason is that, when a laser light source is used as the light source 4002
possessing a coherent characteristic, brightness can be maintained even if the maximum spread angle $\alpha$ of the numerical aperture NA of the illumination light flux is reduced in terms of the relationship of etendue because a degradation in the high frequency component of the spatial frequency of the laser light is small. Therefore, the resolution of a projected image can be maintained even with a smaller F-number for the projection lens than an F-number in the case of using a discharge lamp light source or the like.

In addition, a larger deflection angle of mirror may be set than the theoretically calculated conventional deflection angle of mirror in this case. Further, by increasing the deflection angle of mirror, it is possible to prevent the diffraction light or scattered light generated by the mirror in the OFF light state and OFF angle from entering the projection optical system more securely. As a result, the contrast of the projected image is improved.

Further, in the case of using a laser light source, the F-number of a projection lens can be increased, and the deflection angle of mirror can be set at smaller, than in the case of using a discharge lamp light source or the like as described above.

The following exemplifies the setting of the deflection angle of a mirror element of the present embodiment with reference to Figs. 78A, 78B, 79, 80A, 80B, 81, 82 and 83. Note that the present embodiment designates the conventional optical axis 4123a of the light reflected by the mirror 4003 in the initial state as the optical axis 4123 of an intermediate light, that is, a portion of the light enters the projection optical system.

In the case of using a laser light source as the light source 4002 possessing a coherent characteristic, the numerical aperture NA of the light flux emitted from the laser light source configured as described above can be reduced, and therefore the deflection angle of the mirror 4003 can be set at smaller angle, that is, $\pm 3$ degrees, in the ON light state and OFF light state, respectively, than the conventional case when the numerical aperture NA is set at 10.

Fig. 78A is an illustrative cross-sectional diagram delineating a situation in which an f/10 light flux, which possesses a coherent characteristic, is reflected by a spatial light modulator for which the deflection angles of the ON light state and OFF light state of a mirror are set at $\pm 3$ degrees, respectively.

In the configuration of Fig. 78A, with the deflection angle of mirror in an ON light state being set at $+3$ degrees, an angle of $+6$ degrees is provided between the optical axis 4122 of an ON light and the optical axis 4121 of the illumination light so that the ON light enters the projection optical system 4125 without an overlap between the light flux of the ON light the illumination light flux.
Further, with the deflection angle of the mirror 4003 in an initial state set at 0 degrees, an angle of -6 degrees is provided between the optical axis 4123 of an intermediate light and the optical axis 4122 of the ON light so that the light flux of the intermediate light enters the projection optical system 4125 without overlapping with the light flux of the ON light.

Further, with the deflection angle of the mirror 4003 in an OFF state being set at -3 degrees, an angle of -6 degrees is provided between the optical axis 4124 of an OFF light and the optical axis 4122 of the intermediate light so that the light flux of the OFF light does not overlap not only with the light flux of the ON light but also that of the intermediate light. That is, an angle of -12 degrees is provided between the optical axis 4124 and the optical axis 4122 of the ON light.

Configuring as such makes it possible to prevent the diffraction light or scattered light generated by the mirror producing an OFF light and tilting in an OFF angle from entering the projection optical system 4125 more securely.

Fig. 78B is a diagram further showing an expansion of diffraction light by delineating, in three dimensions, the relationship, which is shown in Fig. 78A, between the deflection angle of the mirror and the light flux thereof.

While diffraction light 4110 is generated perpendicularly to the directions of the respective sides of the mirror 4003, the light does not overlap with the light path of an ON light since the deflection axis is set in the diagonal direction of the mirror 4003. Particularly, the diffraction light 4110 does not enter the projection optical system since the configuration is such that the diffraction light 4110 generated when the mirror 4003 is in an OFF state does not overlap with the light path of the ON light. As a result, the extraneous diffraction light 4110 generated by the spatial light modulator reflecting incident light does not enter the projection optical system, and thereby the contrast of an image is improved.

Further, the deflection angle of the mirror 4003 in the OFF state and ON state may be increased from the ±3 degree deflection angle shown in Figs. 78A and 78B in order to further improve the contrast.

Fig. 79 is an illustrative cross-sectional diagram delineating a situation in which an f/10 light flux emitted from a light source, which possesses a coherent characteristic, is reflected by a spatial light modulator for which the deflection angles of the ON light state and OFF light state of the mirror shown in Fig. 78A are set at ±13 degrees, respectively.

The configuration of Fig. 79 sets the deflection angle of the mirror 4003 in the ON state larger, at +13 degrees, than the theoretically calculated angle, i.e., +3 degrees, from the numerical aperture NA of a laser light source. The setting of such a deflection angle of
mirror designates the angle, as +26 degrees, between the optical axis 4122 of the ON light and the optical axis 4121 of the illumination light.

Further, the deflection angle of the mirror 4003 in an intermediate light state (i.e., an intermediate angle) is set at "0" degrees. The setting of such a deflection angle of mirror designates the angle, as -26 degrees, between the optical axis 4123 of the intermediate light and the optical axis 4122 of the ON light.

Further, the configuration of Fig. 79 sets the deflection angle of the mirror 4003 in the OFF state larger, at -13 degrees, than the theoretically calculated angle, i.e., -3 degrees, from the numerical aperture NA of the laser light source. The setting of such a deflection angle of mirror designates the angle, as -26 degrees, between the optical axis 4124 of the OFF light and the optical axis 4123 of the intermediate light. That is the angle between the optical axis of the OFF light and the optical axis 4122 of the ON light is -52 degrees.

As described above, each light flux can be clearly separated by using such a light source 4002 possessing a coherent characteristic and setting the deflection angle of the mirror 4003 larger than the conventional theoretically calculated deflection angle of the mirror 4003. As a result, it is possible to prevent more securely the diffraction light and/or scattered light, which are generated by a mirror producing an OFF light and tilting in an OFF angle, from entering the projection optical system 4125. As a result, the contrast of an image is improved.

Further, the setting of the deflection angle of mirror larger than a theoretically calculated value makes it possible to reduce the influence of diffraction light on a projected image even in the case of changing the deflection axis of a mirror element.

Note that the deflection angle of the mirror 4003 in the OFF state and ON state may be set at any angle provided that it is larger than the ±3-degree deflection angle shown in Fig. 78A.

Fig. 80A is a top view diagram of a mirror array, with the deflection axis of the mirror shown in Fig. 69 changed.

The difference between Fig. 80A and Fig. 69 is where the deflection axis 4005 is placed on the center division line of the mirror 4003 in the former configuration, in stead of the diagonal direction of the mirror 4003 in the latter. Further in Fig. 80A, the optical axis 4121 of the illumination light emitted from a light source 4002 possessing a coherent characteristic is made to enter the mirror 4003 perpendicularly to the deflection axis.

Fig. 80B illustratively shows the deflection of the mirror 4003 and the reflecting direction of light in the configuration shown in Fig. 80A.

When the mirror 4003 is tilted CW, the deflection angle of the mirror 4003 is in an
ON light state in which the illumination light is reflected to the optical axis 4122 of an ON light with which the entirety of light is incident toward the projection optical system.

When the mirror 4003 is in the initial state, the deflection angle thereof is in an intermediate state in which the illumination light is reflected to the optical axis 4123 of an intermediate light with which a portion of light is incident toward the projection optical system.

When the mirror 4003 is tilted CCW, the deflection angle of the mirror 4003 is in an OFF light state in which the illumination light is reflected to the optical axis 4124 of an OFF light with which no light is incident toward the projection optical system.

Fig. 79 is a diagram further showing the expansion of diffraction light by delineating, in three dimensions, the relationship between the deflection angle of the mirror and the light flux shown in Fig. 79 in the case in which the directions of the deflection axis of a mirror element are changed as shown in Fig. 80A.

The diffraction light of an OFF light is generated perpendicularly to the direction of the respective sides of a mirror and in the direction of the light path of an ON light starting from the optical axis of the OFF light. A larger value is provided as an angle between the optical axis of the ON light and that of the OFF light, however, and therefore the diffraction light 4110 does not enter the projection optical system. As a result, the extraneous diffraction light 4110 generated by the reflection of light by a spatial light modulator does not enter the projection optical system and thereby the contrast of the projected image is improved.

Furthermore, the present embodiment does not need to set the deflection angle of an ON light state and that of an OFF light state in an equal angle such as ±12 degrees, as in a conventional method. Accordingly, the following provides examples of different deflection angles between the ON light state of mirror and the OFF light state thereof with reference to Figs. 82 and 83.

Fig. 82 is an illustrative cross-sectional diagram delineating a situation in which an f/10 light flux emitted from a light source 4002, which possesses a coherent characteristic, is reflected by a spatial light modulator for which the deflection angles of the ON light state and OFF light state of a mirror are set at +13 degrees and -3 degrees, respectively.

With the deflection angle of a mirror 4003 in an ON light state being set at +13 degrees, an angle of +26 degrees is provided between the optical axis 4122 of an ON light and the optical axis 4121 of an illumination light so that the light flux of the ON light enters a projection optical system 4125 without overlapping with the illumination light flux.
Further, with the deflection angle of the mirror 4003 in an intermediate state being set at "0" degrees, an angle of -26 degrees is provided between the optical axis 4123 of an intermediate light and the optical axis 4122 of the ON light so that the light flux of the intermediate light enters the projection optical system 4125 without overlapping with the flux of the ON light.

Further, with the deflection angle of the mirror 4003 in an OFF state being set at -3 degrees, an angle of -6 degrees is provided between the optical axis 4124 of an OFF light and the optical axis 4123 of the intermediate light so that the flux of the OFF light does not overlap with either the flux of the ON light or the flux of the intermediate light.

Configuring as described above makes it possible to more reliably prevent the diffraction light and/or scattered light generated by a mirror producing the OFF light and tilting in the OFF angle from entering the projection optical system 4125.

As exemplified in Fig. 76, unique phrase Diffraction light 4110 is generated perpendicularly to the directions of the respective sides of a mirror 4003. The optical axis of an OFF light, which is designated by setting a deflection angle considering an optimization of the usage efficiency of light output from a discharge lamp light source according to the conventional method, is close to the optical axis 4122 of an ON light, allowing the diffraction light 4110 to enter the projection optical system 4125, and there is accordingly a possibility of making the projected light brighter. The present embodiment, however, using a light source possessing a coherent characteristic, is enabled to set the optical axis 4124 of an OFF light and the optical axis 4122 of an ON light sufficiently far apart from the theoretical optical axis of the OFF light (i.e., the ±3-degree deflection angle of a mirror), and thereby the influence of the diffraction light 4110 on the projection optical system 4125 can be reduced. This in turn improves the contrast of an image.

Fig. 83 is an illustrative cross-sectional diagram delineating a situation in which an f/10 light flux emitted from a light source, which possesses a coherent characteristic, is reflected by a spatial light modulator for which the deflection angles of the ON light state and OFF light state of a mirror are set at +3 degrees and -13 degrees, respectively.

With the deflection angle of mirror in an ON state being set at +3 degrees, an angle of +6 degrees is provided between the optical axis 4122 of an ON light and the optical axis 4121 of an illumination light so that the flux of the ON light enters a projection optical system 4125 without overlapping with the illumination light flux.

Further, with the deflection angle of mirror in an intermediate state being set at "0" degrees, an angle of -6 degrees is provided between the optical axis 4123 of an intermediate light and the optical axis 4122 of the ON light so that the flux of the intermediate light enters the projection optical system 4125 without overlapping with the
Further, with the deflection angle of mirror in an OFF state being set at -13 degrees, an angle of -26 degrees is provided between the optical axis 4124 of the OFF light and the optical axis 4123 of the intermediate light so that the flux of the OFF light does not overlap with not only that of the ON light but also that of the intermediate light. Configuring as such makes it possible to reliably prevent the OFF light from entering the projection optical system 4125.

As exemplified in Fig. 76 unique phrase, Diffraction light 4110 is generated perpendicularly to the directions of the respective sides of a mirror 4003. The optical axis of an OFF light, which is designated by setting a deflection angle considering an optimization of the usage efficiency of light output from a discharge lamp light source according to the conventional method, is close to the optical axis 4122 of an ON light, allowing the diffraction light 4110 to enter the light path of the ON light, leading to the projection optical system 4125, and there is accordingly a possibility of making the projected light brighter. The present embodiment, however, is enabled to set the optical axis 4124 of an OFF light and the optical axis 4122 of an ON light sufficiently apart from the theoretical optical axis of the OFF light (i.e., the ±3-degree deflection angle of a mirror), and thereby the influence of the diffraction light 4110 on the projection optical system 4125 can be reduced. This in turn improves the contrast of an image.

As described thus far, the present embodiment, comprising a light source possessing a coherent characteristic, allows an appropriate alternative setting of the deflection axis of a mirror, the deflection angle of the mirror in an ON light state and that of the mirror in an OFF light state. Preferably, the deflection angle of a mirror can possibly be set in such a manner that the mirror deflects clockwise (CW) in any of ±3 degrees through ±13 degrees in relation to the initial state, and the deflection angle of the ON light state and that of the OFF light state may be asymmetrically set.

Note that the mirror pitch, mirror gap, deflection angle and drive voltage of the mirror device according to the present embodiment are not limited to the values exemplified in the above description. Rather, they preferably fall in the following ranges (including values at both ends of the range): the mirror pitch is between 4µm and 10µm; the mirror gap is between 0.15µm and 0.55µm; the maximum deflection angle of mirror is between 2 degrees and 14 degrees; and the drive voltage of mirror is between 3 volts and 15 volts.

Note that the present invention can be modified in various manners possible within the scope of the present invention and is not limited to the configurations exemplified in the above-described preferred embodiments.
What is claimed is:

1. A projection apparatus, comprising:
   a plurality of mirror devices for modulating and reflecting the incident light emitted from a light source;
   light synthesizer comprising both a synthesis surface where the reflection lights from the mirror devices are synthesized and an incidence surface which is placed on a flat surface crossing with the synthesis surface and to which the incident light is incident; and
   a projection lens for projecting the reflection light.

2. The projection apparatus according to claim 1, wherein:
   the flat surface on which the incidence surface is placed is approximately orthogonal to the synthesis surface.

3. The projection apparatus according to claim 1, further comprising:
   a package in which the mirror device is placed, wherein the package includes a transparent light transmission member transmitting the incident light and the reflection light that is incoming from the mirror device are incident in different angles, wherein the incident light incident to the light transmission member enters the incidence surface that crosses the synthesis surface.

4. The projection apparatus according to claim 3, wherein:
   a plurality of the mirror devices is placed in a singularity of the package.

5. The projection apparatus according to claim 4, wherein:
   light shield members are placed between a plurality of the mirror devices.

6. The projection apparatus according to claim 3, wherein:
   the light transmission member and the light synthesizer are joined by a thermal conduction member.

7. The projection apparatus according to claim 6, wherein:
   the light transmission member and the light synthesizer have the coefficient of thermal expansion approximately equal to the coefficient of thermal expansion of thermal conduction member respectively.
8. The projection apparatus according to claim 3, further comprising:
a light shield member equipped between the mirror device and light synthesizer, wherein the light shield member is fixed to the light transmission member or light synthesizer.

9. The projection apparatus according to claim 1, wherein:
the incident light is incident at least to two of the incidence surfaces that cross the synthesis surface.

10. The projection apparatus according to claim 9, wherein:
  at least two of the incidence surface to which the incident light is incident crosses the synthesis surface approximately orthogonally.

11. The projection apparatus according to claim 1, wherein:
  the light synthesizer has at least one reflection surface between the synthesis surface and mirror device.

12. The projection apparatus according to claim 1, wherein:
a reflection light, which is reflected by the mirror device toward a direction other than the incidence pupil of the projection lens, is reflected toward an opposite surface that is opposite to the incidence surface.

13. The projection apparatus according to claim 1, wherein:
a light absorption layer is equipped on an opposite surface that is opposite to the incidence surface.

14. The projection apparatus according to claim 1, further comprising:
a light transmission member equipped between the light synthesizer and the mirror device, wherein a portion of the reflection light reflected by the light transmission member is reflected toward an opposite surface that is opposite to an incidence surface to which the incident light enters the light synthesizer.

15. The projection apparatus according to claim 1, wherein:
a polarization element is equipped between the light synthesizer and the mirror device.

16. The projection apparatus according to claim 1, further comprising:
two of the mirror devices, wherein the mirror device has a rectangular contour, and the two mirror devices are placed in directions in which respective one side forming the respective contours of the individual mirror devices are mutually orthogonal on the same plane or on parallel planes.
17. The projection apparatus according to claim 1, wherein:
the incident lights with at least two different wavelengths are simultaneously incident to one of the mirror devices, wherein the present mirror device modulates the incident light on the basis of a video image signal corresponding to either of the wavelengths of the incident lights.

18. The projection apparatus according to claim 1, further comprising:
three of the mirror devices, wherein the lights emitted from the light source have three independent frequency domains, or no less than four frequency domains including [i] and [ii], or including [i] and [iii], where:

[i] is the three frequency domains, [ii] is a frequency domain of which a part of frequencies overlap with either of the aforementioned three frequency domains and which includes a different frequency, and [iii] is a frequency domain adjacent to either of the three frequency domains.

19. The projection apparatus according to claim 1, further comprising:
a light source control circuit, wherein the light source includes a plurality of laser light sources.

20. The projection apparatus according to claim 19, wherein:
the light source control circuit controls the emission light intensity of the light source in accordance with an input signal.

21. The projection apparatus according to claim 19, wherein:
a plurality of the laser light sources simultaneously emits lights, wherein at least respective portions of individual light fluxes of the lights emitted from at least two of the plurality of the laser light sources are intermixed in an illumination light path.

22. The projection apparatus according to claim 19, wherein:
at least a light of one color emitted from the plurality of laser light sources has a different light path length of the illumination light path to the mirror device or a different angle of irradiation onto the mirror device than the lights of the other colors.

23. The projection apparatus according to claim 1, wherein:
the optical axis of the incident light forms an angle that is no larger than 14 degrees with the optical axis of the reflection light from the mirror device synthesized by the light synthesizer.
24. The projection apparatus according to claim 1, wherein:
the F-number of the projection lens is no less than 4.

25. The projection apparatus according to claim 1, further comprising:
a plurality of mirror devices, which is so arranged as to cancel shifts one another in
the projection positions of a projection image by means of the plurality of mirror
devices due to a temperature rise in the projection apparatus.

26. A projection apparatus, comprising:
a light source;
an illumination optical system for guiding the incident light emitted from the light
source;
a plurality of light modulator arrays, in each of which light modulation elements
for modulating and reflecting the incident light are arrayed in two dimensions;
light synthesizer comprising an incidence surface to which the incident light is
incident, a synthesis surface on which the modulation lights from the light
modulator arrays are synthesized, an undesirable light guide surface to which an
undesirable portion of the modulation light is guided, and an ejection surface from
which a synthesized modulation light is ejected;
a projection lens for projecting the synthesized modulation light, wherein the
optical axis of the incident light or the undesirable modulation light is
approximately orthogonal to the normal line of the synthesis surface.

27. The projection apparatus according to claim 26, wherein:
the distance between at least one of a plurality of the light modulator arrays and
the light synthesizer is different from the distances between the other light
modulator arrays and the light synthesizer.

28. The projection apparatus according to claim 26, wherein:
the light source emits a plurality of the incident lights, wherein the light path
length of at least one of the incident lights to the light modulator array is different
from the light path length of another of the incident lights to the light modulator
array.

29. The projection apparatus according to claim 26, wherein:
the light source, which is a laser light source, constituted by a plurality of sub-light
sources and which further includes a light source control circuit for controlling the
entirety of the light source and the individual sub-light sources respectively.
30. The projection apparatus according to claim 29, wherein:
the light source control circuit controls the emission light intensity of the light source in accordance with an input signal.

31. The projection apparatus according to claim 26, wherein:
the optical axes of a plurality of the modulation lights are approximately parallel to one another.

32. The projection apparatus according to claim 26, wherein:
the light modulator array has a rectangular contour, and two of a plurality of the light modulator arrays are placed in directions in which respective one side forming the respective contours of the individual mirror devices are mutually orthogonal on the same plane or on parallel planes.
FIG. 1C (Prior Art)

<table>
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<tr>
<th>Word</th>
<th>MSB (1000)</th>
<th>(0100)</th>
<th>(0010)</th>
<th>LSB (0001)</th>
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</thead>
<tbody>
<tr>
<td>Number of LSB times</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Field Time = $1 + 2 + 4 + 8 = 15$ LSB Times

FIG. 1D (Prior Art)
FIG. 8B

Mirror state
ON
OFF
Applying signal (0,1) to electrodes

FIG. 8C

Mirror state
ON
OFF
Applying signal (1,0) to electrodes

FIG. 8D

Mirror state
ON
OFF
Applying signal (0,0) to electrodes
Gray scale N bit $\geq n$

$I_1$ = a first current for $I_{th}$ and LSB
$I_2$ = a first current for LSB+1
$I_3$ = a first current for LSB+2
$
\vdots$
$I_n$ = a first current for MSB

- non SW: $P_b = k \times I_b \div 0$ [mW] ($I_b \div I_{th}$)
- SW$_1$: $P_1 = k \times (I_b + I_1)$
- SW$_2$: $P_2 = k \times (I_b + I_1 + I_2)$
$
\vdots$
- SW$_n$: $P_n = k \times (I_b + I_1 + I_2 + \cdots + I_{n-1} + I_n)$

**FIG. 26**
* $t_{\text{set}}$ : predetermined period
* $t_{\text{LSB}}$ : modulation period corresponding to LSB

FIG. 31
\[ t_D + t_r < t_{\text{LSB}} \]
\[ t_D + t_f < t_{\text{LSB}} \]
\[
\begin{align*}
  f_m &= \frac{1}{t_{\text{osc}}} \\
  f_p &= \frac{1}{tp + ti}
\end{align*}
\]
**FIG. 41A**

SLM control data

1frame

ON

OFF

6808

tp

ti

Light pulse pattern

Ph1

brightness

**FIG. 41B**

SLM control data

1frame

ON

OFF

6809

6720

6721

6722

Light pulse pattern

Ph2

brightness
FIG. 44
Input data: 8 bit

Mirror angle

ON
OFF

ON
OFF

ON
OFF

ON
OFF

input data=64

7705

input data=128

7705

input data=192

7705

input data=255

7705

Light intensity

7801

H0

time

Output data

7700
L

7700

Input data

0

255

FIG. 52
FIG. 55A

Light intensity

1 frame

7808

ti

tp

time

FIG. 55B

Output data

\gamma \text{ correction curve}

7700f

7700L

Input data
FIG. 57

Light intensity

Mirror angle

ON

OFF

Most bright red pixel in a frame

Most bright green pixel in a frame

Most bright blue pixel in a frame

52/79
FIG. 58
FIG. 60
FIG. 61
FIG. 64
FIG. 65C
FIG. 71C
FIG. 80A

FIG. 80B

OFF angle
Intermediate angle
ON angle
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G03B 21/00 (2008.04)
USPC - 353/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G03B 21/00, 21/14; 21/18; 21/26 (2008.04)
USPC - 353/46,57,97

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO EAST System (US, USPG-PUB, EPO, DERWENT), PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
</tr>
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<tbody>
<tr>
<td>X</td>
<td>US 2005/0030484 A1 (KURODA) 10 February 2005 (10 02.2005) entire document</td>
<td>1-4,6,7,9-12,14-18,23</td>
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<tr>
<td>Y</td>
<td>US 6,273,569 B1 (IECHIKA et al) 14 August 2001 (14 08 2001) entire document</td>
<td>5,8,24</td>
</tr>
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</table>

D. Further documents are listed in the continuation of Box C. □

* Special categories of cited documents

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 14 November 2008

Date of mailing of the international search report 11 NOV 2008

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