



(19) **United States**

(12) **Patent Application Publication**

Shikama

(10) **Pub. No.: US 2002/0005994 A1**

(43) **Pub. Date: Jan. 17, 2002**

(54) **RETROFOCUS LENS SYSTEM AND PROJECTION DISPLAY APPARATUS**

(52) **U.S. Cl.** **359/749; 359/753; 359/784; 359/786; 359/787; 359/788**

(76) Inventor: **Shinsuke Shikama**, Tokyo (JP)

(57) **ABSTRACT**

Correspondence Address:
BIRCH STEWART KOLASCH & BIRCH
PO BOX 747
FALLS CHURCH, VA 22040-0747 (US)

A retrofocus lens system has a negative first, a positive second and a positive third lens group. The first lens group includes an aspheric first lens, a negative meniscus second and third lenses that are convex on the large conjugate side, and a negative meniscus fourth lens being convex on the small conjugate side. The second lens group includes a positive fifth lens and a sixth lens joined to the fifth lens. The third lens group includes a positive meniscus seventh lens being convex on the small conjugate side, a biconcave eighth lens, a positive ninth lens joined to the eighth lens, a biconvex tenth and eleventh lenses, and an aspheric twelfth lens. The system satisfies $0.8 < f_2/f_3 < 1.5$, $1.6 < |f_1|/f < 2.4$, $|f_4|/f > 30$, $f_5/f > 6$, where f is a focal distance of the system, f_2 and f_3 are respectively focal distances of the second and third lens groups, $|f_1|$ is an absolute value of a focal distance of the first lens group, $|f_4|$ is an absolute value of an axial focal distance of the first lens, and f_5 is an axial focal distance of the twelfth lens.

(21) Appl. No.: **09/799,078**

(22) Filed: **Mar. 6, 2001**

(30) **Foreign Application Priority Data**

May 17, 2000 (JP) 144317/00

Publication Classification

(51) **Int. Cl.⁷** **G02B 13/04; G02B 9/12; G02B 9/14**

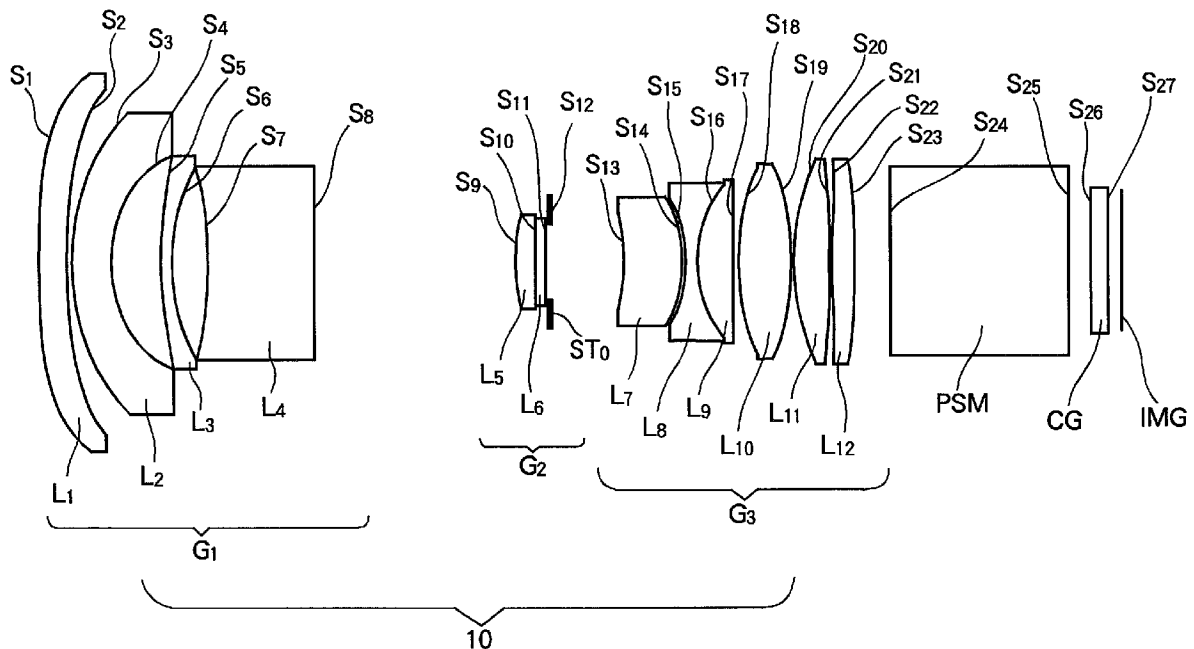


FIG. 2A

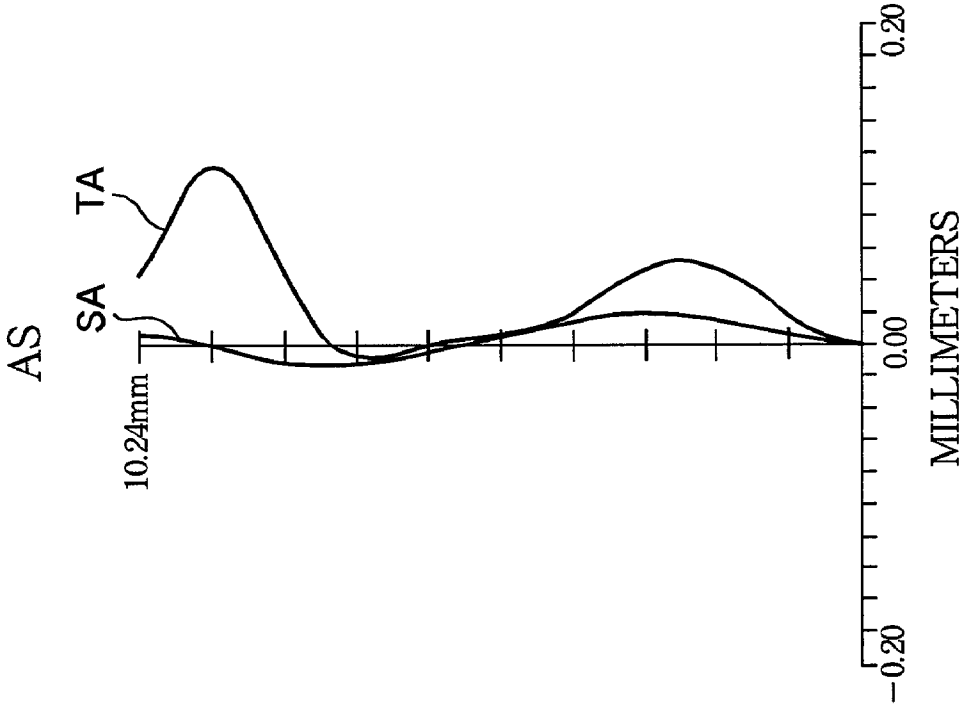


FIG. 2B

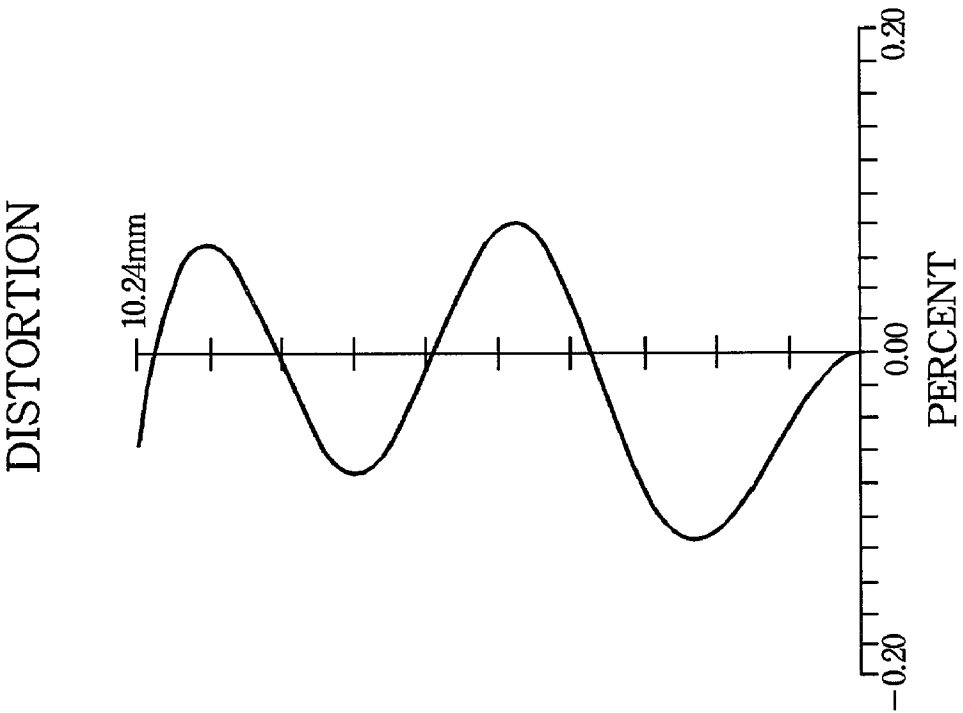


FIG.3A

FIG.3B

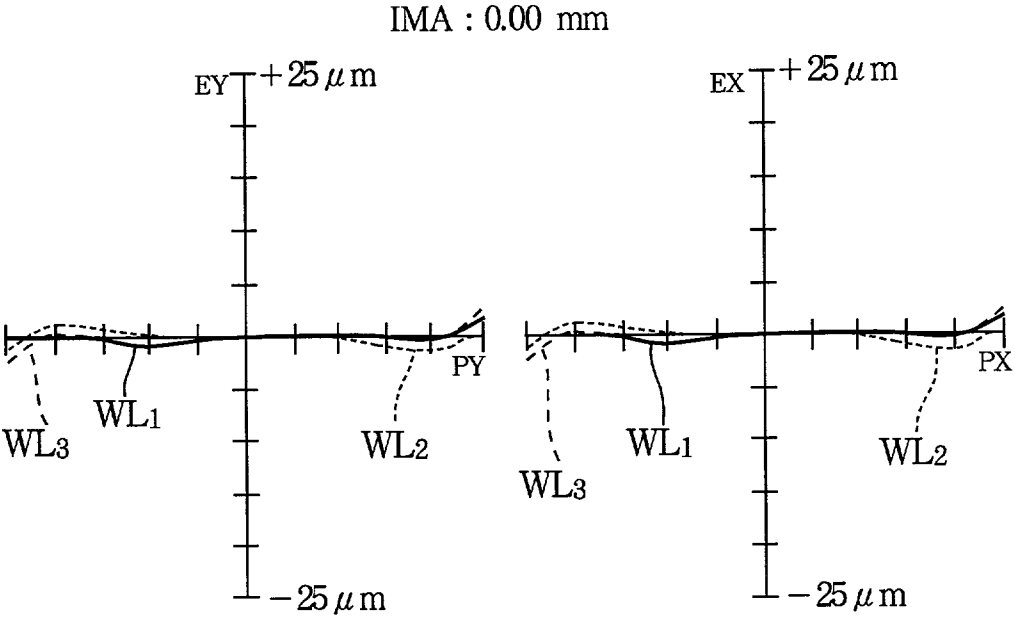


FIG.3C

FIG.3D

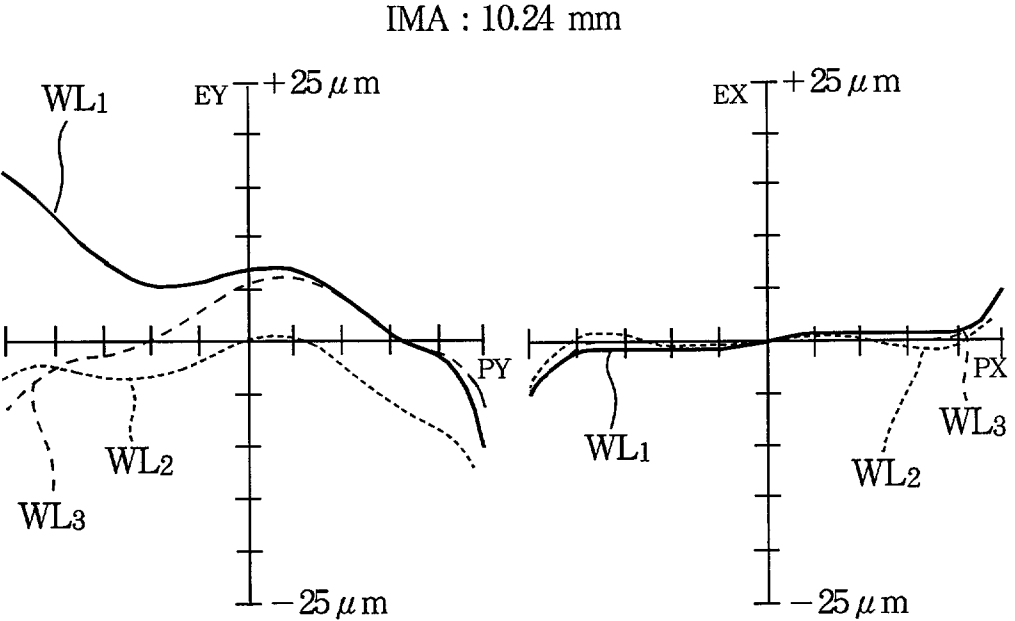


FIG. 4A

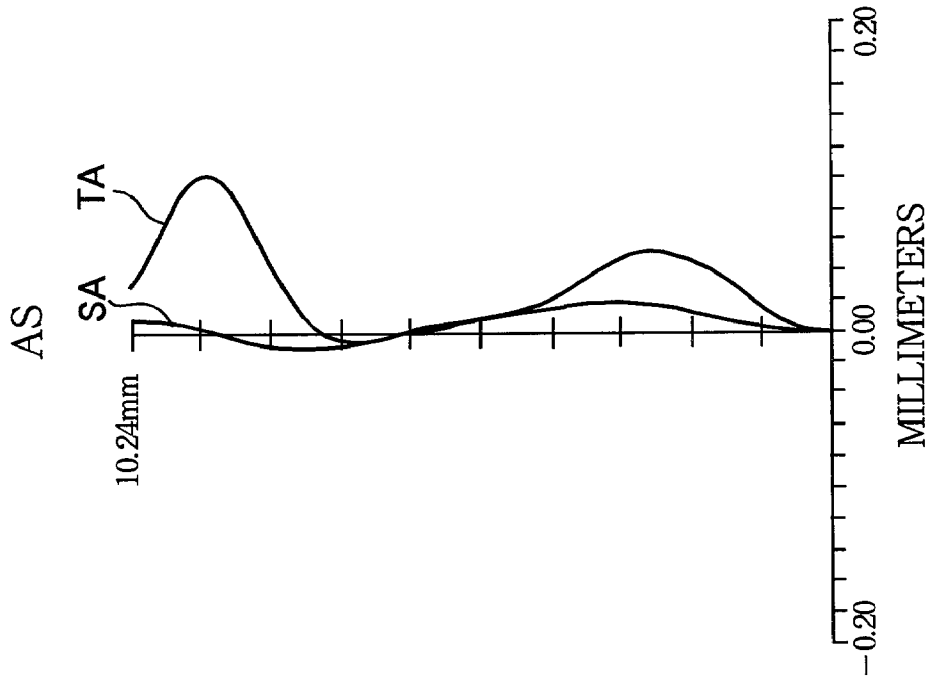


FIG. 4B

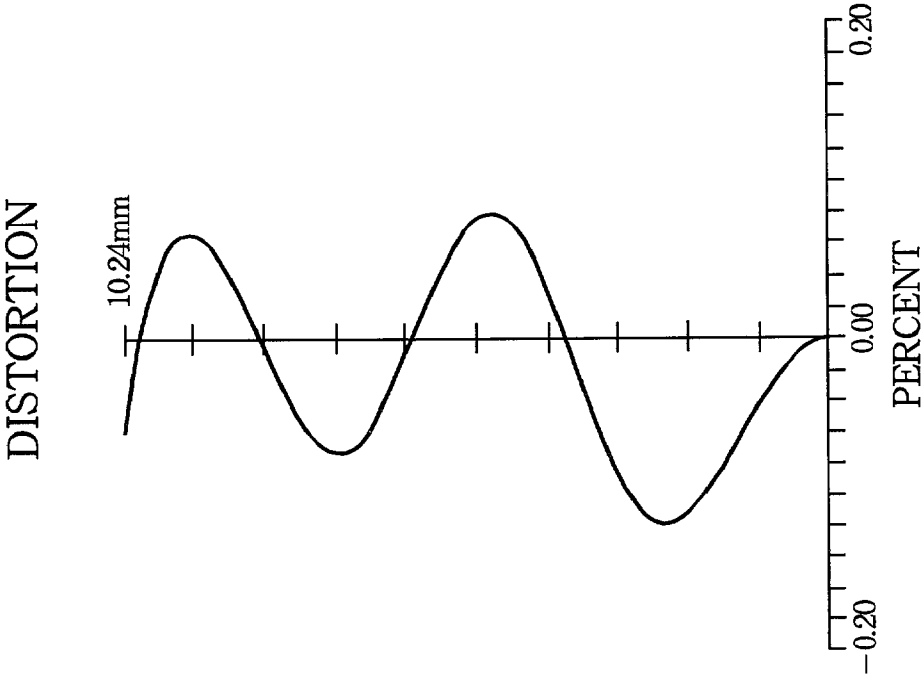


FIG.5A

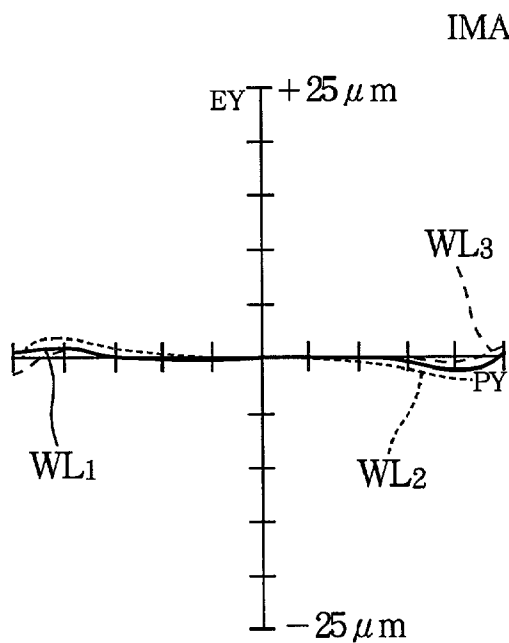


FIG.5B

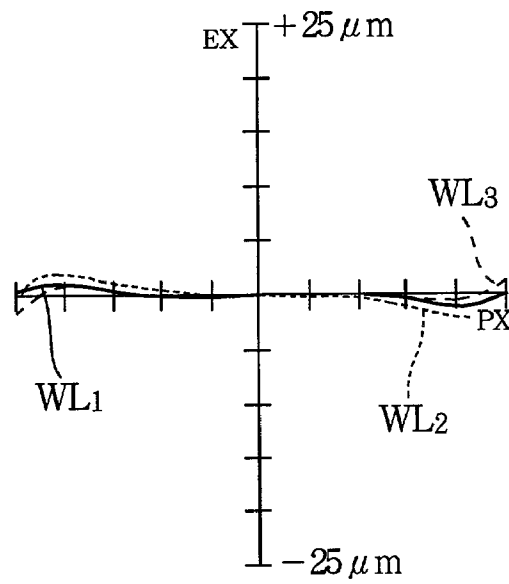


FIG.5C

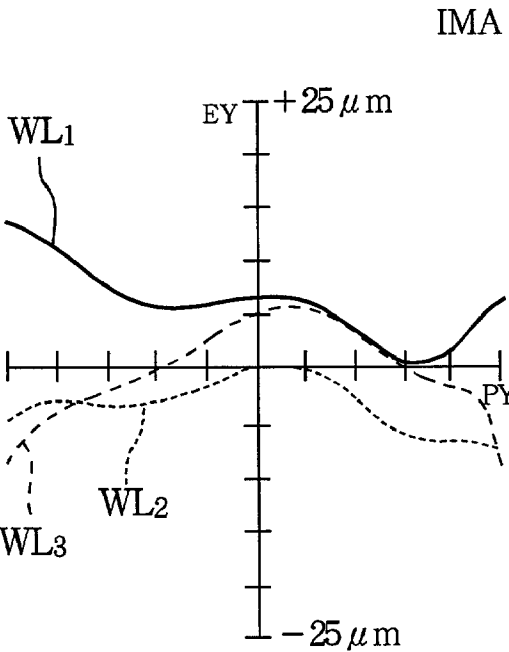


FIG.5D

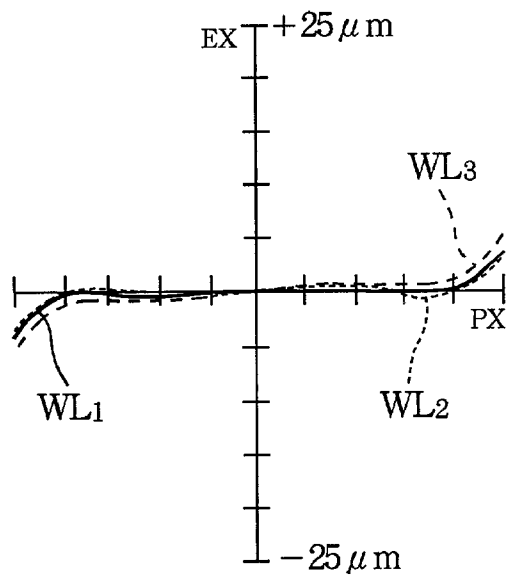


FIG. 6A

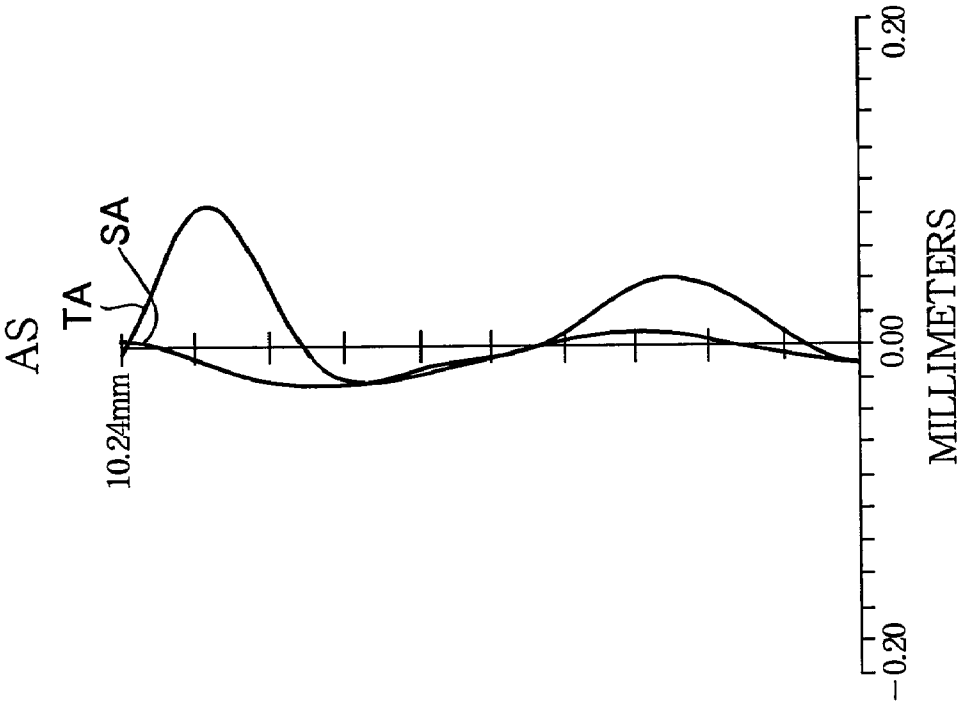


FIG. 6B

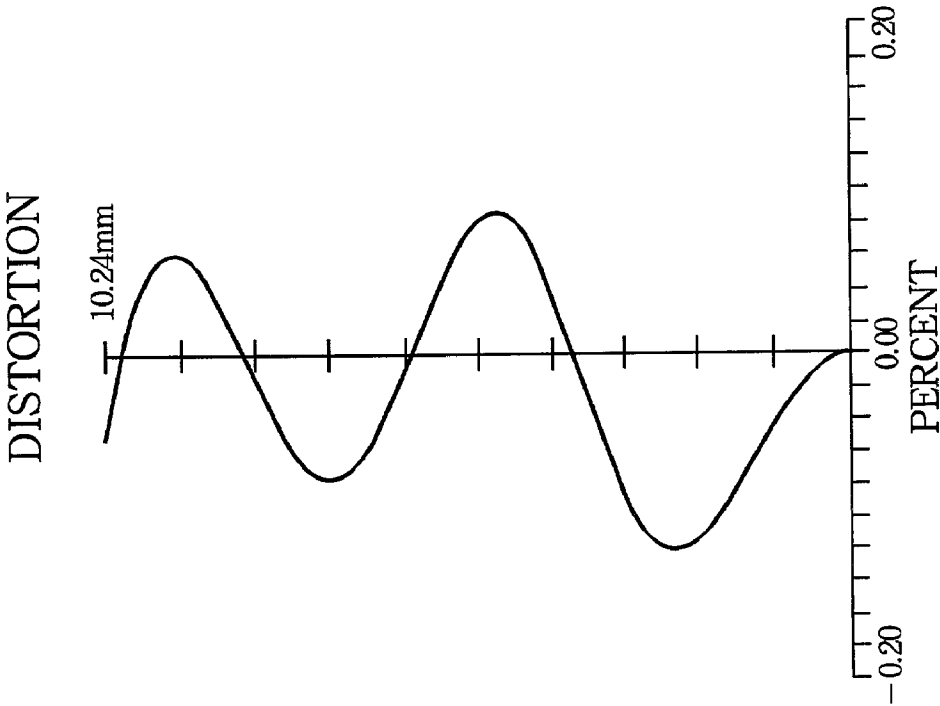


FIG.7A

FIG.7B

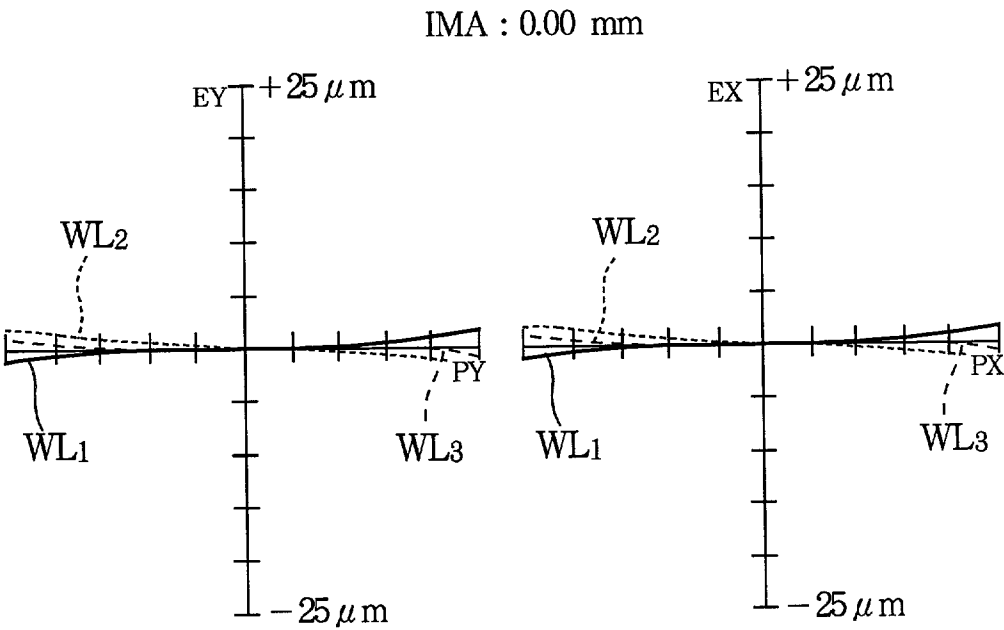


FIG.7C

FIG.7D

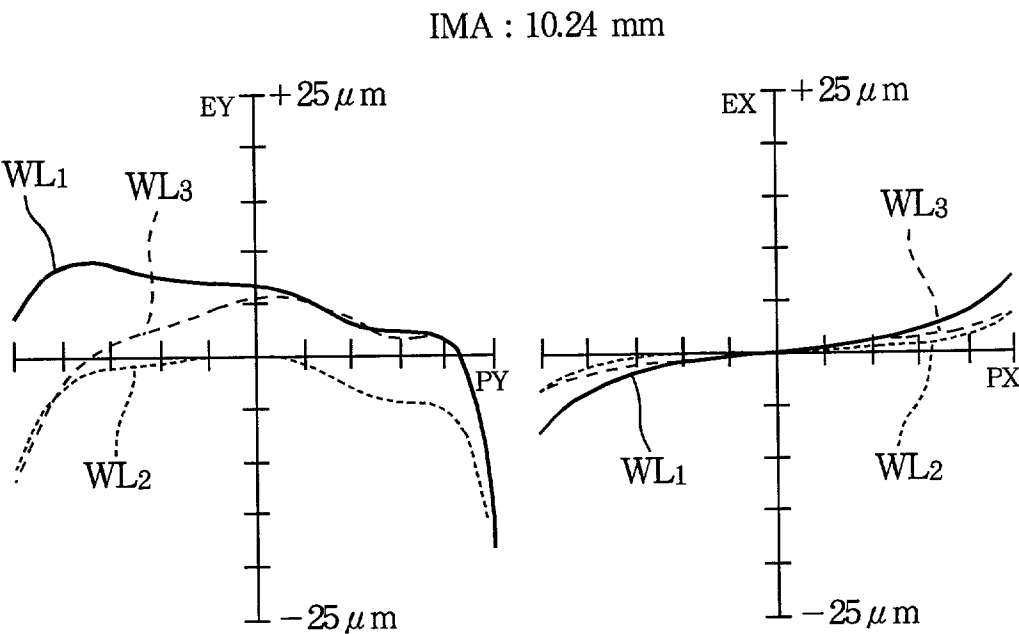


FIG.8A

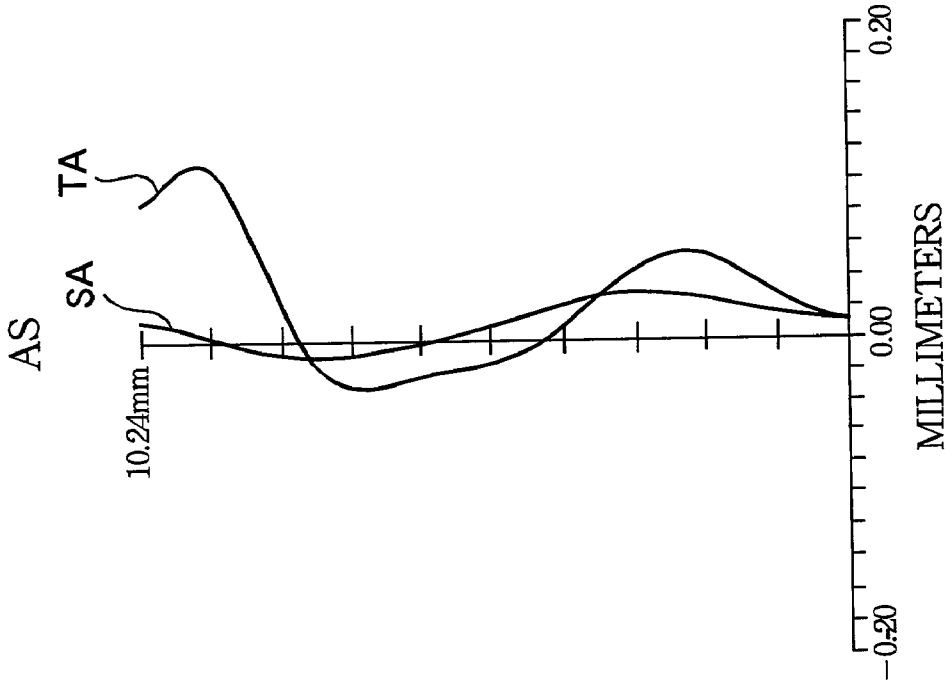


FIG.8B

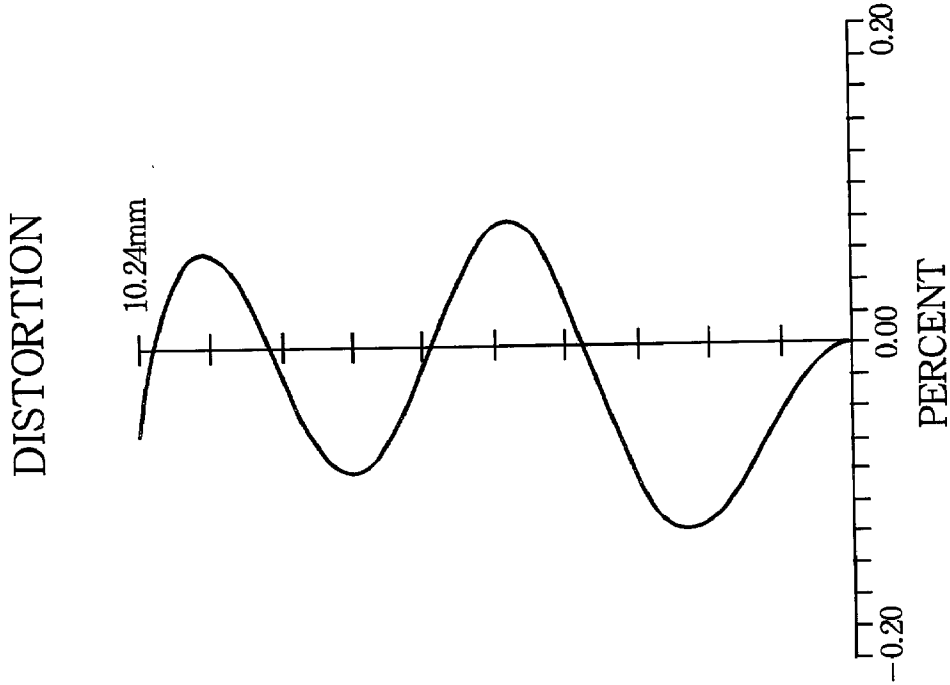


FIG.9A

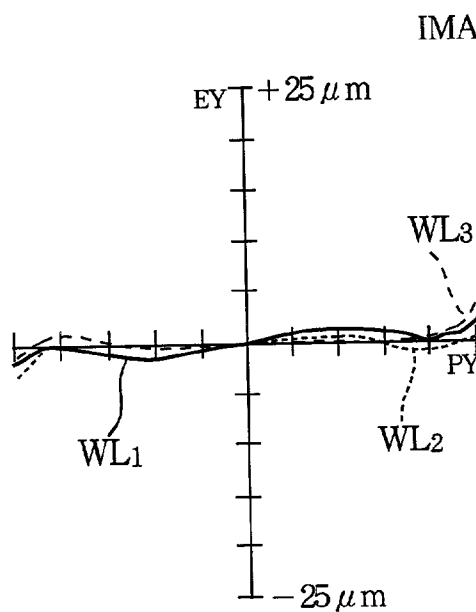


FIG.9B

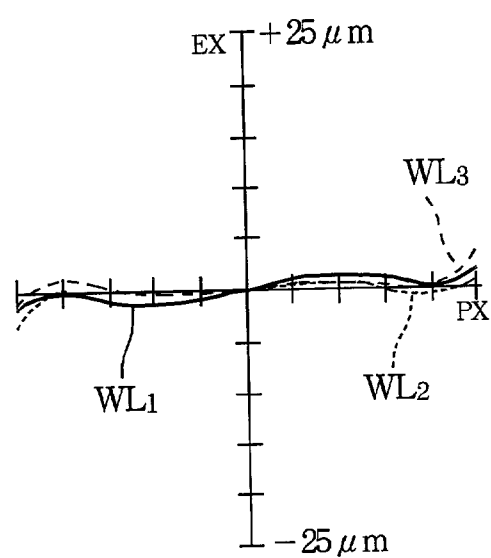


FIG.9C

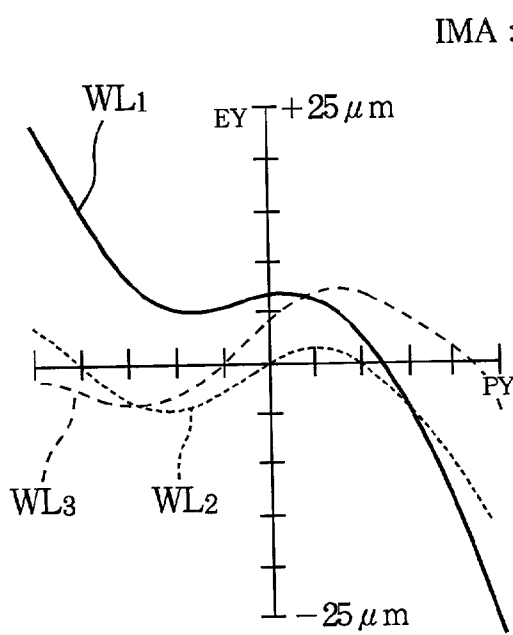


FIG.9D

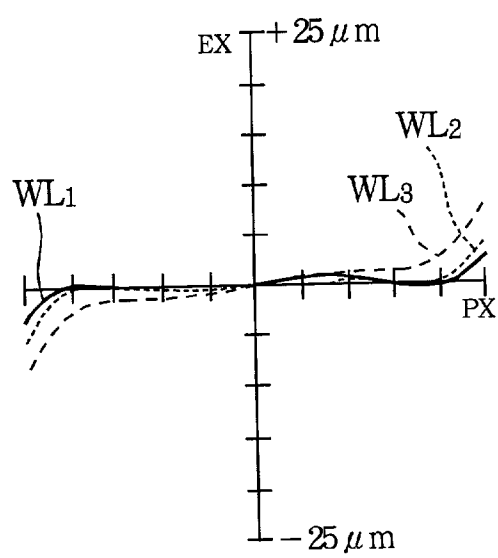


FIG.10A

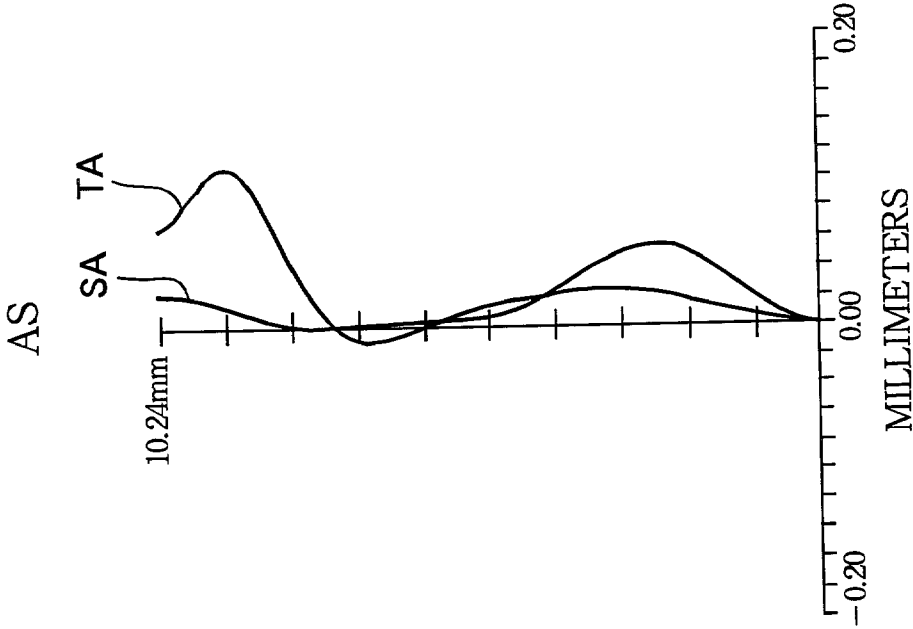


FIG.10B

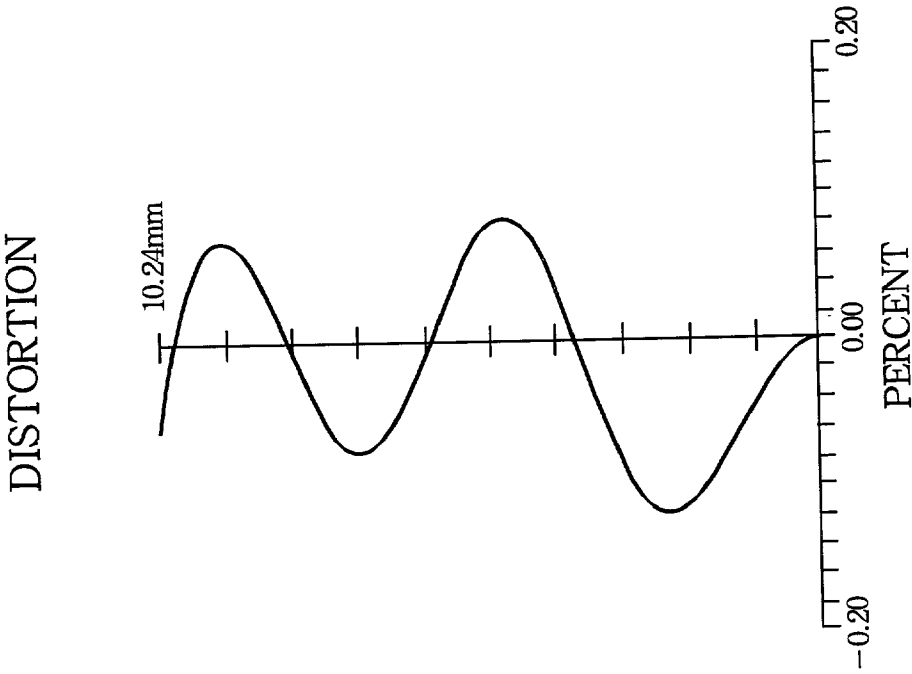


FIG.11A

FIG.11B

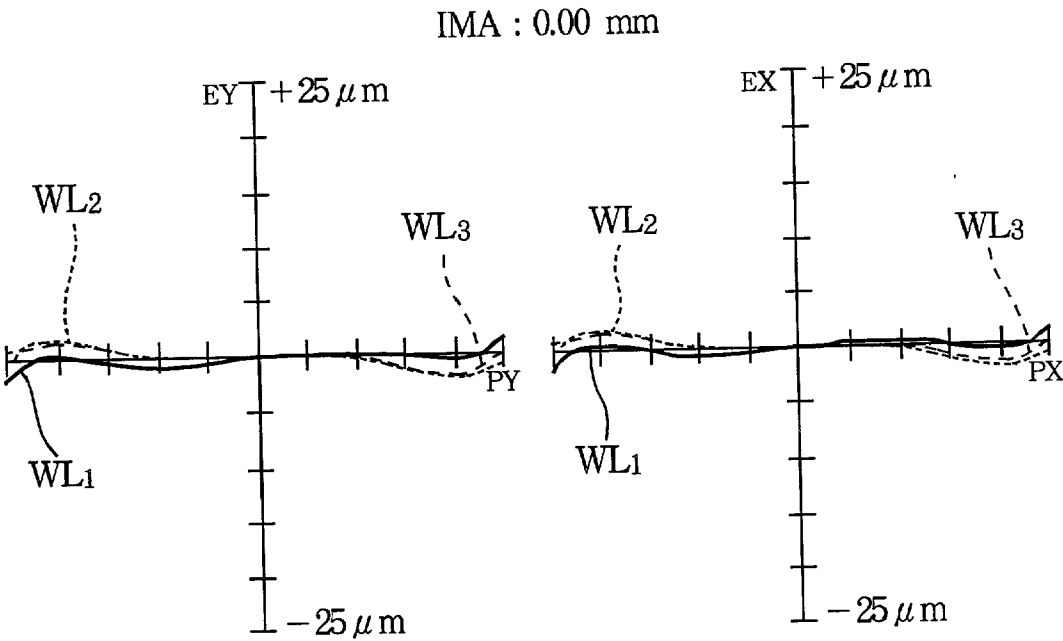


FIG.11C

FIG.11D

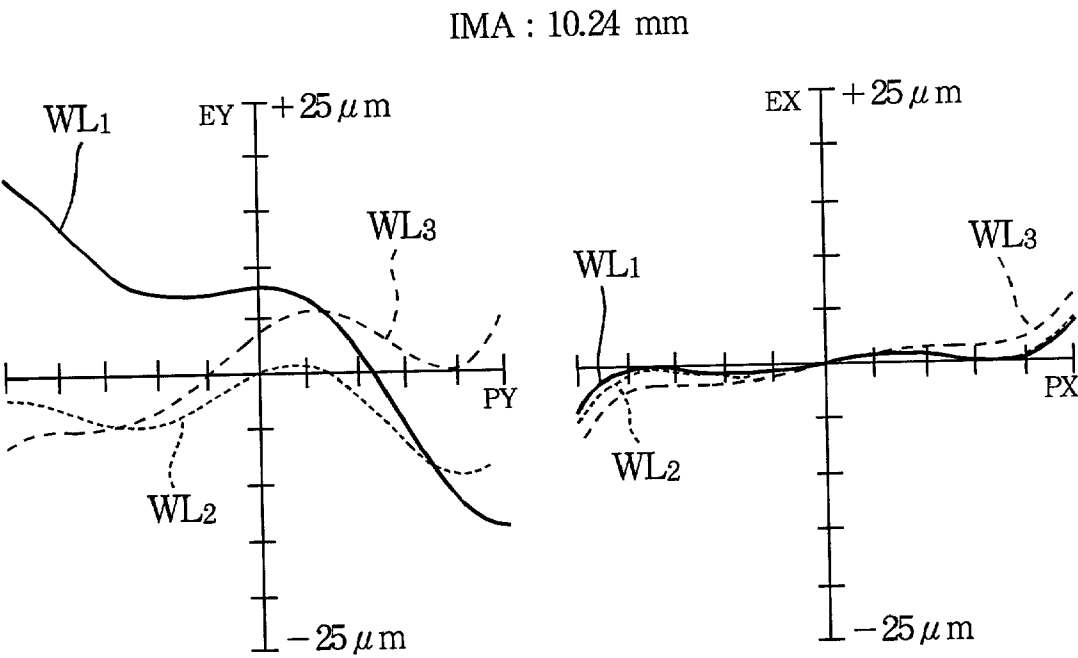


FIG.12A

SCHOTT

GLASS MATERIAL	νd	PgF
K7	60.41	0.5422
F2	36.37	0.5828

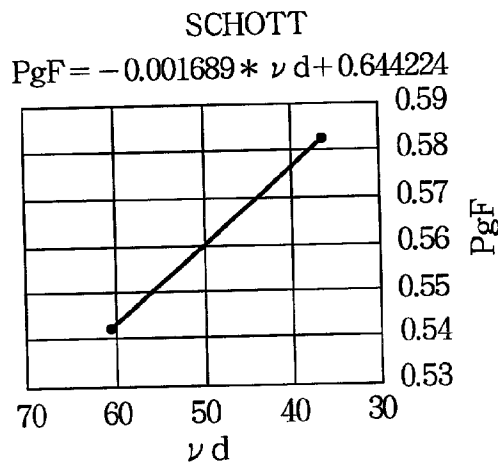


FIG.12B

OHARA

GLASS MATERIAL	νd	PgF
NSL7	60.49	0.5436
PBM2	36.26	0.5828

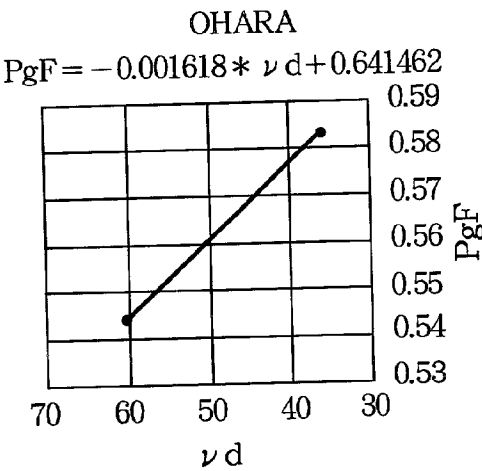


FIG.12C

HOYA

GLASS MATERIAL	νd	PgF
C7	60.49	0.5393
F2	36.30	0.5829

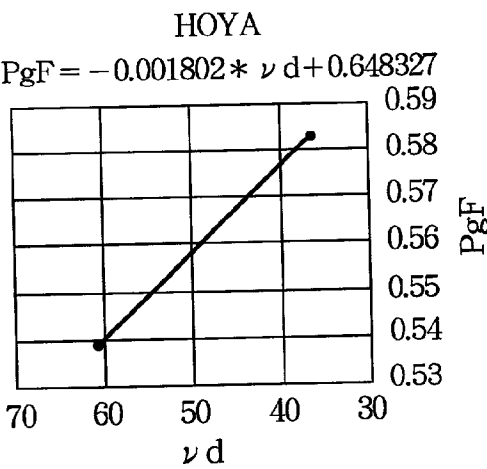


FIG.12D

SUMITA

GLASS MATERIAL	νd	PgF
K7	60.5	0.547
F2	36.3	0.583

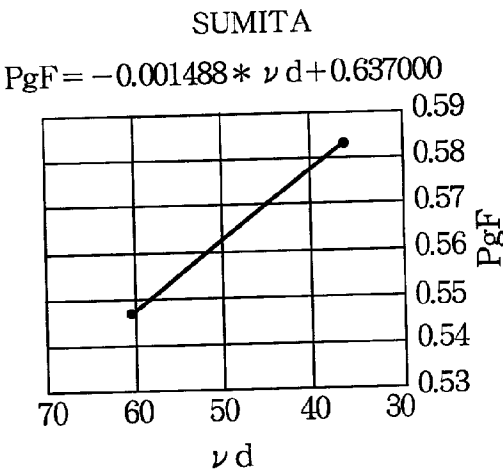


FIG.13
CONVENTIONAL ART

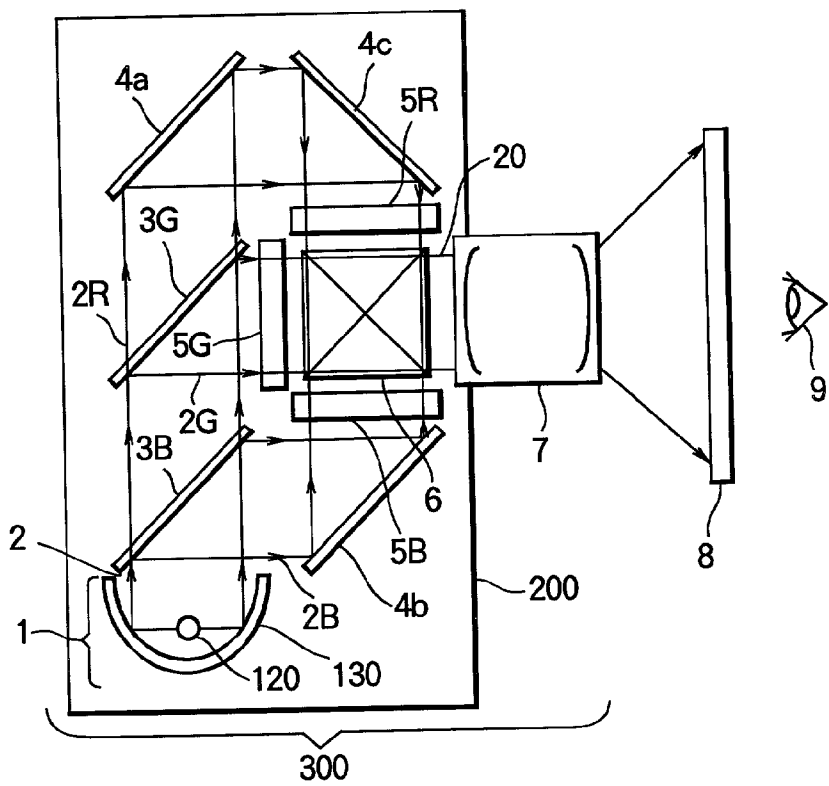


FIG.14

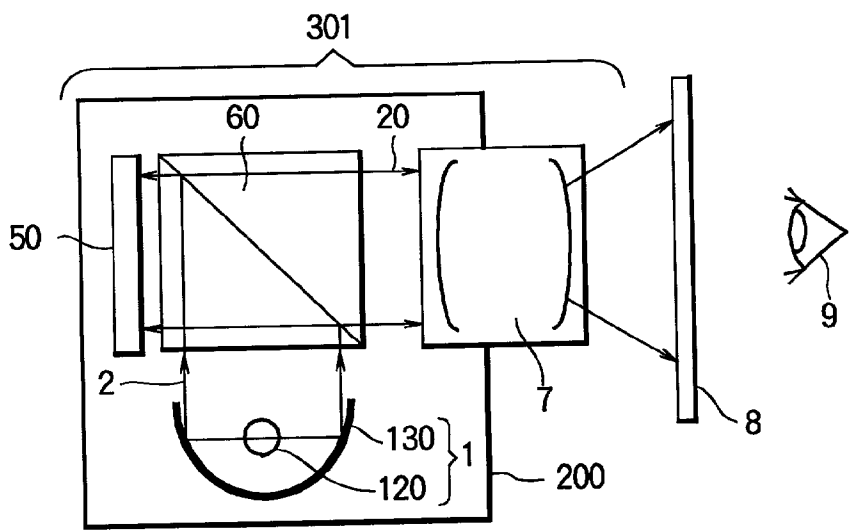
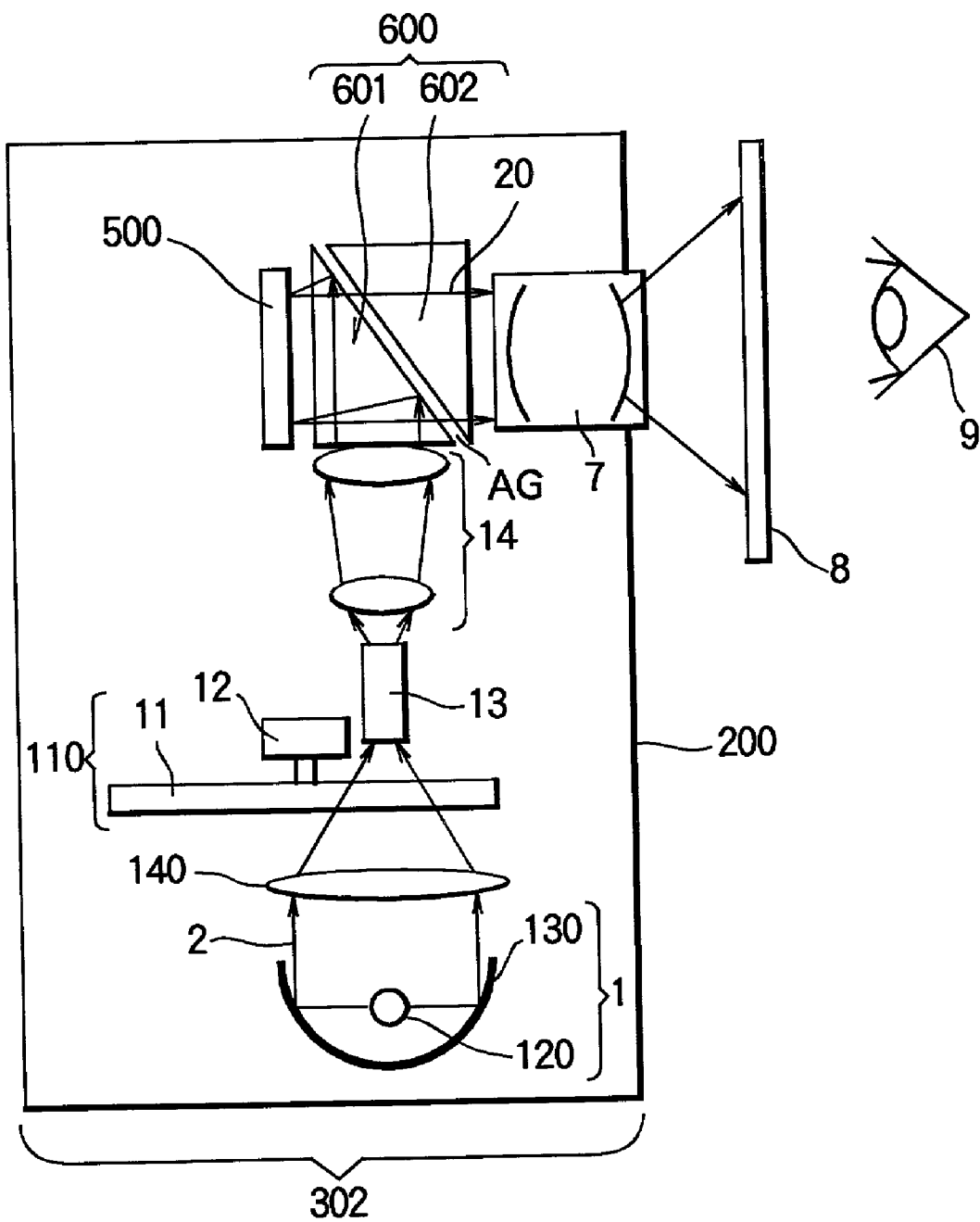


FIG.15



RETROFOCUS LENS SYSTEM AND PROJECTION DISPLAY APPARATUS

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a retrofocus lens system suitable for a projection optical system which requires a long back focal distance in comparison with a focal distance and a projection display apparatus incorporating the retrofocus lens system.

[0002] FIG. 13 is a schematic diagram showing a configuration of an optical system of a conventional projection display apparatus (a liquid crystal projector). As shown in FIG. 13, the projection display apparatus 300 comprises a light source 1 which includes a lamp 120 and a reflecting mirror 130 and emits approximately parallel illuminating light 2, dichroic mirrors 3B and 3G, and light reflection mirrors 4a, 4b, and 4c. The projection display apparatus 300 further comprises a transmissive liquid crystal panel 5R for displaying a red image, a transmissive liquid crystal panel 5G for displaying a green image, a transmissive liquid crystal panel 5B for displaying a blue image, a dichroic prism 6 which outputs combined light 20 of red (R), green (G), and blue (B) by reflecting the red light 2R and the blue light 2B and passing the green light 2G, and a projection lens 7 for projecting incident light 20 onto a screen 8 with a magnification. In the figure, a reference numeral 200 denotes a housing.

[0003] The dichroic mirror 3B receives the light 2 emitted from the light source 1, reflects the blue light 2B, and allows the red light 2R and the green light 2G to pass. The blue light 2B reflected from the dichroic mirror 3B is reflected by the mirror 4b, passes the liquid crystal panel 5B, and then enters the dichroic prism 6. The dichroic mirror 3G reflects the green light 2G that has passed the dichroic mirror 3B and allows the red light 2R to pass. The green light 2G reflected from the dichroic mirror 3G passes the liquid crystal panel 5G and enters the dichroic prism 6. The red light 2R that has passed the dichroic mirror 3B is reflected by the mirrors 4a and 4c, passes the liquid crystal panel 5R, and enters the dichroic prism 6. The dichroic prism 6 sends out the combined light 20 of the incident red light 2R, green light 2G, and blue light 2B toward the projection lens 7. The projection lens 7 projects the combined light 20 onto the screen 8 with a magnification.

[0004] In the above-mentioned projection display apparatus, the thick dichroic prism 6 must be disposed between the projection lens 7 and the liquid crystal panels 5R, 5G, and 5B functioning as light valve components, which are picture sources, so that the projection lens 7 requires a long back focal distance.

[0005] If the above-mentioned projection display apparatus is used in a rear projector (a rear projection display apparatus), it is preferable that the distance between the projection lens 7 and the screen 8 should be short (that is, the projection lens 7 should have a wide angle of view) in order to reduce the outer dimensions of the apparatus.

[0006] Because the spectral transmittance, polarization generation characteristics, and reflectivity of the dichroic prism 6 greatly vary with the incident angle of the light, the design is provided so that the illuminating light striking the liquid crystal panels 5R, 5G, and 5B become approximately

parallel light (that is, telecentric illumination is provided). In this case, the light striking the projection lens 7 is approximately parallel light. If this type of optical system uses a conventional wide-angle projection lens having a short back focal distance, the light that passes the perimeter of the liquid crystal panels 5R, 5G, and 5B and then strike the projection lens 7 is extremely reduced, making the projection image dark in the perimeter of the screen 8. Accordingly, it is desired that the apparatus should be configured to make the principal ray of the light coming from the individual points of the picture source approximately parallel to the optical axis of the projection lens 7 (telecentric configuration). This configuration requires such a projection lens that the distance between the projection lens 7 and the position of the pupil is sufficiently greater than the focal distance.

[0007] As has been described above, a projection lens used in a projection display apparatus is required to satisfy the basic specifications associated with (1) a wide angle of view, (2) a long back focal distance, and (3) telecentric characteristics on the image display component side. The projection lens of the projection display apparatus is also required to have basic aberration characteristics (4) to (7) described below.

[0008] (4) Low chromatic aberration: The chromatic aberration of magnification must be representatively kept around the pixel pitch or preferably suppressed below a half of the pixel pitch, so that the projection magnification difference in primary-color pixels of the projection image is sufficiently reduced. When an ultra-high pressure mercury lamp is used for the illumination light source, the light output may contain a strong spectrum at a wavelength shorter than the inherent spectral wavelength of the blue light, which is on the order of 450 nm to 470 nm, or in the proximity of the mercury g-line (436 nm). In such a situation, it is necessary that the chromatic aberration of magnification for such emission line spectral component should be corrected in consideration of the chromatic aberration of magnification for red spectral component so as to suppress violet flare components. It is also necessary to control the longitudinal chromatic aberration so that the focal points for primary colors are placed at the same point.

[0009] (5) Low distortion: Since a wide-angle lens for the rear projector projects a rectangular projection image inside the frame of the projection screen, the distortion around the perimeter of the screen often stands out. Accordingly, the deviation of a pixel from its ideal point resulting from the distortion must be representatively restricted to the order of the pixel pitch. In rear projectors for use in CAD, multi-vision projectors that increase the number of pixels by arranging unit screens formed by rear projection and the like, it is required to control the distortion so that the absolute deviation from an ideal point is restricted to or below a half of the pixel pitch.

[0010] (6) Wide operating temperature range: The projection lens should be designed to maintain desired optical characteristics over a wide temperature range, so that the lens can be used in a wide temperature environment in which the projector is placed and can endure the heat generated by the illumination lamp. To provide the wide operating temperature range, it is preferable that the projection lens be configured only by glass lenses. In comparison with plastic

materials lens, glass lenses generally exhibit small variations in expansion and refractive index with temperature variations, which favors the maintenance of stable optical characteristics. However, if an aspheric surface is used to correct aberrations, glass lenses have a cost disadvantage. The lens system of the present invention corrects aberrations with plastic aspheric lenses and implements a projection lens with small defocusing due to temperature variations.

[0011] (7) High resolution: To project an original image produced by a light valve component having many pixels on the order of one million pixels at a high density, which has been increasingly developed in recent years, with a magnification, a projection lens having a high resolution matching the fine pixel structure of the light valve is needed. To ensure the high resolution of the projection lens, the chromatic aberration and distortion described above, and other axial aberrations and off-axis aberrations must be sufficiently corrected.

SUMMARY OF THE INVENTION

[0012] It is an object of the present invention to provide a retrofocus lens system which has a long back focal distance in comparison with a focal distance and telecentric characteristics on the picture source side and allows wide-angle projection, and a projection display apparatus utilizing the retrofocus lens system.

[0013] According to the present invention, a retrofocus lens system comprises in order from a large conjugate side toward a small conjugate side: a first lens group having a negative refracting power; a second lens group having a positive refracting power; and a third lens group having a positive refracting power. The first lens group includes in order from the large conjugate side toward the small conjugate side, a first lens having an aspheric surface, a meniscus second lens having a negative refracting power and having a convex surface on the large conjugate side, a meniscus third lens having a negative refracting power and having a convex surface on the large conjugate side, and a meniscus fourth lens having a negative refracting power and having a convex surface on the small conjugate side. The second lens group includes in order from the large conjugate side toward the small conjugate side, a fifth lens having a positive refracting power, and a sixth lens joined to the fifth lens. The third lens group includes in order from the large conjugate side toward the small conjugate side, a meniscus seventh lens having a positive refracting power and having a convex surface on the small conjugate side, a biconcave eighth lens, a ninth lens joined to the eighth lens and having a positive refracting power, a biconvex tenth lens, a biconvex eleventh lens, and a twelfth lens having an aspheric surface. The retrofocus lens system satisfies the following expressions:

$$0.8 < f_2/f_3 < 1.5 \quad (1)$$

$$1.6 < |f_1|/f < 2.4 \quad (2)$$

$$|r_4|/l > 30 \quad (3)$$

$$f_5/f > 6 \quad (4)$$

[0014] where f is a focal distance of the whole lens system, f_2 is a focal distance of the second lens group, f_3 is a focal distance of the third lens group, $|f_1|$ is an absolute value of a focal distance of the first lens group, $|r_4|$ is an absolute value of an axial focal distance of the first lens, and f_5 is an axial focal distance of the twelfth lens.

[0015] The retrofocus lens system satisfying the expressions (1) to (4) can provide an advantage that off-axis aberrations can be appropriately corrected while the long back focal distance and the telecentric performance are maintained. In addition, by restricting the axial power of the first lens and the twelfth lens, both of which comprise a plastic material, to a small value, the retrofocus lens system can provide another advantage that it can be used over a wide temperature range while defocusing and degradation in the resolution due to the temperature change can be eliminated.

[0016] The retrofocus lens system may further comprise a stop disposed between the second lens group and the third lens group; wherein the retrofocus lens system satisfies the following expression:

$$|EXP|/f > 50 \quad (5)$$

[0017] where $|EXP|$ is an absolute value of a distance from an image surface on the small conjugate side to a pupil surface on the small conjugate side in the whole lens system.

[0018] The retrofocus lens system satisfying the expression (5) can provide an arbitrary choice of the brightness and the focussing performance in accordance with an illumination system up to the projection lens. Further, the retrofocus lens system can project light modulated by the light valve that is subject to the telecentric illumination with a favorable peripheral relative illumination, by increasing the pupil distance on the light valve side.

[0019] The retrofocus lens system may satisfy the following expression:

$$BFL/f > 2 \quad (6)$$

[0020] where BFL is a back focal distance of the whole lens system.

[0021] The retrofocus lens system satisfying the expression (6) can provide a long back focal distance so that a required air spacing can be secured between the light valve and the retrofocus lens system in order to mount a thick prism element, a cover glass which protects the front surface of the light valve and a projection system in an appropriate manner.

[0022] The retrofocus lens system may satisfy the following expressions:

$$15 < v_4 < 30 \quad (7)$$

$$15 < v_5 < 30 \quad (8)$$

$$40 < v_7 < 100 \quad (9)$$

$$15 < v_8 < 32 \quad (10)$$

$$20 < v_9 < 50 \quad (11)$$

$$70 < v_{10} < 100 \quad (12)$$

[0023] where v_4 is an Abbe number at d-line of a glass material forming the fourth lens, v_5 is an Abbe number at d-line of a glass material forming the fifth lens, v_7 is an Abbe number at d-line of a glass material forming the seventh lens, v_8 is an Abbe number at d-line of a glass material forming the eighth lens, v_9 is an Abbe number at d-line of a glass material forming the ninth lens, and v_{10} is an Abbe number at d-line of a glass material forming the tenth lens.

[0024] The retrofocus lens system satisfying the expressions (7) to (12) can provide appropriate chromatic aberrations (longitudinal chromatic aberration and chromatic aber-

ration of magnification) to suppress a color shift of primary color images which is projected with a magnification and to achieve a high resolution.

[0025] The retrofocus lens system may satisfy the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d) \quad (13)$$

$$0.008 < dPgF4 < 0.03 \quad (13)$$

$$0.01 < dPgF5 < 0.025 \quad (14)$$

$$0.01 < dPgF8 < 0.02 \quad (15)$$

$$0.03 < dPgF10 < 0.055 \quad (16)$$

[0026] where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 4, 5, 8 or 10, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

[0027] The retrofocus lens system satisfying the expressions (13) to (16) can provide a satisfactory projection image which is relatively free from flare components in a projection display apparatus including a light source of a short wavelength emission line spectrum.

[0028] The retrofocus lens system may satisfy the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d) \quad (17)$$

$$-0.01 < dPgF7 < 0.045 \quad (17)$$

$$-0.015 < dPgF9 < 0.02 \quad (18)$$

[0029] where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 7 or 9, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

[0030] The retrofocus lens system satisfying the expressions (17) and (18) can provide a satisfactory projection image which is relatively free from flare components in a projection display apparatus including a light source of a short wavelength spectrum.

[0031] According to another aspect of the present invention, a projection display apparatus comprises: a light source for emitting light; a light valve for two-dimensionally modulating the light from the light source; and the above-mentioned retrofocus lens system for projecting with a magnification the light modulated by the light valve.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

[0033] FIG. 1 is a schematic diagram showing a configuration of a retrofocus lens system according to Embodiments 1 to 5 of the present invention;

[0034] FIGS. 2A and 2B respectively show an astigmatism and a distortion of the retrofocus lens system according to Embodiment 1;

[0035] FIGS. 3A and 3B respectively show an axial lateral aberration of the retrofocus lens system according to Embodiment 1;

[0036] FIGS. 3C and 3D respectively show a lateral aberration at a maximum image height of the retrofocus lens system according to Embodiment 1;

[0037] FIGS. 4A and 4B respectively show an astigmatism and a distortion of the retrofocus lens system according to Embodiment 2;

[0038] FIGS. 5A and 5B respectively show an axial lateral aberration of the retrofocus lens system according to Embodiment 2;

[0039] FIGS. 5C and 5D respectively show a lateral aberration at a maximum image height of the retrofocus lens system according to Embodiment 2;

[0040] FIGS. 6A and 6B respectively show an astigmatism and a distortion of the retrofocus lens system according to Embodiment 3;

[0041] FIGS. 7A and 7B respectively show an axial lateral aberration of the retrofocus lens system according to Embodiment 3;

[0042] FIGS. 7C and 7D respectively show a lateral aberration at a maximum image height of the retrofocus lens system according to Embodiment 3;

[0043] FIGS. 8A and 8B respectively show an astigmatism and a distortion of the retrofocus lens system according to Embodiment 4;

[0044] FIGS. 9A and 9B respectively show an axial lateral aberration of the retrofocus lens system according to Embodiment 4;

[0045] FIGS. 9C and 9D respectively show a lateral aberration at a maximum image height of the retrofocus lens system according to Embodiment 4;

[0046] FIGS. 10A and 10B respectively show an astigmatism and a distortion of the retrofocus lens system according to Embodiment 5;

[0047] FIGS. 11A and 11B respectively show an axial lateral aberration of the retrofocus lens system according to Embodiment 5;

[0048] FIGS. 11C and 11D respectively show a lateral aberration at a maximum image height of the retrofocus lens system according to Embodiment 5;

[0049] FIGS. 12A to 12D are diagrams respectively showing Abbe lines of different manufacturers;

[0050] FIG. 13 is a schematic diagram showing a configuration of an optical system of a conventional projection

display apparatus or a projection display apparatus according to Embodiment 6 of the present invention;

[0051] FIG. 14 is a schematic diagram showing a configuration of an optical system of a projection display apparatus according to Embodiment 7 of the present invention; and

[0052] FIG. 15 is a schematic diagram showing a configuration of an optical system of a projection display apparatus according to Embodiment 8 of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0053] Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred Embodiments of the invention, are given by way of illustration only, since various changes and modifications will become apparent to those skilled in the art from the detailed description.

[0054] FIG. 1 is a schematic diagram showing a configuration of a retrofocus lens system according to Embodiments 1 to 5 of the present invention. As shown in FIG. 1, the retrofocus lens system 10 according to Embodiments 1 to 5 comprises a first lens group G_1 having a negative refracting power, a second lens group G_2 having a positive refracting power, a stop STO (a stop surface being indicated by S_{12}), and a third lens group G_3 having a positive refracting power, which are sequentially disposed in order from a large conjugate side toward a small conjugate side. The term "large conjugate side" means a projection light emitting side (that is, the screen side in a projection display apparatus using a retrofocus lens system as its projection lens or the left side as viewed in FIG. 1). The term "small conjugate side" means a projection light incident side (that is, the light valve side in a projection display apparatus using a retrofocus lens system as its projection lens or the right side as viewed in FIG. 1).

[0055] The first lens group G_1 includes, in order from the large conjugate side toward the small conjugate side, a first lens L_1 having a weak negative refracting power in the vicinity of the center thereof, a meniscus second lens L_2 having a negative refracting power and having a convex surface on the large conjugate side, a meniscus third lens L_3 having a negative refracting power and having a convex surface on the large conjugate side, and a meniscus fourth lens L_4 having a negative refracting power and having a convex surface on the small conjugate side.

[0056] The second lens group G_2 includes in order from the large conjugate side toward the small conjugate side, a fifth lens L_5 having a positive refracting power and a sixth lens L_6 joined to the fifth lens L_5 .

[0057] The third lens group G_3 includes in order from the large conjugate side toward the small conjugate side, a meniscus seventh lens L_7 having a positive refracting power and having a convex surface on the small conjugate side, a biconcave eighth lens L_8 , a ninth lens L_9 joined to the eighth lens L_8 and having a positive refracting power, a biconvex tenth lens L_{10} , a biconvex eleventh lens L_{11} , and a twelfth lens L_{12} having a weak positive refracting power in the vicinity of the center thereof.

[0058] The retrofocus lens system 10 according to Embodiments 1 to 5 satisfies the following expressions (1) to (4):

$$0.8 < f_2/f_3 < 1.5 \quad (1)$$

$$1.6 < |f_1|/f < 2.4 \quad (2)$$

$$|f_4|/f > 30 \quad (3)$$

$$f_5/f > 6 \quad (4)$$

[0059] where r is a focal distance of the whole lens system, f_2 is a focal distance of the second lens group G_2 , f_3 is a focal distance of the third lens group G_3 , $|f_1|$ is an absolute value of a focal distance of the first lens group G_1 , $|f_4|$ is an absolute value of a focal distance of the first lens L_1 , and f_5 is an axial focal distance of the twelfth lens L_{12} .

[0060] The retrofocus lens system 10 described above can keep a wide angle of view and can ensure such a long back focal distance that a prism PSM can be disposed between the projection lens and the light valve although the focal distance is short. The principal ray of light from individual image heights, directed from the light valve onto the projection lens, can be kept approximately parallel to the optical axis, a high peripheral relative illumination can be ensured, and an adverse effect on projection images caused by variations in optical properties due to incident angle characteristics for a prism can be eliminated. Both surfaces of the first lens L_1 and the twelfth lens L_{12} are aspheric in order to precisely correct spherical aberration, distortion, and other high-order aberrations with a small number of lenses.

[0061] The expression (1) represents a condition for ensuring a long back focal distance and maintaining telecentric characteristics. If the upper limit is exceeded, the positive refracting power of the third lens group G_3 is too large, making it difficult to provide a telecentric configuration for maintaining off-axis principal rays almost parallel and to correct the distortion. If the lower limit is exceeded, the positive refracting power of the third lens group G_3 is too small, weakening the retrofocus performance and making it difficult to keep a long back focal distance.

[0062] Further, the expression (2) represents a condition for keeping a long back focal distance, excellently correcting off-axis aberrations by restricting the power of the first lens group G_1 , and preventing the lens from becoming larger than necessary. If the upper limit is exceeded, the negative refracting power of the first lens group G_1 becomes too small, and the retrofocus performance weakens, making it difficult to keep a long back focal distance and making the outside dimensions of the first lens group G_1 larger than necessary. If the lower limit is exceeded, the negative refracting power of the first lens group G_1 becomes too large, making it difficult to correct off-axis aberrations.

[0063] Furthermore, the expressions (3) and (4) respectively represents a condition for restricting the axial power of the first lens L_1 and the twelfth lens L_{12} , both of which are made of plastic materials, to small values to extend the operating temperature range of the retrofocus lens system 10 while preventing defocusing due to changes in temperature. If the powers of the first lens L_1 and the twelfth lens L_{12} increase in such a way that $|f_4|/f$ decreases below 30 and f_5/f decreases below 6, inconveniences occur that a change in the resolution and the defocusing, which results from a change in the environmental temperature at which the retrofocus lens system 10 is used, increases too much.

[0064] It is preferable that the retrofocus lens system 10 according to Embodiments 1 to 5 has a stop between the second lens group G_2 and the third lens group G_3 and is configured to satisfy the following expression (5):

$$|EXP|/f > 50 \quad (5)$$

[0065] where $|EXP|$ is an absolute value of a distance from an image surface on the small conjugate side to a pupil surface on the small conjugate side in the whole lens system.

[0066] In the retrofocus lens system 10 which satisfies the expression (5), the principal ray of light from individual image heights, directed from the light valve onto the projection lens, can be kept approximately parallel to the optical axis, a high peripheral relative illumination can be ensured, and an adverse effect on projection images caused by variations in optical properties due to the incident angle characteristics for a prism can be eliminated. If the distance between the pupil surface on the small conjugate side and the image field on the small conjugate side is reduced so that $|EXP|/f$ becomes beyond the lower limit of the expression (5), an inconvenience occurs that the principal ray on the light valve side has too great an inclination.

[0067] It is preferable that the retrofocus lens system 10 according to Embodiments 1 to 5 be configured to satisfy the following expression (6):

$$BFL/f > 2 \quad (6)$$

[0068] where BFL is a back focal distance of the whole lens system.

[0069] The retrofocus lens system 10 satisfying the expression (6) can ensure such a long back focal distance that a prism PSM, a cover glass CG for protecting the light valve and an appropriate air spacing can be disposed between the projection lens and the light valve despite the wide angle and the short focal distance. If the back focal distance is reduced below the lower limit of the expression (6), an inconvenience occurs in disposing the thick prism PSM, the cover glass CG and the like.

[0070] It is preferable that the retrofocus lens system 10 according to Embodiments 1 to 5 be configured to satisfy the following expressions (7), (8), (9), (10), (11), and (12):

$$15 < v_4 < 30 \quad (7)$$

$$15 < v_5 < 30 \quad (8)$$

$$40 < v_7 < 100 \quad (9)$$

$$15 < v_8 < 32 \quad (10)$$

$$20 < v_9 < 50 \quad (11)$$

$$70 < v_{10} < 100 \quad (12)$$

[0071] where v_4 is an Abbe number at d-line of a glass material forming the fourth lens L_4 , v_5 is an Abbe number at d-line of a glass material forming the fifth lens L_5 , v_7 is an Abbe number at d-line of a glass material forming the seventh lens L_7 , v_8 is an Abbe number at d-line of a material forming the eighth lens L_8 , v_9 is an Abbe number at d-line of a glass material forming the ninth lens L_9 , and v_{10} is an Abbe number at d-line of a glass material forming the tenth lens L_{10} .

[0072] In the retrofocus lens system 10 which satisfies the expressions (7) to (12) where the Abbe numbers of the fourth

lens L_4 , the fifth lens L_5 , the seventh lens L_7 , the eighth lens L_8 , the ninth lens L_9 and the tenth lens L_{10} are restricted within the respective ranges given above, the axial chromatic aberration and the chromatic aberration of magnification can be controlled in an appropriate manner. When the Abbe numbers of the glass materials which form the respective lenses L_4 , L_5 , L_7 , L_8 , L_9 and L_{10} exceed either the upper or the lower limits of the respective expressions, the axial chromatic aberration, the absolute value of the chromatic aberration of magnification and a correction balance of chromatic aberrations between R-G-B primary colors are collapsed. This results in an insufficient resolution of a particular primary color or colors due to an increased axial chromatic aberration and a deviation of picture elements of a particular primary color or colors due to an increase in the chromatic aberration of magnification.

[0073] It is preferable that the retrofocus lens system 10 according to Embodiments 1 to 5 be configured to satisfy the following expressions (13), (14), (15), and (16):

$$dPgFm = PgFm(v_d) - PgFn(v_d) \\ 0.008 < dPgF4 < 0.03 \quad (13)$$

$$0.01 < dPgF5 < 0.025 \quad (14)$$

$$0.01 < dPgF8 < 0.02 \quad (15)$$

$$0.03 < dPgF10 < 0.055 \quad (16)$$

[0074] where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m-th lens, m being equal to 4, 5, 8 or 10, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFm(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m-th lens having the Abbe number v_d at d-line.

[0075] In the above-mentioned expressions, $PgF = (ng - nF)/(nF - nC)$, where ng , nF and nC represent refractive indices at g-line (wavelength of 435.8 nm), F-line (wavelength of 486.1 nm) and C-line (wavelength of 656.3 nm), respectively. The Abbe line used herein represents a straight line joining two points which represent two different varieties of normal partial dispersion glasses in the coordinate system having an ordinate indicating the partial dispersion ratio PgF and an abscissa indicating the Abbe number v_d . The Abbe lines used in respective glass manufacturers are slightly different to each other, but generally similar. FIGS. 12A to 12D show the Abbe lines used in respective glass manufacturers including SCHOTT GLASS Corporation, OHARA Inc., HOYA Corporation, and SUMITA OPTICAL GLASS Corporation, and these Abbe lines are indicated by the linear functions given below.

$$\text{SCHOTT: } PgF = -0.001689 \cdot v_d + 0.644224$$

$$\text{OHARA: } PgF = -0.001618 \cdot v_d + 0.641462$$

$$\text{HOYA: } PgF = -0.001802 \cdot v_d + 0.648327$$

$$\text{SUMITA: } PgF = -0.001488 \cdot v_d + 0.637000$$

[0076] In this manner, the Abbe lines have generally similar values, and accordingly, it is only required that $dPgFm$ satisfies the expressions (13) to (16) for either one of the Abbe lines shown in FIGS. 12A to 12D.

[0077] The restriction of the anomalous dispersion of glass materials which form the fourth lens L₄, the fifth lens L₅, the eighth lens L₈ and the tenth lens L₁₀ within respective given ranges as defined by the expressions (13) to (16) enables an effective reduction of flare components of shorter wavelengths, in particular. For example, when the ultra-high pressure mercury lamp is used as a light source, the illumination light contains an emission line spectrum located near the mercury g-line, but the use of the retrofocus lens system 10 according to Embodiments 1 to 5 allows flare components in the projection image which are attributable to the emission line spectrum to be effectively suppressed. Consequently, when the projection image contains thin letters and lines, problems that the violet flare components degrade the resolution of the displayed picture and that blurred picture is perceived can be eliminated. Conversely, if the anomalous dispersion of the individual lenses is chosen to be above the upper limit or below the lower limit of the expressions (13) to (16), an increase of the violet flare components impairs the high picture quality.

[0078] It is preferable that the retrofocus lens system 10 according Embodiments 1 to 5 be configured to satisfy the following expressions (17) and (18):

-0.01< dPgF7<0.045 (17)

-0.015< dPgF9<0.02 (18)

[0079] When the anomalous dispersion of the seventh lens L₇ and the ninth lens L₉ are restricted to the given ranges in accordance with the expressions (17) and (18) in addition to the correction of aberrations according to the expressions (7) to (12) and the suppression of flares according to the expressions (13) to (16), it is possible to suppress the flare components in the projection image in a more controlled manner. As a consequence, if the projection image contains thin letters or lines, the problems that the resolution of the displayed picture is degraded by the violet flare components and that a blurred picture is perceived can be eliminated. When the anomalous dispersion of the individual lenses is allowed to exceed either the upper or the lower limit of the expressions (17) and (18), an increase of the violet flare components impairs the high picture quality.

Embodiment 1

[0080] The components constituting the retrofocus lens system 10 according to Embodiment 1 are specified by numerical examples given in Table 1. In Table 1, characters S₁ to S₂₃ respectively denote the surfaces of the lenses L₁ to L₁₂. Characters S₂₄ and S₂₅ respectively denote surfaces of the prism PSM, and characters S₂₆ and S₂₇ respectively denote surfaces of the cover glass CG. Further, a character OBJ denotes a screen, a character "R" denotes a radius of curvature of each surface, a character "T" denotes a spacing between the adjacent surfaces, a character Nddenotes a refractive index of a glass material at d-line (helium d-line; a wavelength is 587.56 nm), and a character v_d denotes an Abbe number at d-line. Furthermore, a character TYPE denotes a special surface type, a character ASP denotes an aspheric surface, and a character STO denotes a stop surface.

TABLE 1

S	R	T	Nd	vd	TYPE
OBJ	INFINITY	858.55			
1	-523.6556	4	1.491000	57.562	ASP
2	514.0728	0.5304008			ASP
3	33.83429	5.479604	1.816000	46.600	
4	18.11977	7.402664			
5	60.944	1.930828	1.516800	64.200	
6	29.00685	5.523577			
7	-62.45322	15.25701	1.915357	21.200	
8	-694.9453	30.34551			
9	26.82546	3.041943	1.846659	23.800	
10	-365.2097	1.68066	1.806100	40.730	
11	257.9009	0.2485364			
12	INFINITY	10.12673			STO
13	-42.11169	6.136205	1.668921	45.000	
14	-23.92971	1.092819			
15	-18.54591	1.508804	1.846660	23.830	
16	18.54591	4.072995	1.797120	35.080	
17	234.3953	2.943065			
18	35.36946	6.982814	1.434250	95.000	
19	-37.2984	0.8544881			
20	37.99807	6.120832	1.516800	64.200	
21	-123.2559	0.4768649			
22	83.18422	3.34	1.491000	57.562	ASP
23	-137.8496	5.03			ASP
24	INFINITY	26	1.516800	64.200	
25	INFINITY	3			
26	INFINITY	2.74	1.471693	65.850	
27	INFINITY				

[0081] The first lens L₁ is formed of a plastic material (PMMA polymethylmethacrylate) and has aspheric lens surfaces S₁ and S₂. The twelfth lens L₁₂ is also formed of the same PMMA and has aspheric lens surfaces S₂₂ and S₂₃. The configurations of the lens surfaces S₁, and S₂ and the lens surfaces S₂₂ and S₂₃ are defined by the following expression:

Z = (19)

$$\frac{Y^2/R}{1 + \{1 - (1 + K)Y^2/R^2\}^2} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12} + IY^{14}$$

[0082] where a character "Z" is a distance along the optical axis from an apex on the lens surface, a character "Y" is a distance from the optical axis in a direction perpendicular to the optical axis, a character "K" is a conic constant, a character "R" is a radius of curvature, a character "D" is an aspheric coefficient of fourth order, a character "E" is an aspheric coefficient of sixth order, a character "F" is an aspheric coefficient of eighth order, a character "G" is an aspheric coefficient of tenth order, a character "H" is an aspheric coefficient of twelfth order, and a character "I" is an aspheric coefficient of fourteenth order. The aspheric coefficients "K", "D", "E", "F", "G", "H" and "I" have values indicated in Table 2.

TABLE 2

<ASPHERIC COEFFICIENT>							
S	K	D	E	F	G	H	I
1	32.79982	3.5020967e-5	-8.659474e-8	1.2542213e-10	-6.6214841e-14	-1.0583201e-17	2.1834647e-20
2	-3.143952	3.8128909e-5	-1.3036009e-7	2.3490044e-10	-1.595244e-13	-2.3343029e-18	3.3386459e-20
22	-96.65446	1.8810461e-6	-1.372124e-7	-1.4116834e-10	2.6262719e-12	-9.9308871e-15	1.4447615e-17
23	-2.165457	3.4512883e-6	-3.2416442e-8	-4.9537585e-10	3.3877491e-12	-9.6148395e-15	1.1066089e-17

[0083] Since the first lens L₁ and the twelfth lens L₁₂ are formed of plastic material as aspheric lenses, the spherical aberration, the distortion and a variety of off-axis aberrations can be favorably corrected. Since the axial focal distance of each plastic lens is chosen to be large with respect to the focal distance of the whole lens system, as indicated by the expressions (3) and (4), it is possible to reduce defocusing accompanying any change in temperature, and variations in resolution of the whole lens system and other imaging optical properties can be suppressed low even if the environmental temperature changes.

[0084] The plastic material chosen to form the first lens L₁ and the twelfth lens L₁₂ is not limited to PMMA, but may be a certain material such as ZEONEX-280S (trade name) available from NIPPON ZEON Corporation or OZ-1000 (trade name) available from HITACHI CHEMICAL Co., Ltd., which are effective in raising the upper limit of the operating temperature range of the whole lens system.

[0085] The stop STO indicated in FIG. 1 and Table 1 is associated with the inclination of the principal ray on the light valve side and adjusts a balance between the resolution and brightness of the projection image. For instance, if the light 20 modulated by the light valve of the apparatus shown in FIG. 13 is substantially parallel to the optical axis of the lens, a sufficient brightness can be obtained even when the aperture diameter of the stop STO is small, thanks to the telecentric characteristics of the projection lens 7. However, the illuminating light 2 actually illuminates the light valve surface with an angle distribution. If the aperture diameter of the stop STO is too small, the projection image cannot be produced with a sufficient brightness. Conversely, if the aperture diameter of the stop STO is increased to ensure sufficient brightness, the resolution of the rays striking the light valve surface at an angle may be impaired. Therefore, it is preferable that the stop STO is configured so that the aperture diameter can be changed as desired in accordance with the combination of the illumination system and the lenses.

[0086] f₂/f₃, |f₁|/f, |f₄|/f, f₅/f, |EXP|/f and BFL/f of the retrofocus lens system 10 according to Embodiment 1 have values given in Table 11, and v₄, v₅, v₇, v₈, v₉, v₁₀, dPgF₄, dPgF₅, dPgF₇, dPgF₈, dPgF₉ and dPgF₁₀ have values given in Table 12, and the system 10 therefore satisfies the above-mentioned expressions (1) to (18). The fourth lens L₄, the fifth lens L₅, the seventh lens L₇, the eighth lens L₈, the ninth lens L₉ and the tenth lens L₁₀ have dPgF values which are given in Table 13 together with the manufacturer's names as well as the product number of glass materials (GLASS MATERIAL column in Table 13).

[0087] Further, the retrofocus lens system 10 according to Embodiment 1 has a long back focal distance so that the prism PSM and the color glass CG located in front of the light valve can be disposed between the retrofocus lens system 10 and the light valve surface while providing a suitable air spacing in the light path from the retrofocus lens system 10 to the image forming surface IMG of the light valve. The design is provided to make the principal ray at each angle of view approximately parallel to the lens optical axis on the light valve side, so that a sufficient peripheral illumination can be obtained and the transmission and reflection in the prism become even in the screen. Therefore, the factors causing inconsistencies in color and brightness of the projection image can be reduced.

[0088] FIGS. 2A and 2B show the characteristics of the retrofocus lens system of Embodiment 1, FIG. 2A shows an astigmatism (AS) on the small conjugate side, and FIG. 2B shows a distortion. FIGS. 2A and 2B show the plotted astigmatism and distortion of light having a wavelength of 546.1 nm. In FIG. 2A, TA is a tangential ray in a plane containing the principal off-axis ray and optical axis, and SA is a sagittal ray orthogonal to the tangential surface containing the principal off-axis ray.

[0089] FIGS. 3A to 3D show the characteristics of the retrofocus lens system of Embodiment 1. FIGS. 3A and 3B show an axial (that is, at an image height of 0.00 mm) lateral aberration. FIGS. 3C and 3D show a lateral aberration at an image height of 10.24 mm (an angle of view of 40.8° on the screen side). In the figures, PY denotes a direction of the Y-axis perpendicular to the optical axis, and EY denotes a lateral aberration in the direction of the Y-axis. PX denotes a direction of the X-axis perpendicular to the optical axis and Y-axis, and EX denotes the lateral aberration in the direction of the X-axis. The lateral aberrations of light having a wavelength WL₁ (=470 nm), a wavelength WL₂ (=546.1 nm), and a wavelength WL₃ (=610 nm) are plotted.

[0090] Since the projection display apparatus using a light valve having a matrix of pixels can correct the color convergence across the whole screen and the distortion of the projection screen by means of the lens only, the magnitude of chromatic aberration, distortion and the like of the lens directly and greatly affects the quality of the projection image. The retrofocus lens system 10 of Embodiment 1 suppresses the chromatic aberration of the whole lens system, especially chromatic aberration of magnification, by limiting the upper or lower limit of the respective Abbe numbers of the fourth, fifth, seventh, eighth, ninth, and tenth lenses L₄, L₅, L₇, L₈, L₉ and L₁₀ in the expressions (7) to (12) indicated above, so that the color convergence of the primary-color images of the projection image is kept under 7 μm on the light valve surface.

[0091] Since the anomalous dispersion of the lenses L₄, L₅, L₈ and L₁₀ are restricted in accordance with the expressions (13) to (16), it is possible to suppress the flare components in the projection image, which results from an emission line spectrum located close to the mercury g-line which is contained in the illuminating light emitted from the ultra-high pressure mercury lamp. As a consequence, if the projection image contains thin letters or lines, the problems that the resolution of the displayed picture is degraded by the violet flare components and that a blurred picture is perceived can be eliminated. The flare suppressing effect will be even more effective when the upper and the lower limit of the anomalous dispersion of the lenses L₇ and L₉ are restricted in accordance with the expressions (17) and (18).

TABLE 3-continued

S	R	T	Nd	vd	TYPE
23	-137.8496	5.03			ASP
24	INFINITY	26	1.516800	64.200	
25	INFINITY	3			
26	INFINITY	2.74	1.471693	65.850	
27	INFINITY				

[0094] The shapes of the lens surfaces S₁ and S₂ and the lens surfaces S₂₂ and S₂₃ are defined by the expression (19) indicated above. The aspheric coefficients “K”, “D”, “E”, “F”, “G”, “H” and “I” have values indicated in Table 4 below.

TABLE 4

<ASPHERIC COEFFICIENT>							
S	K	D	E	F	G	H	I
1	32.79982	3.5020967e-5	-8.659474e-8	1.2542213e-10	-6.6214841e-14	-1.0583201e-17	2.1834647e-20
2	-3.143952	3.8128909e-5	-1.3036009e-7	2.3490044e-10	-1.595244e-13	-2.3343029e-18	3.3386459e-20
22	-96.65446	1.8810461e-6	-1.372124e-7	-1.4116834e-10	2.6262719e-12	-9.9308871e-15	1.4447615e-17
23	-2.165457	3.4512883e-6	-3.2416442e-8	-4.9537585e-10	3.3877491e-12	-9.6148395e-15	1.1066089e-17

[0092] As has been described above, the retrofocus lens system 10 of Embodiment 1 sufficiently corrects both chromatic aberration (the longitudinal chromatic aberration, the chromatic aberration of magnification and the flare components) and distortion and has adequate properties for use in a rear projector. Moreover, the other axial aberrations and the off-axis aberrations are also appropriately corrected so that a light valve having many pixels on the order of million pixels can be projected.

Embodiment 2

[0093] The arrangement of the retrofocus lens system 10 according to embodiment 2 is specified by numerical examples given in Table 3 below.

TABLE 3

S	R	T	Nd	vd	TYPE
OBJ	INFINITY	858.55			
1	-523.6556	4	1.491000	57.562	ASP
2	514.0728	0.3460913			
3	32.46232	5.741718	1.815500	44.540	
4	17.70302	7.509995			
5	61.35029	1.513102	1.516800	64.200	
6	28.64692	5.370549			
7	-62.80119	15.68162	1.952500	20.360	
8	-591.8352	29.28073			
9	27.42022	2.96639	1.846660	23.780	
10	523.2012	1.640253	1.835000	42.980	
11	239.0524	0.4799632			
12	INFINITY	10.7825			STO
13	-36.80036	8.578273	1.670030	47.110	
14	-21.68061	0.8112146			
15	-17.80312	1.499474	1.806450	24.400	
16	17.80312	5.136428	1.803490	30.400	
17	166.289	0.7903997			
18	36.07789	7.570944	1.455999	90.300	
19	-37.86468	0.4496936			
20	37.05455	5.229943	1.516800	64.200	
21	-124.2783	0.3900116			
22	83.18422	3.34	1.491000	57.562	ASP

[0095] The values of f₂/f₃, |f₁|/f, |f₄|/f, f₅/f, |EXP|/f and BFL/f in the retrofocus lens system 10 according to Embodiment 2 are indicated in Table 11, which is described later. Further, the values of v₄, v₅, v₇, v₈, v₉, v₁₀, dPgF4, dPgF5, dPgF7, dPgF8, dPgF9 and dPgF10 are indicated in Table 12, which is described later. The retrofocus lens system 10 according to Embodiment 2 therefore satisfies the expressions (1) to (18) indicated above. The values of dPgF of the fourth lens L₄, the fifth lens L₅, the seventh lens L₇, the eighth lens L₈, the ninth lens L₉ and the tenth lens L₁₀ are indicated in Table 14 together with the manufacturers's names and product numbers of glass materials (GLASS MATERIAL column in Table 14).

[0096] FIGS. 4A and 4B show the characteristics of the retrofocus lens system of Embodiment 2, FIG. 4A shows an astigmatism (AS) on the small conjugate side, and FIG. 4B shows a distortion. FIGS. 4A and 4B show the plotted astigmatism and distortion of light having a wavelength of 546.1 nm.

[0097] FIGS. 5A to 5D show the characteristics of the retrofocus lens system of Embodiment 2. FIGS. 5A and 5B show an axial (that is, at an image height of 0.00 mm) lateral aberration. FIGS. 5C and 5D show a lateral aberration at an image height of 10.24 mm (an angle of view of 40.8° on the screen side). The lateral aberrations of light having a wavelength WL₁ (=470 nm), a wavelength WL₂ (=546.1 nm), and a wavelength WL₃ (=610 nm) are plotted. In other respects, Embodiment 2 is the same as Embodiment 1.

Embodiment 3

[0098] The arrangement of the retrofocus lens system 10 according to Embodiment 3 is specified by numerical examples given in Table 5 below.

TABLE 5

S	R	T	Nd	vd	TYPE
OBJ	INFINITY	858.55			
1	-523.6556	4	1.491000	57.562	ASP
2	514.0728	0.290537			ASP
3	35.40269	6.328004	1.815500	44.540	
4	17.97651	9.225756			
5	732.3459	1.511957	1.565800	61.000	
6	39.71425	4.475727			
7	-61.05018	17.00026	1.846660	23.830	
8	-88.2142	25.28463			
9	31.6968	7.644573	1.806450	24.400	
10	-56.61138	1.525936	1.850259	32.300	
11	400.5343	0.2472514			
12	INFINITY	6.278201			STO
13	-45.30546	7.217551	1.668921	45.000	
14	-29.10246	1.844334			
15	-22.93409	1.499244	1.806450	24.400	
16	22.93409	5.404707	1.880670	41.010	
17	84.79871	3.100244			
18	35.30042	6.928448	1.438750	95.000	
19	-39.75226	0.3045151			
20	38.59989	5.269955	1.565800	61.000	
21	-120.6387	0.4012553			
22	83.18422	3.34	1.491000	57.562	ASP
23	-137.8496	5.03			ASP
24	INFINITY	26	1.516800	64.200	
25	INFINITY	3			
26	INFINITY	2.74	1.471693	65.850	
27	INFINITY				

[0099] The shapes of the lens surfaces S₁ and S₂ and the lens surfaces S₂₂ and S₂₃ are defined by the expression (19) indicated above. The aspheric coefficients “K”, “D”, “E”, “F”, “G”, “H” and “I” have values indicated in Table 6 below.

TABLE 6

<ASPHERIC COEFFICIENT>							
S	K	D	E	F	G	H	I
1	32.79982	3.5020967e-5	-8.659474e-8	1.2542213e-10	-6.6214841e-14	-1.0583201e-17	2.1834647e-20
2	-3.143952	3.8128909e-5	-1.3036009e-7	2.3490044e-10	-1.595244e-13	-2.3343029e-18	3.3386459e-20
22	-96.65446	1.8810461e-6	-1.372124e-7	-1.4116834e-10	2.6262719e-12	-9.9308871e-15	1.4447615e-17
23	-2.165457	3.4512883e-6	-3.2416442e-8	-4.9537585e-10	3.3877491e-12	-9.6148395e-15	1.1066089e-17

[0100] The values of f₂/f₃, |f₁|/f, |f₄|/f, f₅/f, |EXP|/f and BFL/f in the retrofocus lens system 10 according to Embodiment 3 are indicated in Table 11, which is described later. Further, the values of v₄, v₅, v₇, v₈, v₉, v₁₀, dPgF4, dPgF5, dPgF7, dPgF8, dFgF9 and dPgF10 are indicated in Table 12, which is described later. The retrofocus lens system 10 according to Embodiment 3 therefore satisfies the expressions (1) to (18) indicated above. The values of dPgF of the fourth lens L₄, the fifth lens L₅, the seventh lens L₇, the eighth lens L₈, the ninth lens L₉ and the tenth lens L₁₀ are indicated in Table 15 together with the manufacturers’ names and product numbers of glass materials (GLASS MATERIAL column).

[0101] The astigmatism (AS) on the small conjugate side and the distortion of the present lens system are shown in FIGS. 6A and 6B, while the lateral aberration is shown in FIGS. 7A to 7D. The astigmatism and the distortion of light having a wavelength of 546.1 nm are plotted in FIGS. 6A

and 6B. The lateral aberration with a wavelength WL₁ (=470 nm), a wavelength WL₂ (=546.1 nm), and a wavelength WL₃ (=610 nm) is plotted in FIGS. 7A to 7D. FIGS. 7A and 7B show the lateral aberration on the axis and FIGS. 7C and 7D show the lateral aberration at the maximum image height of 10.24 nm (with an angle of view of 40.8° on the screen side). In other respects, Embodiment 3 is the same as Embodiment 1.

Embodiment 4

[0102] The arrangement of the retrofocus lens system 10 according to Embodiment 4 is specified by numerical examples given in Table 7 below.

TABLE 7

S	R	T	Nd	vd	TYPE
OBJ	INFINITY	858.55			
1	-523.6556	4	1.491000	57.562	ASP
2	514.0728	0.3106203			ASP
3	32.11425	4.897889	1.815500	44.540	
4	18.13915	9.891571			
5	615.953	1.867131	1.516800	64.200	
6	38.07008	4.872353			
7	-55.8922	10.76093	1.952500	20.360	
8	-158.9936	33.43624			
9	27.15409	1.71539	1.846660	23.780	
10	65.88343	1.703782	1.83500	42.980	
11	389.4769	1.885492			
12	INFINITY	10.1411			STO
13	-34.59501	7.346158	1.434250	95.000	
14	-20.98952	1.303026			
15	-16.54598	1.698124	1.806450	24.400	
16	16.54598	5.182819	1.784696	26.300	
17	173.9901	0.2414552			

TABLE 7-continued

S	R	T	Nd	vd	TYPE
18	35.77961	8.228911	1.455999	90.300	
19	-29.56398	0.734205			
20	38.65487	5.236639	1.516800	64.200	
21	-96.22279	0.312764			ASP
22	83.18422	3.34	1.491000	57.562	ASP
23	-137.8496	5.03			ASP
24	INFINITY	26	1.516800	64.200	
25	INFINITY	3			
26	INFINITY	2.74	1.471693	65.850	
27	INFINITY				

[0103] The shapes of the lens surfaces S₁ and S₂ and the lens surfaces S₂₂ and S₂₃ are defined by the expression (19) indicated above. The aspheric coefficients “K”, “D”, “E”, “F”, “G”, “H” and “I” have values indicated in Table 8 below.

TABLE 8

<ASPHERIC COEFFICIENT>							
S	K	D	E	F	G	H	I
1	32.79982	3.5020967e-5	-8.659474e-8	1.2542213e-10	-6.6214841e-14	-1.0583201e-17	2.1834647e-20
2	-3.143952	3.8128909e-5	-1.3036009e-7	2.3490044e-10	-1.595244e-13	-2.3343029e-18	3.3386459e-20
21	5.656857	5.7780988e-8	5.0172158e-9	5.67066e-12	1.4116746e-14	0.00	0.00
22	-96.65446	1.8810461e-6	-1.372124e-7	-1.4116834e-10	2.6262719e-12	-9.9308871e-15	1.4447615e-17
23	-2.165457	3.4512883e-6	-3.2416442e-8	-4.9537585e-10	3.3877491e-12	-9.6148395e-15	1.1066089e-17

[0104] The values of f_2/f_3 , $|f_1|/f$, $|f_4|/f$, f_5/f , $|EXP|/f$ and BFL/ f in the retrofocus lens system **10** according to Embodiment 4 are indicated in Table 11, which is described later. Further, the values of v_4 , v_5 , v_7 , v_8 , v_9 , v_{10} , dPgF4, dPgF5, dPgF7, dPgF8, dPgF9 and dPgF10 are indicated in Table 12, which is described later. The retrofocus lens system **10** according to Embodiment 4 therefore satisfies the expressions (1) to (18) indicated above. The values of dPgF of the fourth lens L₄, the fifth lens L₅, the seventh lens L₇, the eighth lens L₈, the ninth lens L₉ and the tenth lens L₁₀ are indicated in Table 16 together with the manufacturers' names and product numbers of glass materials (GLASS MATERIAL column in Table 16).

[0105] The astigmatism (AS) on the small conjugate side and the distortion of the present lens system are shown in **FIGS. 8A and 8B**, while the lateral aberration is shown in **FIGS. 9A to 9D**. The astigmatism and the distortion of light having a wavelength of 546.1 nm are plotted in **FIGS. 8A and 8B**. The lateral aberration with a wavelength WL₁ (=470 nm), a wavelength WL₂ (=546.1 nm), and a wavelength WL₃ (=610 nm) is plotted in **FIGS. 9A to 9D**. **FIGS. 9A and 9B** show the lateral aberration on the axis and **FIGS. 9C and 9D** show the lateral aberration at the maximum image height of 10.24 nm (with an angle of view of 40.7° on the screen side). In other respects, Embodiment 4 is the same as Embodiment 1.

Embodiment 5

[0106] The arrangement of the retrofocus lens system **10** according to Embodiment 5 is specified by numerical examples given in Table 9 below.

TABLE 9

S	R	T	Nd	vd	TYPE
OBJ	INFINITY	858.55			
1	-523.6556	4	1.491000	57.562379	ASP
2	514.0728	0.2507191			ASP
3	31.79713	5.83051	1.815500	44.540001	
4	17.41408	8.94829			
5	250.0999	1.500401	1.518206	65.000000	
6	32.69828	5.044313			
7	-50.54402	17.00136	1.808095	22.800000	
8	-116.8878	28.05658			
9	27.78104	2.077707	1.784700	26.100000	
10	-379.0815	1.499639	1.822230	37.450001	
11	192.1694	1.933463			
12	INFINITY	13.95595			STO
13	-33.44034	1.499981	1.670030	47.110001	
14	-17.82397	0.4832298			
15	-15.78343	1.498544	1.806450	24.400000	
16	15.78343	5.389283	1.784723	25.700000	
17	188.8437	0.447158			
18	35.68195	6.9571	1.455999	90.300000	
19	-31.56879	3.626223			
20	33.3398	5.424156	1.518350	60.300000	
21	-157.8581	0.5667947			
22	83.18422	3.34	1.491000	57.562379	ASP
23	-137.8496	5.03			ASP
24	INFINITY	26	1.516800	64.199997	
25	INFINITY	3			
26	INFINITY	2.74	1.471693	65.849544	
27	INFINITY				

[0107] The shapes of the lens surfaces S₁ and S₂ and the lens surfaces S₂₂ and S₂₃ are defined by the expression (19) indicated above. The aspheric coefficients “K”, “D”, “E”, “F”, “G”, “H” and “I” have values indicated in Table 10 below.

TABLE 10

<ASPHERIC COEFFICIENT>							
S	K	D	E	F	G	H	I
1	32.79982	3.5020967e-5	-8.659474e-8	1.2542213e-10	-6.6214841e-14	-1.0583201e-17	2.1834647e-20
2	-3.143952	3.8128909e-5	-1.3036009e-7	2.3490044e-10	-1.595244e-13	-2.3343029e-18	3.3386459e-20
22	-96.65446	1.8810461e-6	-1.372124e-7	-1.4116834e-10	2.6262719e-12	-9.9308871e-15	1.4447615e-17
23	-2.165457	3.4512883e-6	-3.2416442e-8	-4.9537585e-10	3.3877491e-12	-9.6148395e-15	1.1066089e-17

[0108] The values of f_2/f_3 , $|f_1|/f$, $|f_4|/f$, f_5/f , $|EXP|/f$ and BFL/f in the retrofocus lens system 10 according to Embodiment 5 are indicated in Table 11, which is described later. Further, the values of v_4 , v_5 , v_7 , v_8 , v_9 , v_{10} , dPgF4, dPgF5, dPgF7, dPgF8, dPgF9 and dPgF10 are indicated in Table 12, which is described later. The retrofocus lens system 10 according to Embodiment 5 therefore satisfies the expressions (1) to (18) indicated above. The values of dPgF of the fourth lens L₄, the fifth lens L₅, the seventh lens L₇, the eighth lens L₈, the ninth lens L₉ and the tenth lens L₁₀ are indicated in Table 17 together with the manufacturers' names and product numbers of glass materials (GLASS MATERIAL column in Table 17).

[0109] The astigmatism (AS) on the small conjugate side and the distortion of the present lens system are shown in FIGS. 10A and 10B, while the lateral aberration is shown in FIGS. 11A to 11D. The astigmatism and the distortion of light having a wavelength of 546.1 nm are plotted in FIGS. 10A and 10B. The lateral aberration with a wavelength WL₁ (=470 nm), a wavelength WL₂ (=6.1 nm), and a wavelength WL₃ (=610 nm) is plotted in FIGS. 11A to 11D. FIGS. 11A and 11B show the lateral aberration on the axis and FIGS. 11C and 11D show the lateral aberration at the maximum image height of 10.24 nm (with an angle of view of 40.8° on the screen side). In other respects, Embodiment 5 is the same as Embodiment 1.

[0110] All of the parameters appearing in the numerical examples Tables 1 to 10) described in connection with Embodiments 1 to 5 are collectively summarized in Tables 11 to 17 below.

[0112]

TABLE 13

EMBODIMENT 1			
LENS	GLASS MATERIAL	dPgF	MANUFACTURER
L ₄	PBH72	0.022	OHARA
L ₅	TIH53	0.0181	OHARA
L ₇	BAH13	0.0005	OHARA
L ₈	SF57	0.0123	SCHOTT
L ₉	LASF36A	0.0011	SCHOTT
L ₁₀	CAFK95	0.0385	SUMITA

[0113]

TABLE 14

EMBODIMENT 2			
LENS	GLASS MATERIAL	dPgF	MANUFACTURER
L ₄	SF59	0.0217	SCHOTT
L ₅	FDS90	0.0136	HOYA
L ₇	BAFN10	-0.0001	SCHOTT
L ₈	SFLD60	0.0136	SUMITA
L ₉	LASF32	0.0055	SCHOTT
L ₁₀	S-FPL52	0.0386	OHARA

TABLE 11

EMBOD- IMENT	f(mm)	ω (deg)	F	β	f1	f2	f3	EXP	f4	f5	BFL	$ f1 /f$	f2/f3	$ f4 /f$	f5/f	$ EXP /f$	BFL/f
1	11.79	40.8	3.0	75.3	-21.33	34.36	35.05	-1332.6	-526	105.8	28.40	1.8	1.0	44.6	9.0	113.0	2.4
2	11.78	40.8	3.0	75.3	-21.43	35.82	34.19	-1569.9	-526	105.8	28.39	1.8	1.0	44.6	9.0	133.3	2.4
3	11.78	40.8	3.0	75.3	-26.83	43.18	30.72	-826.4	-526	105.8	23.38	2.3	1.4	44.6	9.0	70.2	2.4
4	11.84	40.7	3.0	75.0	-21.64	34.21	35.47	-2859.1	-526	105.8	28.40	1.8	1.0	44.4	8.9	241.5	2.4
5	11.77	40.8	3.0	75.4	-23.05	41.07	34.28	-1956.7	-526	105.8	28.39	2.0	1.2	44.7	9.0	166.2	2.4

[0111]

TABLE 12

EMBODIMENT	v4	v5	v7	v8	v9	v10	dPgF4	dPgF5	dPgF7	dPgF8	dPgF9	dPgF10
1	21.20	23.80	45.00	23.83	35.08	95.00	0.0220	0.0181	0.0005	0.0123	0.0011	0.0385
2	20.36	23.78	47.11	24.40	30.40	90.30	0.0217	0.0136	-0.0001	0.0136	0.0055	0.0386
3	23.83	24.40	45.00	24.40	41.01	95.00	0.0123	0.0136	0.0005	0.0136	-0.0084	0.0463
4	20.36	23.78	95.00	24.40	26.30	90.30	0.0217	0.0136	0.0385	0.0136	0.0146	0.0386
5	22.80	26.10	47.11	24.40	25.70	90.30	0.0261	0.0142	-0.0001	0.0136	0.0162	0.0386

[0114]

TABLE 15

EMBODIMENT 3			
LENS	GLASS MATERIAL	dPgF	MANUFACTURER
L ₄	SF57	0.0123	SCHOTT
L ₅	SFLD60	0.0136	SUMITA
L ₇	BAH13	0.0005	OHARA
L ₈	SFLD60	0.0136	SUMITA
L ₉	LASFN31	-0.0084	SCHOTT
L ₁₀	SFPL53	0.0463	OHARA

[0115]

TABLE 16

EMBODIMENT 4			
LENS	GLASS MATERIAL	dPgF	MANUFACTURER
L ₄	SF59	0.0217	SCHOTT
L ₅	FDS90	0.0136	HOYA
L ₇	CAFK95	0.0385	SUMITA
L ₈	SFLD60	0.0136	SUMITA
L ₉	STIH23	0.0146	OHARA
L ₁₀	SFPL52	0.0386	OHARA

[0116]

TABLE 17

EMBODIMENT 5			
LENS	GLASS MATERIAL	dPgF	MANUFACTURER
L ₄	S-NPH1	0.0261	OHARA
L ₅	FDS30	0.0142	HOYA
L ₇	BAFN10	-0.0001	SCHOTT
L ₈	SFLD60	0.0136	SUMITA
L ₉	S-TIH11	0.0162	OHARA
L ₁₀	S-FPL52	0.0386	OHARA

[0117] In the tables, “F” denotes a focal distance of the whole lens system, ω denotes a half field angle of the projection light (large conjugate side), “F” denotes an effective F-value at the reference projecting magnification (small conjugate side), and β denotes a reference projecting magnification. Further, f_1 denotes the focal distance of the first lens group G_1 , f_2 denotes the focal distance of the second lens group G_2 , f_3 denotes the focal distance of the third lens group G_3 , f_4 denotes the axial focal distance of the aspheric first lens L_1 , and f_5 denotes the axial focal distance of the aspheric twelfth lens L_{12} . Furthermore, EXP denotes the distance from the image surface on the small conjugate side to the pupil surface on the small conjugate side in the whole lens system, and BFL denotes the back focal distance of the whole lens system (BFL is measured by removing the prism PSM and cover glass CG and irradiating the system with light from an infinite distance on the large conjugate side). The parameters given in Table 11 are determined all at the wavelength of 564.1 nm.

[0118] In addition, v_4 represents the Abbe number at d-line of a glass material which forms the fourth lens L_4 , v_5 the Abbe number at d-line of a glass material which forms the fifth lens L_5 , v_7 the Abbe number at d-line of a glass material which forms the seventh lens L_7 , v_8 the Abbe number at d-line of a glass material which forms the eighth lens L_8 , v_9 the Abbe number at d-line of a glass material which forms the ninth lens L_9 , and v_{10} the Abbe number at d-line of a glass which forms the tenth lens L_{10} . dPgF4 represents an anomalous dispersion of the glass material which forms the fourth lens L_4 , dPgF5 an anomalous dispersion of the glass material which forms the fifth lens L_5 , dPgF7 an anomalous dispersion of the glass material which forms the seventh lens L_7 , dPgF8 an anomalous dispersion of the glass material which forms the eighth lens L_8 , dPgF9 an anomalous dispersion of the glass material which forms the ninth lens L_9 and dPgF10 an anomalous dispersion of the glass material which forms the tenth lens L_{10} .

Embodiment 6

[0119] The projection display apparatus according to Embodiment 6 is configured by replacing the projection lens 7 of the projection display apparatus shown in FIG. 13 with the retrofocus lens system 10 of any embodiment described above. The projection display apparatus 300 according to Embodiment 6 has a thick dichroic prism 6 disposed between the liquid crystal panels 5R, 5G, and 5B and the projection lens 7. Accordingly, a projection lens of a rear projector or the like that requires wide-angle projection is required to have the following specifications and performances:

- [0120] (1) Capability of wide-angle projection
- [0121] (2) Long back focal distance in comparison with the focal distance
- [0122] (3) Good telecentric characteristics on the light valve side and the principal ray in the prism component approximately parallel to the optical axis
- [0123] (4) Good correction of chromatic aberration of magnification
- [0124] (5) Small distortion
- [0125] (6) Maintenance of desired imaging performance over a wide temperature range and small defocusing
- [0126] (7) Appropriate correction of various aberrations in the best balance and capability of high-resolution projection of original image on a light valve having many pixels at a high density

[0127] The retrofocus lens system of any embodiment described above satisfies the performances (1) to (7) indicated above. By incorporating the lens in the projection display apparatus as shown in FIG. 13, a compact projection display apparatus that features a high picture quality and low cost and can be used in a wide temperature range can be realized.

Embodiment 7

[0128] FIG. 14 is a schematic diagram showing a configuration of an optical system of a projection display apparatus 301 according to Embodiment 7 of the present invention. As shown in FIG. 14, the projection display

apparatus **301** comprises a light source **1** which has a lamp **120** and a reflecting mirror **130** and outputs approximately parallel illuminating light **2**, a reflective liquid crystal panel **50** displaying color images, a polarizing beam splitter **60** which reflects and directs the light **2** from the light source **1** onto the reflective liquid crystal panel **50** and passes the reflected light **20** from the reflective liquid crystal panel **50**, and the projection lens **7** which projects the incident light **20** onto the screen **8** with a magnification. The projection lens **7** of Embodiment 7 is the retrofocus lens system **10** of any embodiment described above. In the figure, a reference numeral **200** denotes a housing.

[0129] On the reflective liquid crystal panel **50**, a reflecting mirror is formed for each pixel and modulates the polarizing state in a cross section of the illuminating light and spectrum. When the light **20** reflected by the liquid crystal panel **50** pass the polarizing beam splitter **60**, the modulation of the polarizing state is converted to intensity modulation, and the projection lens **7** projects a magnified image onto the screen **8**.

[0130] The retrofocus lens system of any embodiment described above satisfies the performances (1) to (7) indicated above. By incorporating the lens in a projection display apparatus as shown in FIG. 14, a compact projection display apparatus which features a high picture quality and low cost and can be used in a wide temperature range can be realized.

Embodiment 8

[0131] FIG. 15 shows a schematic configuration of the optical system of the projection display apparatus according to Embodiment 8 of the present invention. As shown in FIG. 15, the projection display apparatus **302** comprises a light source **1** which has a lamp **120** and a reflecting mirror **130** and outputs approximately parallel illuminating light **2**, a condenser lens **140**, and a color wheel unit **110**. The color wheel unit **110** comprises a color filter **11** having an array of angularly divided regions through which the primary R-G-B colors transmit and a motor **12** for turning the filter **11**. The projection display apparatus **302** also comprises a rod integrator **13**, a relay lens system **14**, and a total internal reflection (TIR) prism **600** which totally reflects approximately telecentric light. The TIR prism **600** includes a first prism block **601** and a second prism block **602**, and inclined surfaces of the two blocks **601** and **602** face each other with a minute air gap AG in between.

[0132] The projection display apparatus **302** further comprises a digital micromirror device (DMDTM) **500** and a projection lens **7**. The DMD **500** is an image display component utilizing micro electromechanical system (MEMS) technology. The DMD **500** is a spatial modulator in which arrays of micromirrors are disposed in the two-dimensional plane, and the inclination of each mirror is modulated to ON or OFF state within the component surface. In Embodiment 8, the projection lens **7** is the retrofocus lens system **10** of any embodiment described above. In the figure, a reference numeral **200** denotes a housing.

[0133] The light striking the inclined surface of the first prism block **601** are totally reflected because of the differ-

ence in refractive index between the glass material forming the prism and the air gap AG and directed onto the DMD **500**. The light **20** reflected by the micromirror in ON-state in a surface of the DMD **500** passes each surface of the TIR prism **600**, a magnified image is formed on the screen **8** by the projection lens **7**, and a viewer **9** can see the image.

[0134] The retrofocus lens system of any embodiment described above satisfies the performances (1) to (7) indicated above. By incorporating the lens in a projection display apparatus as shown in FIG. 15, a compact projection display apparatus which features a high picture quality and low cost and can be operated in a wide temperature range can be realized.

[0135] In place of the DMD **500**, a grating light valve (GLVTM) component may be used. The GLV component includes a lot of movable grating elements densely arranged like a two or one-dimensional array using the MEMS technique. By replacing the DMD component with the GLV component, full color image can be displayed.

[0136] The type of light valve components is not limited to those shown in Embodiments 6 to 8.

[0137] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of following claims.

What is claimed is:

1. A retrofocus lens system comprising in order from a large conjugate side toward a small conjugate side:

- a first lens group having a negative refracting power;
- a second lens group having a positive refracting power; and
- a third lens group having a positive refracting power;

said first lens group including in order from the large conjugate side toward the small conjugate side, a first lens having an aspheric surface, a meniscus second lens having a negative refracting power and having a convex surface on the large conjugate side, a meniscus third lens having a negative refracting power and having a convex surface on the large conjugate side, and a meniscus fourth lens having a negative refracting power and having a convex surface on the small conjugate side;

said second lens group including in order from the large conjugate side toward the small conjugate side, a fifth lens having a positive refracting power, and a sixth lens joined to said fifth lens;

said third lens group including in order from the large conjugate side toward the small conjugate side, a meniscus seventh lens having a positive refracting power and having a convex surface on the small conjugate side, a biconcave eighth lens, a ninth lens joined to said eighth lens and having a positive refracting power, a biconvex tenth lens, a biconvex eleventh lens, and a twelfth lens having an aspheric surface;

wherein said retrofocus lens system satisfies the following expressions:

$$0.8 < f_2/f_3 < 1.5$$

$$1.6 < |f_1|/f < 2.4$$

$$|f_4|/f > 30$$

$$f_5/f > 6$$

where f is a focal distance of the whole lens system, f_2 is a focal distance of said second lens group, f_3 is a focal distance of said third lens group, $|f_1|$ is an absolute value of a focal distance of said first lens group, $|f_4|$ is an absolute value of an axial focal distance of said first lens, and f_5 is an axial focal distance of said twelfth lens.

2. The retrofocus lens system of claim 1, further comprising a stop disposed between said second lens group and said third lens group;

wherein said retrofocus lens system satisfies the following expression:

$$|EXP|/f > 50$$

where $|EXP|$ is an absolute value of a distance from an image surface on the small conjugate side to a pupil surface on the small conjugate side in the whole lens system.

3. The retrofocus lens system of claim 1, satisfying the following expression:

$$BFL/f > 2$$

where BFL is a back focal distance of the whole lens system.

4. The retrofocus lens system of claim 1, satisfying the following expressions:

$$15 < v_4 < 30$$

$$15 < v_5 < 30$$

$$40 < v_7 < 100$$

$$15 < v_8 < 32$$

$$20 < v_9 < 50$$

$$70 < v_{10} < 100$$

where v_4 is an Abbe number at d-line of a glass material forming said fourth lens, v_5 is an Abbe number at d-line of a glass material forming said fifth lens, v_7 is an Abbe number at d-line of a glass material forming said seventh lens, v_8 is an Abbe number at d-line of a glass material forming said eighth lens, v_9 is an Abbe number at d-line of a glass material forming said ninth lens, and v_{10} is an Abbe number at d-line of a glass material forming said tenth lens.

5. The retrofocus lens system of claim 4, satisfying the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d)$$

$$0.008 < dPgF4 < 0.03$$

$$0.01 < dPgF5 < 0.025$$

$$0.01 < dPgF8 < 0.02$$

$$0.03 < dPgF10 < 0.055$$

where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 4, 5, 8 or 10, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line

and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

6. The retrofocus lens system of claim 4, satisfying the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d)$$

$$-0.01 < dPgF7 < 0.045$$

$$-0.015 < dPgF9 < 0.02$$

where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 7 or 9, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

7. A projection display apparatus comprising:

a light source for emitting light;

a light valve for two-dimensionally modulating the light from said light source; and

a retrofocus lens system for projecting with a magnification the light modulated by said light valve;

said retrofocus lens system comprising in order from a large conjugate side toward a small conjugate side:

a first lens group having a negative refracting power;

a second lens group having a positive refracting power; and

a third lens group having a positive refracting power;

said first lens group including in order from the large conjugate side toward the small conjugate side, a first lens having an aspheric surface, a meniscus second lens having a negative refracting power and having a convex surface on the large conjugate side, a meniscus third lens having a negative refracting power and having a convex surface on the large conjugate side, and a meniscus fourth lens having a negative refracting power and having a convex surface on the small conjugate side;

said second lens group including in order from the large conjugate side toward the small conjugate side, a fifth lens having a positive refracting power, and a sixth lens joined to said fifth lens;

said third lens group including in order from the large conjugate side toward the small conjugate side, a meniscus seventh lens having a positive refracting power and having a convex surface on the small conjugate side, a biconcave eighth lens, a ninth lens joined to said eighth lens and having a positive refracting power, a biconvex tenth lens, a biconvex eleventh lens, and a twelfth lens having an aspheric surface;

wherein said retrofocus lens system satisfies the following expressions:

$$0.8 < f_2/f_3 < 1.5$$

$$1.6 < |f_1|/f < 2.4$$

$$|f_4|/f > 30$$

$$f_5/f > 6$$

where f is a focal distance of the whole lens system, f_2 is a focal distance of said second lens group, f_3 is a focal distance of said third lens group, $|f_1|$ is an absolute value of a focal distance of said first lens group, $|f_4|$ is an absolute value of an axial focal distance of said first lens, and f_5 is an axial focal distance of said twelfth lens.

8. The projection display apparatus of claim 7,

wherein said retrofocus lens system further comprises a stop disposed between said second lens group and said third lens group; and

said retrofocus lens system satisfies the following expression:

$$|EXP|/f > 50$$

where $|EXP|$ is an absolute value of a distance from an image surface on the small conjugate side to a pupil surface on the small conjugate side in the whole lens system.

9. The projection display apparatus of claim 7, wherein said retrofocus lens system satisfies the following expression:

$$BFL/f > 2$$

where BFL is a back focal distance of the whole lens system.

10. The projection display apparatus of claim 7, wherein said retrofocus lens system satisfies the following expressions:

$$15 < v_4 < 30$$

$$15 < v_5 < 30$$

$$40 < v_7 < 100$$

$$15 < v_8 < 32$$

$$20 < v_9 < 50$$

$$70 < v_{10} < 100$$

where v_4 is an Abbe number at d-line of a glass material forming said fourth lens, v_5 is an Abbe number at d-line of a glass material forming said fifth lens, v_7 is an Abbe number at d-line of a glass material forming said seventh lens, v_8 is an Abbe number at d-line of a glass material forming said eighth lens, v_9 is an Abbe number at d-line of a glass material forming said ninth lens, and v_{10} is an Abbe number at d-line of a glass material forming said tenth lens.

11. The projection display apparatus of claim 7, wherein said retrofocus lens system satisfies the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d)$$

$$0.008 < dPgF4 < 0.03$$

$$0.01 < dPgF5 < 0.025$$

$$0.01 < dPgF8 < 0.02$$

$$0.03 < dPgF10 < 0.055$$

where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 4, 5, 8 or 10, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

12. The projection display apparatus of claim 7, wherein said retrofocus lens system satisfies the following expressions:

$$dPgFm = PgFma(v_d) - PgFn(v_d)$$

$$-0.01 < dPgF7 < 0.045$$

$$-0.015 < dPgF9 < 0.02$$

where $dPgFm$ denotes a parameter representing anomalous dispersive properties of the glass material which forms the m -th lens, m being equal to 7 or 9, $PgFn(v_d)$ denotes a straight line representing a normal partial dispersion ratio in a coordinate system that has the abscissa indicating the Abbe number v_d at d-line and the ordinate indicating a partial dispersion ratio PgF from F-line to g-line, and $PgFma(v_d)$ denotes an anomalous partial dispersion ratio of the glass material which forms the m -th lens having the Abbe number v_d at d-line.

13. The projection display apparatus of claim 7, wherein said light valve is a liquid crystal light valve.

14. The projection display apparatus of claim 7, wherein said light valve is a digital micromirror device which has an array of a plurality of movable microscopic unit mirrors.

15. The projection display apparatus of claim 7, wherein said light valve is a grating light valve that has a grating array including a plurality of unit gratings, which are respectively capable of modulating phase of the light from said light source.

* * * * *