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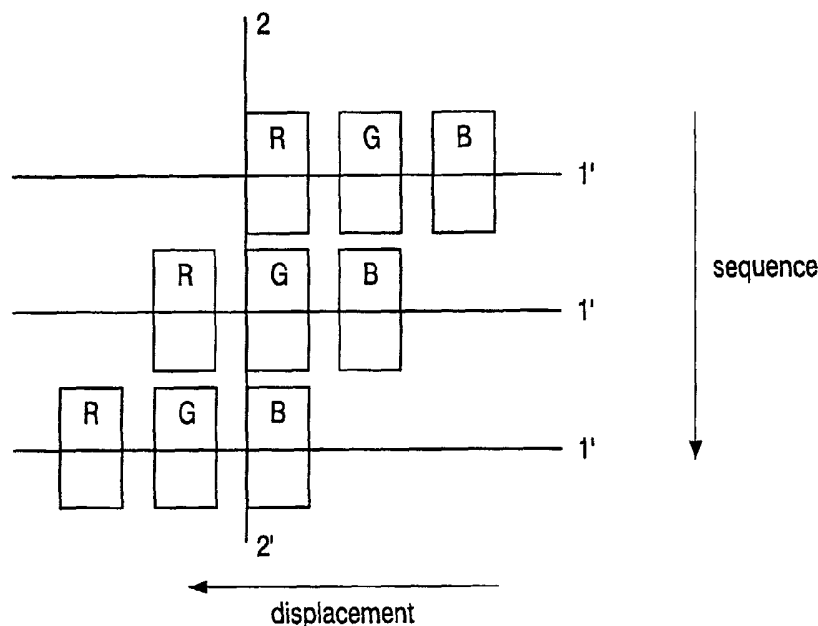
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(54) Title: EMISSIVE DISPLAY DEVICE



(57) Abstract: The invention relates to a display device having a plurality of pixels (5) which upon successive emissions of light give successive optical images. The optical images are movable between at least two positions in which the plurality of pixels (5) can be activated within a time period that is shorter than a retention time of a receptor of a retina of a human eye. The invention also relates to a method of generating an image with the display wherein the optical images of the pixels are moved over a path to at least two positions within the mentioned time period and the pixels are activated so as to emit light in at least one of these positions.



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Emissive display device

The invention relates to a display device having a plurality of pixels which upon successive emissions of light give successive optical images, and to a method of generating an image with a display device having a plurality of said pixels.

5 Emissive displays offer the unique characteristic of providing light within a desired pixel, in contrast to, for instance, an LCD (liquid crystal display) where the display element is defined as the combination of a spatially filtered light source and modulation by the transmission (or reflection) characteristics of the LCD pixel. In the LCD case, scaling down of the physical dimensions of the pixel in order to increase the resolution of the display leads to a loss of total transmitted light due to a smaller fill factor and consequently to a dimmer display. In an emissive technology (notably organic electroluminescent technology) one can compensate for this loss of light by increasing the current through the pixel area by an appropriate factor to compensate for the loss of area. It has been shown that pixels of any desired size can be made and in effect are only limited by the limits of the lithographic process used, i.e. pixels of 10x10 micrometer size have been experimentally made. Although 15 the pixel elements as such can be made very small, the pitch cannot be made very small in the case of individually addressed elements. The pitch at which the individual addressing electrodes can be manufactured is limited, to about 100 micrometers in the case of passive and active addressing. Increasing the resolution, i.e. increasing the number of individually addressable pixels also introduces another undesired feature, this being the great number 20 electrodes which have to be connected to the driving electronics. The increase in the number of connections also significantly increases the Si-area that is required to hold the driving electronics and therefore increases the cost of the total module, of which driver ICs are one of the major cost factors. In modern electronic drivers, the Si-area is bondpad limited, which means that the increase of the number of pin-outs increases the necessary Si-area and hence 25 the cost of the driver. It is therefore an object of the invention to provide a method of increasing the resolution of the display without increasing the number of leads. The invention is defined by the independent claims. The dependent claims define advantageous embodiments.

The present invention provides a solution to this problem and is based upon the recognition that images that are "imprinted" on the retina of the human eye within the retention time of the receptors, are perceived as being present at the same time.

5 The invention thus provides a display device, characterized by means for moving the successive optical images to emit light within a time period that is less than a retention time of a receptor of a retina of a human eye. The emissions may be generated by an emissive display or may be generated by an other type of displays, such as, for example, a transmissive display, whereby the transmission of light originating from a light source is modulated.

10 The invention further provides a method of generating an image with a display device having a plurality of pixels, comprising the step of generating successive emission of light to give successive, optical images, characterized by further comprising the step of moving the optical images within a time period which is shorter than a retention time of a receptor of a retina of a human eye.

15 The present invention renders possible an increase in the resolution of the display. It is further possible that every rendered pixel of the optical image has a full-color representation, without the necessity to keep the viewing distance beyond the limit within which the eye is able to resolve the individual color sub-pixels which together constitute a full color pixel. A further effect of the invention is the possibility to drive the display at a higher resolution without increasing the number of leads. Thus the present method of
20 generating an image with an emissive display has advantages with respect to the improvement of resolution and providing emission of each color component of a pixel of the optical image from a same optical position.

The display device has pixels comprising a light emitting area and electrodes
25 for activating the pixels. Such displays are well known in the art. The display device of the invention further comprises means for moving an optical image of a pixel, which may be, for example, an actuator of the piezoelectric or coil-assembly type, or may be an auxiliary transmissive plate that is mounted at an angle to the front of the display and is movable in a direction having a component perpendicular to the surface of the front of the display. In the
30 mentioned example of the actuator, the display is mechanically moved in the image plane, similarly to the method as used in digital cameras wherein an actuator of the piezoelectric or coil assembly type moves the whole display over the desired physical path.

Typically, the pitch of the display is of the order of 300 micrometers. The movement has to be synchronized with the incoming data stream, and it is preferred that the

time the display resides at positions where the pixels are activated is longer than it takes to arrive at this position. This condition is preferred because it ensures that the pixel elements do not have to be driven to an excessively high brightness and furthermore it avoids blurring of the pixels. The movement therefore is preferably discontinuous: It may be envisaged,

5 however, that even with a continuous movement a similar effect is realized. Alternatively the means for moving the optical image may comprise a grating of a first material sandwiched between a second material, the first material being an isotropic material or an anisotropic material, the second material being an anisotropic material if the first material is isotropic, the second material being isotropic material if the first material is anisotropic, and means for
 10 rotating a polarization direction of the light. The grating may be constructed in the form of a repetitive pattern of parallel bars, each bar covering a column of color sub pixels of a matrix display having rows and columns of pixels. Such a grating is suitable for large displays. In case of small matrix displays one bar may be applied covering all columns of the display. The means for rotating the polarization direction may be a mechanical means which
 15 mechanically rotates an optical rotator for rotating the polarization direction. Alternatively the means for rotating the polarization direction may comprise a liquid crystal plate which is adapted to rotate the polarization direction of the light in dependence on electrical means coupled to the plate. In a further alternative the means for rotating the polarization direction comprises a polymer material becoming birefringent upon application of strains and means
 20 for applying strain to the polymer material are present for rotating the polarization direction of the light. The electrical means may be an electrical source, for example a voltage source, which output changes in synchronization with the desired rotation of the polarization direction.

In general, the following timing conditions have to be fulfilled:

25
$$T_{\text{pixel speed}} < T_{\text{movement}} < T_{\text{retention}}$$

wherein $T_{\text{pixel speed}}$ stands for the time period within which a pixel can be switched on-off, T_{movement} is the travel time of the movement and $T_{\text{retention}}$ is the retention time of the human eye (which is typically 20-40 ms). It is preferred to use the above method such that the pixel is activated so as to emit light in each of the positions. The time period for moving a pixel or
 30 for moving the optical image of a pixel is for that reason preferably less than 40 ms, and more preferably less than 20 ms.

In order to benefit fully from the resolution enhancement of this arrangement, the optical images of the pixels must be moved in a manner in conformity with the data that are supplied by the driving electronics. The data are to be manipulated in such a way as to

address the pixel in synchronization with the movement of the optical images of the pixels and in accordance with the brightness and color that is required at a particular position. To achieve the same areal brightness one has to increase the peak brightness by a factor equivalent to the number of displayed pixels per translation cycle, for example by a factor 4.

5 Although this will put an extra load on the pixels, because they will be driven harder, the total current to the display will be the same as in a display equipped with pixels utilizing the full area within the cross section of the electrodes (but having a lower resolution). In case of emissive displays, the drive voltage will be higher due to the higher current densities required.

10 In another embodiment the means for moving the optical image may comprise an optically transmissive plate in front of a display. The movement is now in the direction perpendicular to the display, where the plate is placed at an angle to the face of the display. By the movement on two axes in a direction having a component perpendicular to the surface of the front of the display, one influences the optical path from the pixel to the viewer and
15 hence can introduce an apparent movement of the pixel. An advantage of this method is that speed is not really an issue, because one has to make one movement which occurs at the same time for all pixels during a frame period.

In another embodiment, one can also introduce a grating in front of the display comprising a liquid crystal plate sandwiched between isotropic material, the liquid crystal
20 plate being adapted to rotate the polarization of the light in dependence on electrical means coupled to the plate. This LC material may be similar to the material used in LCDs (liquid crystal displays). By tuning the voltage across the cell, the diffraction of light traversing the plate can be regulated and hence the apparent position of the emitting pixel. The advantage of this method is that there are no moving parts and that one has to deal with only one LC cell
25 having dimensions equivalent to the whole emissive surface of the display.

For an efficient use of the invention, the optical images of the pixels are moved from its starting position in at least two different directions in such a manner that after at least two movements the pixels or the optical images of the pixels are returned to its starting position. For example, the optical image of the pixel is moved from its starting
30 position in a cycle of two perpendicular directions in such a manner that after one cycle the optical images of the pixel are returned to their starting position.

These and other aspects of the invention will be apparent from and elucidated with reference to the accompanying drawings in which:

Fig. 1A shows a pixel and addressing electrodes in a physical plane;

Fig. 1B shows the image plane of the same pixel and electrodes of Fig. 1A as it is perceived by a viewer;

5 Figs. 2A and 2B show the same pixel and electrodes of Figs. 1A and 1B in a second position;

Figs. 3A and 3B show the same pixel and electrodes of Figs. 1A and 1B in a third position;

Figs. 4A and 4B show the same pixel and electrodes of Figs. 1A and 1B in a fourth position;

10 Fig. 5A and 5B show a situation as in Figs. 1A en 1B, with RGB pixels adjacent to each other;

Fig. 6 shows the image plane of three sequences of a moved RGB pixel;

Fig. 7 shows a display with a movable auxiliary optically transmissive plate;

Fig. 8 shows an electro-optical switch with a grating;

15 Fig. 9 shows a combination of an electro-optical switch with two perpendicularly oriented anisotropic gratings; and

Fig. 10 shows a switchable anisotropic grating.

In Figs. 1A and 1B, two addressing electrodes with a pixel are shown. The
20 addressing electrodes comprise means for activating the pixel. A pixel 5 is located at the intersection of two addressing electrodes 3 and 4 and has an active emissive area smaller than this cross-section. In the example shown here, approximately 25% of the total area are used. Reference lines 1-1' and 2-2' represent the reference frame for the viewer. In Fig. 1A the physical location of the constituents of the display is drawn with respect to the reference
25 plane of the viewer (physical plane). In Fig. 1B the perceived image in case of movement of the optical images of the pixels is shown (image plane). If one moves, for example, the display with respect to the reference plane in vertical direction, so parallel to the line 2-2', and one activates the pixel at the end of this movement only, the situation as shown in Figs. 2A and 2B is obtained. The movement can be continued in horizontal direction, so parallel to
30 the line 1-1', using the same procedure (Figs. 3A and 3B) and the loop can be closed via a movement in vertical direction (Figs. 4A and 4B). During this cycle the pixel is activated four times, and provided that the duration of the cycle is short enough, the viewer will perceive an optical image of a block of four pixels at a pitch that is 2 times higher than the physical pitch of one pixel in both vertical and horizontal direction.

The human brain is very perceptive to regular patterns, which, if present in an image, will distract the observer and can severely degrade the perceived optical image quality. Since, for example, red, green and blue color sub-pixels are preferably aligned in stripes, this is a shortcoming of the state of the art methods.

5 It is desirable, therefore, to have each geometrically defined and individually addressable color sub-pixel capable of emitting all desired colors. The invention now provides a method of using a sort of color addition method by, for example, displacing the green and blue pixels in such a way that, at the time they are activated, their positions overlap each other. This is done in such a way that after one sequence the addition of the individual
10 color pixels adds up in the viewer's perception to a full-color pixel. Figs. 5A and 5B show the conventional organic emissive display whose structure is such that the red R, green G and blue B pixels are adjacent to each other with each of the color sub-pixels having its own addressing line. In the prior art the pitch of the pixels is decreased if a higher detailed image is required. Since the sub-pixels in polymer LED displays are structured by means of inkjet
15 printing, this means a more precise control of the deposition process, which has its limitations. Furthermore, the processing time is increased as well as the risk of defective pixels occurring, simply because one has to print more pixels. In the case of small molecule displays, shadow masks are required having a finer pitch and smaller holes, which clog up more easily during manufacture of the display.

20 For displays comprising red R, green G, and blue B sub-pixels that are adjacent to each other, according to the invention, a method is suitable comprising the process of moving the optical images of the sub-pixels from their starting positions to their adjacent positions in such a manner that after two movements the optical image of the red pixel R has occupied successively the positions of the optical images of the blue B and green
25 pixels G, the optical image of the green pixel G has occupied successively the positions of the optical images of the blue B and red pixels R, and the optical image of the blue pixel B has occupied successively the positions of the optical images of the green G and red pixels R, the pixels being activated so as to emit light in at least one of these positions, after which this process is repeated in the opposite direction until the optical images of the sub-pixels have
30 returned to their original positions, or after which the optical images of the sub-pixels are restored to their original positions in one step.

In Figs. 5A and B, three color pixels 5a, 5b, and 5c characterized in that they have a defined emission area can be individually addressed by column electrodes 4a, 4b, and 4c and their common cathode 3 and are capable of emitting one primary color. In this

example the colors are red, green, and blue, respectively. The lines 1-1' and 2-2' define a reference system for the viewer. A means is provided for moving the pixels in the horizontal direction either mechanically or electro-optically under such conditions that a sequence is followed in which the optical images of the pixels are moved towards the previous position of its adjacent color sub-pixel over a distance defined by the pitch of the color sub-pixels and is subsequently activated so as to emit light. This procedure is shown in Fig. 6. By repeating this process three times, the viewer's perception is that the light of all color sub-pixels of a pixel has been emitted from the same position in the image plane. In order to achieve this result, the successive movements and the synchronized emission of colors has to take place within the retention time of the human eye. The subsequent emission of each of the colors of the respective sub-pixels results in this case in a color addition of these colors by integration of the human eye.

At the end of the sequence the positions of the pixels are either restored to their initial values or continued in the opposite direction to obtain a closed loop.

Special attention has to be paid to the handling of the image data, which depend on the type of movement. If a movement is used as in Fig. 6, it is preferred to activate all sub-pixels at the same time once they are positioned. The data signal on the addressing electrode physically attached to one of the sub-pixels should correspond to the required drive signal (or color contribution) for the specific pixel position in the viewer's plane. Each physically present color sub-pixel is therefore used in three adjacent pixel positions. This principle is comparable to the printing principle of a color magazine, however, the sequence of the primary color addition is different for every pixel.

In this manner one can produce a display having, for example, sub-pixels at a spacing of 300 micrometers, which in the conventional way would lead to a rather coarse display having a combined color pixel pitch of 900 micrometers. The present invention thus enables an increase in the resolution of the display by at least a factor of three in at least one direction. Apart from this advantage, the most significant effect is that every rendered sub-pixel has a full-color representation, without the necessity to keep the viewing distance beyond the limit within which the eye is able to resolve the individual color sub-pixels of a pixel.

A further major advantage is the possibility to drive the display at a three times higher resolution without increasing the number of leads.

A preferred method for video data processing is to take a frame within a video stream and, instead of setting the data on physically different output drivers, arranging them

consecutively in time and synchronized with the displacement. Instead of having discrete positions, a continuous movement of the pixels and activation of the color pixels is alternatively possible, such that the drive signal corresponds to the position of the pixel in the viewer's plane. In order to avoid too much blurring, the pixel area should preferably be made smaller than the cross-section of the addressing electrodes. The resolution enhancement is equal to the physical pixel pitch in the direction of the movement divided by the physical dimension of the color sub-pixel in the direction of the movement. . Seamless image rendering in this way is therefore possible. The embodiments, described so far for organic electroluminescent devices are also applicable , amongst others, to both passive and active matrix-driven organic displays.

In Fig. 7, an auxiliary optically transmissive plate 6 is moved in front of a display. The movement is now in a direction perpendicular to the display 7, the plate 11 being placed at an angle to the face of the emissive display 7. The movement along two axes 8 in a direction having a component perpendicular to the surface of the front of the display, influences the optical path from the pixels to the viewer and hence introduces an apparent movement of the optical images of the pixels.

Figs. 8 to 10 show another embodiment wherein the movement of the optical images of the pixels is obtained by changing the optical path from the pixel to the human eye, for example, by tuning a voltage across a liquid crystal (LC) plate, or by applying a rotator for rotating the polarization direction of the light emitted by the pixels in combination with a grating.

Fig. 8 shows the grating 9, wherein the isotropic material 10 has the same refractive index as the ordinary refractive index (n_o) of the anisotropic material 11 whereas the extraordinary refractive index (n_e) of the anisotropic material 11 is greatly different. The grating contains the anisotropic material 11 sandwiched between two layers of the isotropic material 10. A light polarization rotator 12 is present which may rotate the polarization of the light emitted by the pixels. The propagation of the light through the rotator and grating is indicated with the vertical arrows. The other arrows with two heads indicate the polarization direction of the light. As shown in the left half of Fig. 8 light with a predetermined polarization direction may pass without any change of direction through the rotator 12 and grating 9. However, when the rotator 12 rotates the polarization direction of the light originating from the pixels, the light path is changed as shown in the right half of Fig.8. The rotator 12 may be a switchable half-wave plate or a twisted nematic cell. The polarization direction of the light passing through the cell can be changed by a voltage applied across the

cell. The rotator may alternatively be rotated in a mechanical way. Another alternative is to use a polymer material for the rotator which becomes birefringent upon application of strain to the polymer material. In dependence on the applied strains the polarization direction of the light passing through the polymer material is changed.

5 In Fig. 9, two substantially perpendicular combinations of rotator 12 and grating 9 are shown. This embodiment is able to shift the position of a light beam originating from a pixel in two perpendicular directions, both directions being parallel to the surface of the display. The direction and positions of the original and shifted light beams are indicated with the vertical arrows. So, by appropriately changing the polarization directions of the
10 rotators 12, optical images of a pixel can be generated, for example, on positions as shown in Figs. 1 to 4.

 Instead of using the combination of the rotator 12 and grating 9, it is alternatively possible to use a switchable grating. This is shown in Fig. 10. In this embodiment the switchable grating 9 comprises the isotropic material 10, the anisotropic part
15 11 which is in this embodiment a liquid crystal material, two transparent electrodes 13, and optionally one or two substrates 14. A voltage can be applied across the two electrodes 13 and be switched on and off (respectively $V=U$ and $V=0$). When applying the voltage $V=0$ the polarized beam of light is shifted as shown in the left half of fig. 10, because the molecules are oriented uniaxially. The molecules become oriented in the direction of the incoming beam
20 of light upon the application of the voltage $V=U$. As in this case the refractive index of the isotropic material is the same as the ordinary refractive index of the liquid crystal, the beam passes through without being shifted as shown in the right half of Fig. 10. If the movement of the light beam needs to be in two perpendicular directions, two such switchable gratings are placed perpendicularly to each other.

25 In the embodiments illustrated by Fig. 8 to 10 it is assumed that the light emitted by the pixels is polarized. In case the pixels do not emit polarized light, then an additional polarizer may be applied to polarize the light origination from the pixels.

 Organic electroluminescent displays are very suitable for application in the present method, but one may also envisage, for example, the use of this method for CRTs
30 with a flat surface. In the case of electroluminescent displays the mechanical movement of the whole display is the most preferred method, rather than the use of an auxiliary plate. CRTs, VFDs, Plasma, and LCD displays may also benefit from this method.

 As for the application field, one can imagine the use of this method not only for direct-view displays, such as in desktop monitors and displays for mobile terminals, but

also for head-up displays or virtual goggles. The method may also be applied to projection systems because the formation of the picture in the optical engine and the subsequent projection include the same characteristics.

Power consumption is important in mobile systems, and it is recommended that this method is included as a feature which can be switched on and off at will. For example, one may activate this method in the transmission mode of internet access or the reception of video images and switch it off in the standby mode where only limited text-based information is shown like the provider's name. The scan frequency is then less than in the full-resolution mode, and a considerable capacitive power saving is achieved.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. In the device claim enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS:

1. A display device having a plurality of pixels (5) which upon successive emissions of light give successive optical images, characterized by means for moving the successive optical images to emit light within a time period that is less than a retention time of a receptor of a retina of a human eye.

5

2. A display device as claimed in claim 1, wherein the means for moving the optical images are an actuator for moving the plurality of pixels (5), the actuator preferably being of a piezoelectric or a coil-assembly type.

10

3. A display device as claimed in claim 1, wherein the means for moving the optical images comprise an auxiliary transmissive plate (6) that is mounted to a front (7) of the display device at an angle thereto and is movable in a direction having a component perpendicular to a surface of the front (7) of the display device.

15

4. A display device as claimed in claim 1, wherein the means for moving the optical images comprise a grating of a first material sandwiched between a second material, the first material being an isotropic material or an anisotropic material, the second material being an anisotropic material if the first material is isotropic, the second material being isotropic material if the first material is anisotropic, and means for rotating a polarization

20

direction of the light.

5. A display device as claimed in claim 4, wherein the means for rotating comprise an optical rotator for rotating the polarization direction; and mechanical means for rotating the optical rotator.

25

6. A display device as claimed in claim 4, wherein the means for rotating comprise a liquid crystal plate which is adapted to rotate the polarization direction of the light in dependence on electrical means coupled to the plate.

7. A display device as claimed in claim 4, wherein the means for rotating comprise a polymer material becoming birefringent upon application of strain; and means for applying strain to the polymer material are present for rotating the polarization direction of the light.

5

8. A display device as claimed in claim 1, wherein the means for moving the optical images comprise a grating comprising a liquid crystal plate sandwiched between isotropic material; and the liquid crystal plate is adapted to rotate the polarization of the light in dependence on electrical means coupled to the plate.

10

9. A display device as claimed in claim 4, wherein the device comprises another means for moving the optical images both means for moving being perpendicularly oriented to each other.

15

10. A method of generating an image with a display device having a plurality of pixels (5), comprising the step of generating successive emissions of light to give successive, optical images, characterized by further comprising the step of moving the optical images within a time period which is shorter than a retention time of a receptor of a retina of a human eye.

20

11. A method as claimed in claim 10, wherein the pixels (5) are activated into emitting light in each of the positions.

12. A method as claimed in claim 10, wherein the optical images are moved from a starting position in at least two different directions such that after at least two movements the optical images are returned to their starting position.

25

13. A method as claimed in claim 12, wherein the optical images are moved from the starting position in a cycle of combinations of two perpendicular directions such that after one cycle the optical images are returned to the starting position.

30

14. A method as claimed in claims 10, wherein the optical images are moved in a discontinuous manner.

15. A method as claimed in claim 10, wherein the emissive display has RGB pixels (5a, 5b, 5c) comprising red pixels (5a), green pixels (5b) and blue pixels (5c) positioned adjacent to each other; and the method comprises the step of moving optical images of an RGB pixel (5a, 5b, 5c) from a starting position to adjacent positions such that
- 5 after two movements optical images of the red pixel (5a) have occupied successively the starting positions of optical images of the blue (5c) and green pixel (5b), optical images of the green pixel (5b) have occupied successively the starting positions of the optical images of the blue (5c) and red pixel (5a), and optical images of the blue pixel (5c) have occupied successively the starting positions of the optical images of the green (5b) and red pixel (5a),
- 10 whereby the RGB pixel (5a,5b,5c) is activated into emitting light in synchronization with the movements, after which the step is repeated in a reverse sequence of movements until the optical images of the pixel (5a,5b,5c) have returned to their starting position, or after which the optical images of the pixel (5a,5b,5c) are restored in one step to their starting position.

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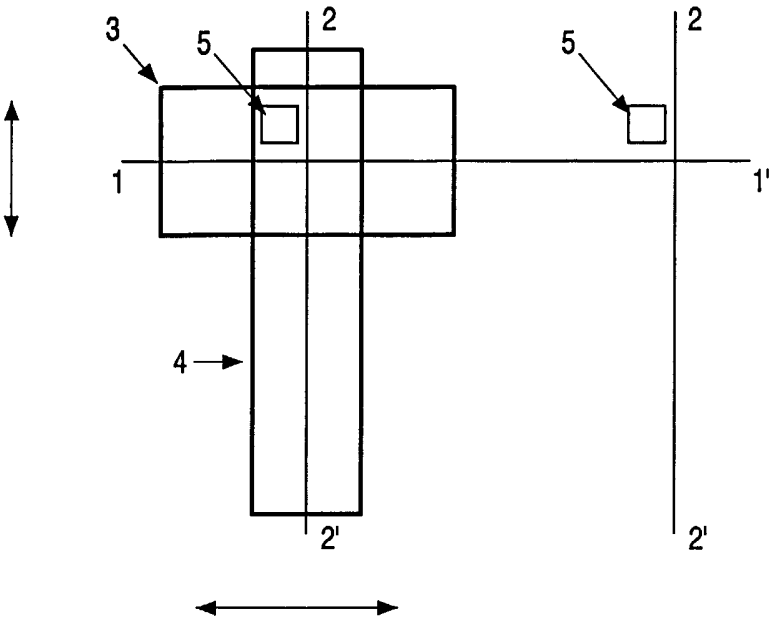


FIG. 1A

FIG. 1B

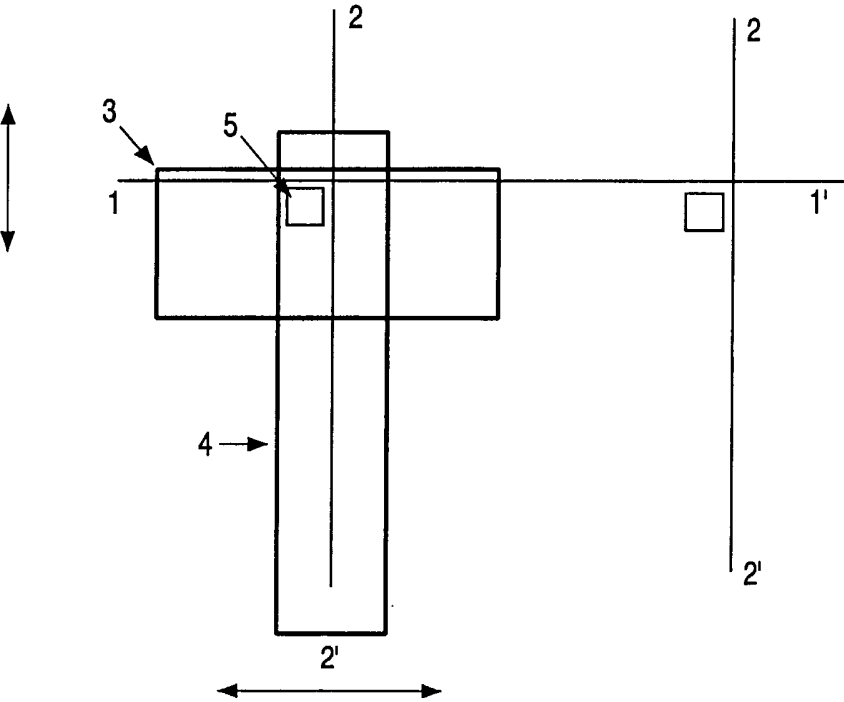


FIG. 2A

FIG. 2B

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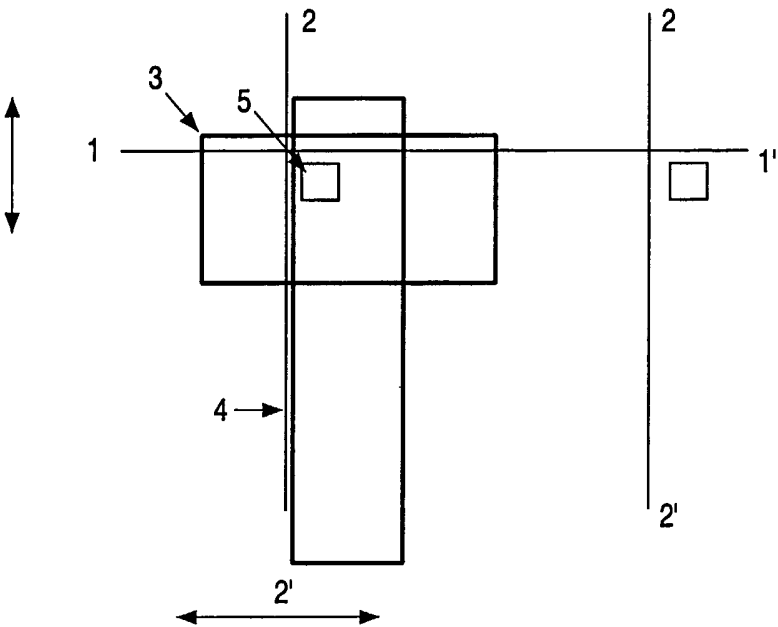


FIG. 3A

FIG. 3B

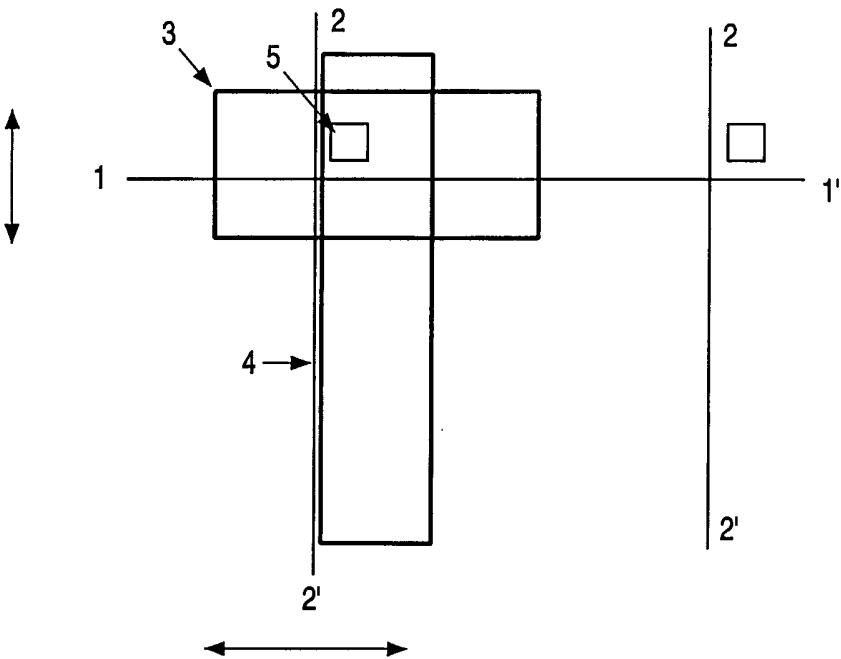


FIG. 4A

FIG. 4B

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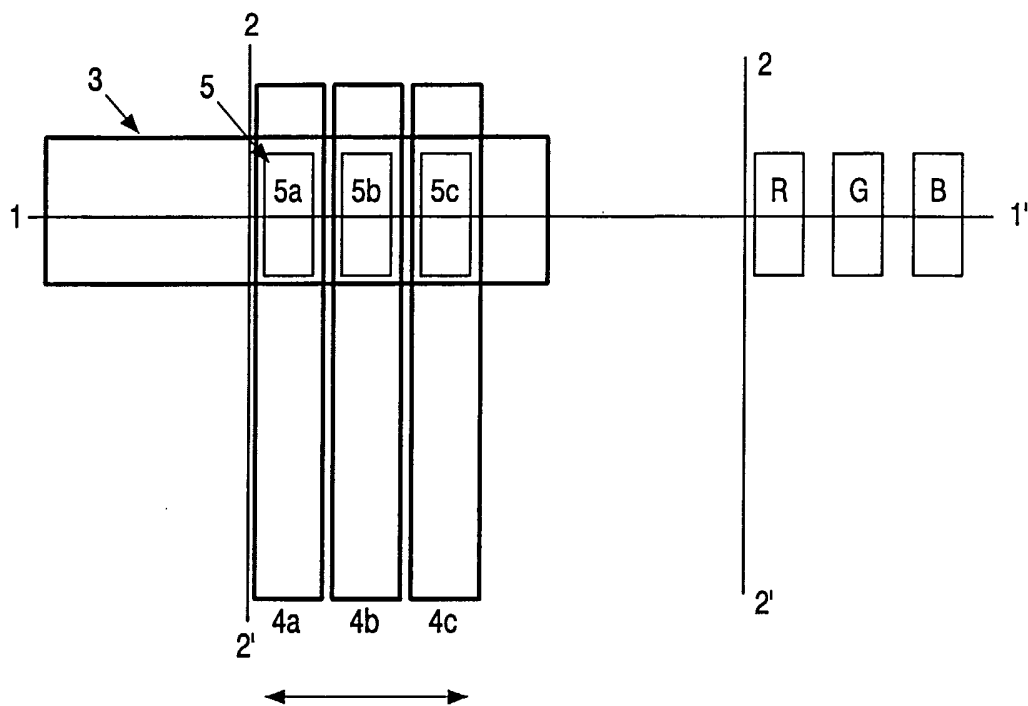


FIG. 5A

FIG. 5B

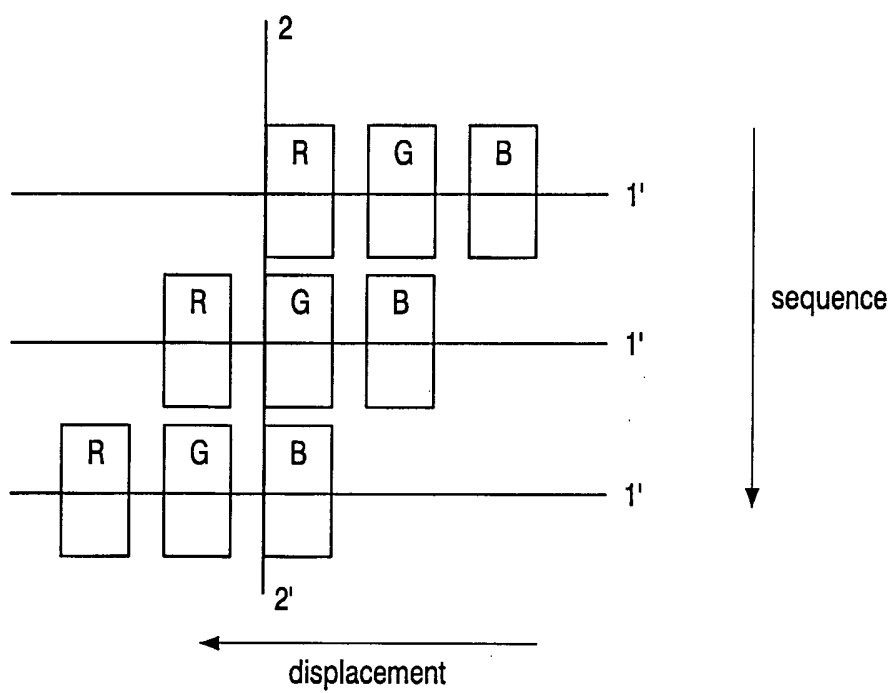


FIG. 6

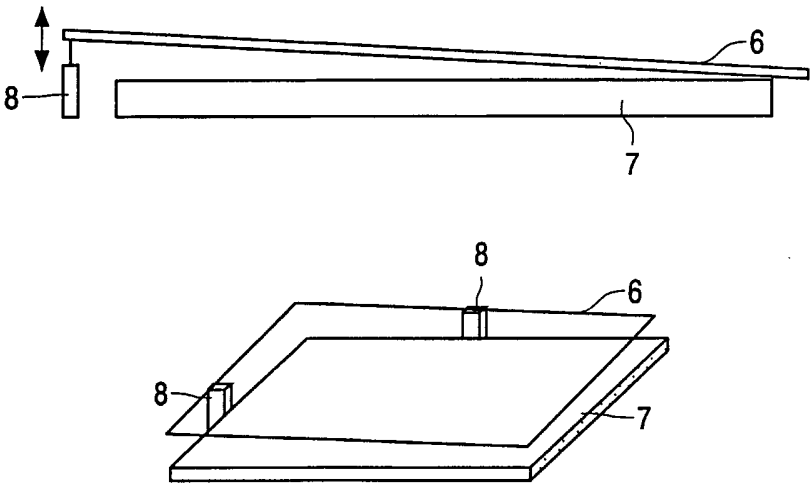


FIG. 7

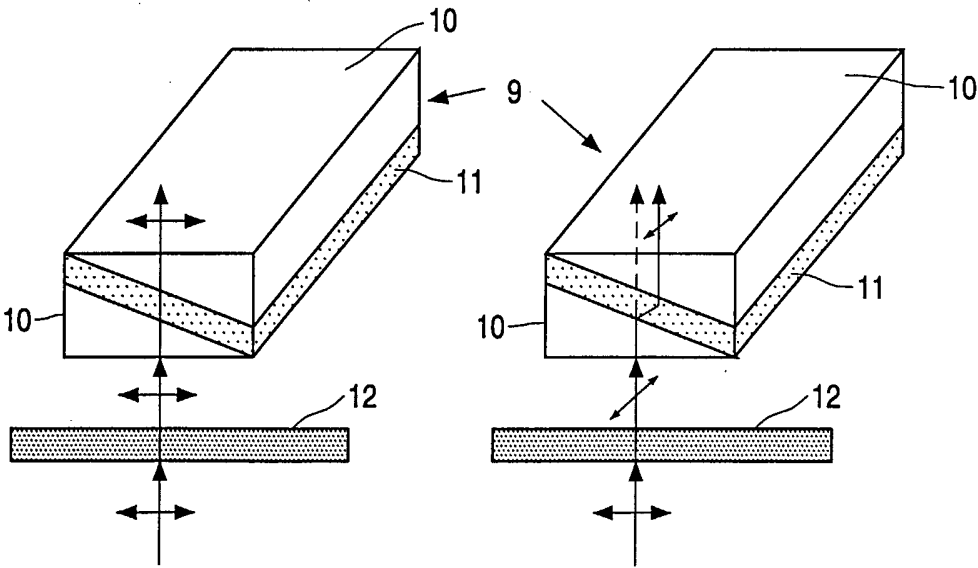


FIG. 8

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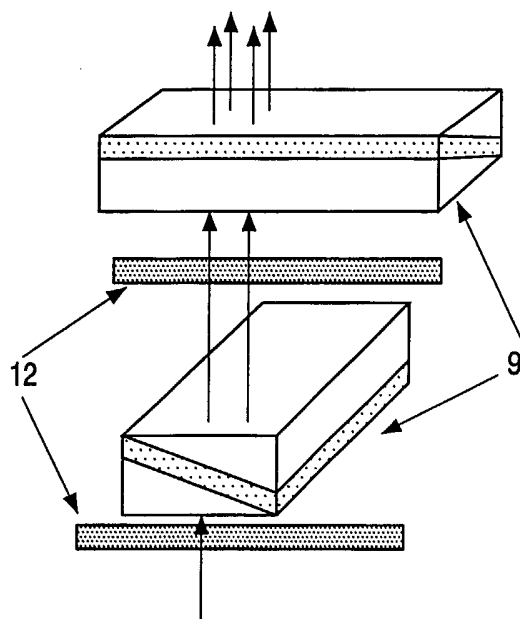


FIG. 9

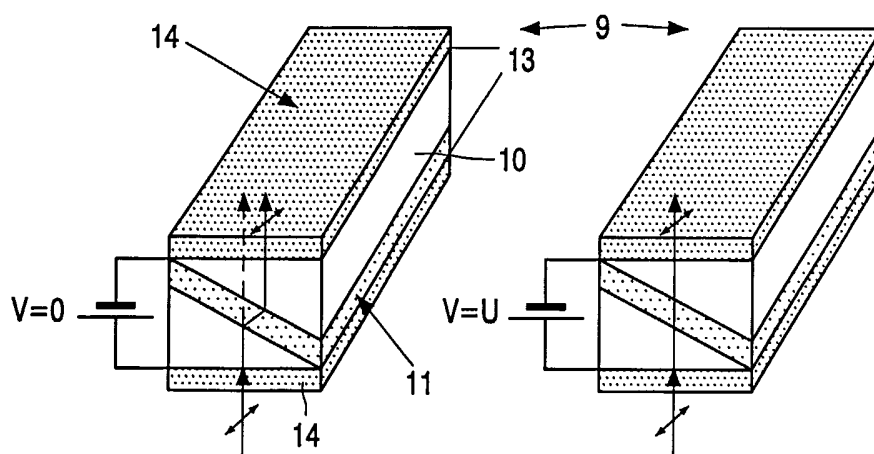


FIG. 10