

DESCRIPTION

TITLE OF INVENTION: SWITCHABLE IMAGING DEVICE,
SWITCHABLE OPTICAL DEVICE, AND DISPLAY

5 TECHNICAL FIELD

This invention relates to switchable imaging optics for use in autostereoscopic (no glasses) 3D displays and other multi-view displays.

10 BACKGROUND ART

For many years people have been trying to create better autostereoscopic 3D displays, and this invention provides a further advance in this field. An autostereoscopic display is a display that gives stereoscopic depth without the user needing
15 to wear glasses. This is accomplished by projecting a different image to each eye. An autostereoscopic 3D display (hereafter 3D display) can be realised by using parallax optic technology such as a parallax barrier or lenticular lenses.

The design and operation of parallax barrier technology
20 for viewing 3D images is well described in a paper from the University of Tokushima Japan ("Optimum parameters and viewing areas of stereoscopic full colour LED display using parallax barrier", Hirotsugu Yamamoto et al., IEICE trans electron, vol E83-c no 10 Oct 2000).

25 Figures 1a and 1b shows the basic design and operation

of parallax barrier technology for use in conjunction with an image display for creating a 3D display. The images for the left eye and right eye are interlaced on alternate columns of pixels of the image display. The slits in the parallax barrier
5 allow the viewer to see only left image pixels from the position of their left eye and right image pixels from the position of their the right eye.

The same autostereoscopic 3D effect as shown in Figures 1a and 1b can be achieved by using lenticular lenses. Each
10 lens is substantially equivalent to a parallax barrier slit. Figures 2a and 2b shows a conventional 3D system comprised of lenticular lenses and an image display.

The lenses image the appropriate pixels of the image display to the viewer's eyes. As shown in Figures 2a and 2b,
15 light from the left image pixels is directed into the observer's left eye, and vice versa. The focal lengths of the lenses are typically designed to be approximately equal to the lens-pixel separation distance (i.e. the focal length of the lens is approximately at the plane of the pixels).

20 The lenticular lenses may also have a light blocking material positioned between the lenses, as described by US7813042B2. The light blocking material reduces light leakage from between the lenses and consequently improves the quality of the 3D image.

25 The technologies illustrated in Figures 1a and 1b and

Figures 2a and 2b can be configured to provide a high quality 3D mode. However, many applications exist whereby a display is also required to operate in a high quality 2D mode. Using the technologies illustrated in Figures 1a to 2b would yield a 2D image with half the native resolution of the image display – this is highly undesirable. For the image display to show an image with 100% native resolution in the 2D mode, the parallax optics (parallax barrier or lenticular) must be switchable between a first mode that provides substantially no imaging function (2D mode) to a second mode of operation that provides an imaging function (3D mode).

An example of a switchable parallax barrier technology is disclosed in US7813042B2. However, switchable parallax barrier technology has the disadvantage that the parallax barrier absorbs light in the 3D mode, reducing transmission by ~65%. This inefficient light usage is a major disadvantage since the 2D mode and 3D mode will have a significantly different brightness. Boosting the brightness of the 3D mode can be achieved at the expensive of increased power consumption, which is highly undesirable, especially for mobile products.

An example of a switchable lens technology, based upon a physical lens in contact with liquid crystal, is disclosed in the paper by Commander et al (EOS Topical Digest Meetings, Microlens Arrays, vol. 5 (1995), pp72-76).

US6069650 discloses an image display used in conjunction with a switchable lens (physical lenses in contact with liquid crystal) to create a display system that is switchable between a 3D mode and a 2D mode. The advantage
5 of this switchable lens system is that the 3D mode is approximately the same brightness as the 2D mode. A first disadvantage of this technology is that the switchable lenses are more complicated and expensive to manufacture than a switchable parallax barrier. A second disadvantage of this
10 technology is the degradation of the 2D mode image quality. This image degradation occurs because the refractive index of the liquid crystal varies as function of temperature and wavelength in a manner that does not exactly match that of the lens material. Consequently, a residual lensing effect
15 occurs that causes an observable brightness non-uniformity.

WO05101855A1 describes the use of electro-wetting lenses that can be used in conjunction with an image display to realise a 3D display that can be switched between a 2D mode and a 3D mode. The disadvantage of this system is that
20 the manufacture of electro-wetting lenses is complicated and expensive.

A liquid crystal lens (LC lens) is a switchable lens that uses conventional liquid crystal display (LCD) manufacturing processes. 3D display systems that use LC lenses have been
25 disclosed by US2007/0296911A1, US07375784 and "30.3

Autostereoscopic Partial 2-D/3-D Switchable Display” by Takagi et al (SID DIGEST 2010 pp 436). The LC lens technologies described above have the disadvantage that the 3D mode is not high quality because the metric of 3D crosstalk for LC lenses is inferior to that of switchable parallax barrier technologies.

An electrode structure to enable a first 3D mode via a LC GRIN lens in a first orientation and second 3D mode via a LCD GRIN lens in a second orientation, from a single LC layer whereby the first and second orientations are orthogonal is disclosed in US2008/0266387A1.

The use of LC lens is also proposed in US 2009/0244682, US 2010/0026920, GB 2455614, and US 2011/0032438. US 2011/0032438 proposes the provision of light blocking members at regions where discontinuities occur in the LC lens.

SUMMARY OF THE INVENTION

A first aspect of the invention provides a switchable imaging device, the device having a first mode of operation in which the device performs an imaging function and a second mode of operation different from the first mode; wherein the device comprises an electro-optic layer and a polarising element disposed in the path of light through the electro-optic layer, wherein, in the first mode of operation the electro-optic

layer comprises at least one first region that performs a lensing action and at least one second region; and wherein the polarising element acts in co-operation with the second region(s) to at least partially absorb light passing through the
5 or each second region. The first mode may be a directional display mode, for example an autostereoscopic 3-D display mode.

It is of course the case that some small degree of absorption of light inherently occurs in practice when light
10 passes through a real polariser. For the avoidance of doubt, it is to be understood that, in the first mode, the absorption by the polariser of light that has passed through the second region(s) of the electro-optic layer is greater than this inherent absorption. The polariser has greater absorption for
15 light that has passed through the second region(s) than for light that has passed through the first region(s).

A second aspect of the invention provides a switchable optical device comprising a liquid crystal layer, the liquid crystal layer having, in one operating mode of the device, a
20 bulk twisted liquid crystal alignment; wherein at least one first region of the liquid crystal layer is switchable by application of a non-zero voltage across the liquid crystal layer to have, in a second operating mode of the device, a second liquid crystal alignment different from the twisted
25 liquid crystal alignment thereby to define a GRIN lens in the

liquid crystal layer.

A third aspect of the invention provides a display comprising an image display panel and a switchable imaging device of the first or second aspect disposed in path of light after passing through the image display panel, i.e. disposed between the image display panel and an observer. This provides a display that may be operable in either a directional display mode such as an autostereoscopic 3D display mode or a 2-D display mode, by controlling the switchable imaging device to be in its first mode or its second mode.

An aspect of the invention comprises a liquid crystal cell that forms a switchable imaging optical device. The switchable imaging optical device can be used in conjunction with an image display, for example, a liquid crystal display (LCD), organic light emitting diode (OLED) display etc. in order to yield a display system that has at least two modes of operation. In a first mode of operation (2D mode), the optical element does not perform an imaging function, thus enabling conventional, high quality 2D images to be viewed on the image display. In a second mode of operation (3D mode), the imaging optical element does perform an imaging function, enabling high quality autostereoscopic 3D images to be viewed on the image display. Switching between the 2D mode and the 3D mode is achieved via the application of an electric field to the liquid crystal layer. In the 3D mode, the optical

element forms an array of GRIN lenses and an array of parallax barriers. The parallax barrier regions attenuate the transmission of light. The combination of GRIN lenses and parallax barriers image light from the pixels of the image display to the user's eyes. Consequently, the user is able to view high quality 3D images on the image display.

The switchable imaging optical device combines the positive features of the liquid crystal parallax barrier technology (low manufacturing costs, high image quality in the 2D mode and low 3D crosstalk in the 3D mode) with the positive features of a switchable lens system (high brightness in the 3D mode). Consequently, a superior switchable imaging optical device for the use in 3D and multi-view applications has been realised. The switchable imaging optical device has great design flexibility since the proportion of parallax barrier to GRIN lens ratio can be varied and customised for any given application.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other objects, advantages and novel features of the

invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

5 BRIEF DESCRIPTION OF THE DRAWINGS

In the annexed drawings, like references indicate like parts or features:

Figures 1a and 1b: Prior Art.

Figures 2a and 1b: Prior Art.

10 Figure 3a: Plan View of first substrate of switchable imaging optic.

Figure 3b: Side View of first substrate of switchable imaging optic.

15 Figure 4a: Plan View of second substrate of switchable imaging optic.

Figure 4b: Side View of second substrate of switchable imaging optic.

Figure 5a: Plan View of switchable imaging optic.

Figure 5b: Side View of switchable imaging optic.

20 Figure 6: Switchable imaging optic and image display.

Figure 7: Switchable imaging optic and image display.

Figure 8: Switchable imaging optic Drive Scheme 1.

Figure 9: Switchable imaging optic Drive Scheme 2.

25 Figure 10: Plot of luminance against viewing angle for Drive Scheme 1.

Figure 11: Plot of 3D Crosstalk against viewing angle for Drive Scheme 1.

Figure 12: Plot of luminance against viewing angle for Drive Scheme 2.

5 Figure 13: Plot of 3D Crosstalk against viewing angle for Drive Scheme 2.

Figure 14: Plot of 3D Crosstalk against viewing angle for Drive Scheme 1 and Drive Scheme 2.

Figure 15a: Modelling switchable imaging optic at 4V.

10 Figure 15b: Modelling switchable imaging optic at 6V.

Figure 16: Micrographs of the GRIN lens focus and parallax barrier.

Figure 17: Plan View of switchable imaging optic.

Figure 18: Plan View of switchable imaging optic.

15 Figure 19: Plan View of switchable imaging optic.

Figure 20a: Plan View 1 of switchable imaging optic.

Figure 20b: Plan View 2 of switchable imaging optic.

Figure 21a: Plan View of second substrate of switchable imaging optic.

20 Figure 21b: Side View of second substrate of switchable imaging optic.

Figure 22a: Plan View of switchable imaging optic.

Figure 22b: Side View of switchable imaging optic.

Figure 23: Switchable imaging optic drive scheme.

25 Figure 24a: Plan View of switchable imaging optic.

Figure 24b: Side View of switchable imaging optic.

Figure 25a: An image display in a portrait (vertical) orientation.

Figure 25b: An image display in a landscape (horizontal) orientation.

Figure 26a: Switchable imaging optic drive scheme for a first orientation.

Figure 26b: Switchable imaging optic drive scheme for a second orientation.

Figure 27a: Plan View of switchable imaging optic.

Figure 27b: Side View of switchable imaging optic.

Figure 28a: Switchable imaging optic drive scheme for a first orientation.

Figure 28b: Switchable imaging optic drive scheme for a second orientation.

Figure 29: Edge seal positioning relative to the electrode structure.

Figure 30a: Positioning of liquid crystal spacers relative to the electrode structure.

Figure 30b: Positioning of liquid crystal spacers relative to the electrode structure.

Figure 31a: Multi-view display using non-oblique switchable imaging optical element and addressing of sub-pixels thereof.

Figure 31b: Multi-view display using non-oblique

switchable imaging optical element and addressing of sub-pixels thereof.

Figure 31c: Multi-view display using oblique switchable imaging optical element and addressing of sub-pixels thereof.

5 Figure 31d: Multi-view display using oblique switchable imaging optical element and addressing of sub-pixels thereof.

Figure 32a: Side view of a switchable imaging.

Figure 32b: Side view of a switchable imaging.

Figure 33a: Side view of a switchable imaging.

10 Figure 33b: Side view of a switchable imaging.

DESCRIPTION OF REFERENCE NUMERALS

1 switchable imaging optical device

2 liquid crystal layer

15 4 image display

5 polariser

6 glue layer

7 polariser

8a 2D-3D switchable display device in 3D mode

20 8b 2D-3D switchable display device in 3D mode

9a left eye

9b right eye

11 a first substrate comprised of an electrode layer and alignment layer

25 11b a first substrate comprised of an electrode layer and

alignment layer

12 a second substrate comprised of an electrode layer
and alignment layer

21 a lens array

5 21b a picture of a physical lens

21c a picture of a physical lens

22 a parallax barrier array

23 a region of liquid crystal beneath a patterned
electrode

10 24 functional form (lateral extent and brightness) of the
parallax barrier region

25 micrograph of GRIN lens focus

26 micrograph of parallax barrier

41 a first substrate of the image display

15 42 a second substrate of the image display

43 pixels of the image display

50 Liquid crystal cell edge seal

51 Liquid crystal cell spacer

111 a first substrate

20 112, 112a, 112b an electrode layer pertaining to the first
substrate

113 an alignment layer pertaining to the first substrate

121 a second substrate

122, 122a, 122b an electrode layer pertaining to the
25 second substrate

1221a a first electrode layer pertaining to the second substrate

123 an alignment layer pertaining to the second substrate

5 124 spatial extent image display

1221 width of the electrode pertaining to the second substrate

1222 pitch of the electrode pertaining to the second substrate

10 1221b width of an electrode pertaining to the second substrate

DS1 a first electrical drive scheme

DS2 a second electrical drive scheme

L1 Luminance response as a function of x

15 L2 Luminance response as a function of x

DESCRIPTION OF EMBODIMENTS

With reference to Figures 3a and 3b, Figures 4a and 4b and Figures 5a and 5b, a switchable imaging optical device 1
20 is fabricated that comprises a liquid crystal cell. With reference to Figure 6 and Figure 7 the switchable imaging optical device 1 is then combined with an image display 4 to yield a 2D-3D switchable display system.

With reference to Figures 3a and 3b, Figures 4a and 4b
25 and Figures 5a and 5b, fabrication of the switchable imaging

optical device 1 will now be described. The first substrate 111 (shown face up in Figure 3a) and second substrate 121 (shown face up in Figure 4a) are coated with transparent electrodes 112, 122 respectively, for example, indium tin oxide (ITO). The electrode layer 122 of the second substrate 121 is patterned in a pre-determined fashion, as illustrated by Figure 4a. The dashed line 124 in Figure 4a shows the approximate spatial extent of the pixelated area of the image display 4. For a 2-View 3D display system which has 1 pixel per image, the pitch 1222, P_e of the electrode is arranged to be approximately twice the pixel pitch of the image display 4. In order to correct for view point, the exact electrode pitch 1222, P_e , is arranged to be equal to $(2 \cdot P_i) / (1 + s/e)$, where P_i is the pixel pitch of the image display 4, s is the distance between the image display pixels 43 and the liquid crystal layer 2 and e is the eye separation distance (typically 65mm). The width 1221 of the electrode may be between 1% and 65% of the electrode pitch 1222. As a general rule, setting the width 1221 of the electrode to be commensurate with the liquid crystal layer 2 thickness, d , was found to produce good 3D performance and provided a basis for subsequent optimisation. The first substrate 111 with electrode 112 and second substrate 121 with electrode 122 are then coated with a standard liquid crystal alignment layer 113, 123 respectively, for example, PI2555 (Dow Corning). The

alignment layers are then baked and rubbed in a standard fashion in order to induce a uniform planar alignment of liquid crystal material. Figure 3a illustrates the first substrate with substantially unpatterned electrode and rubbed alignment layer (alignment layer uppermost) and direction of rubbing shown with arrow, $\phi_1=270^\circ$. Figure 4b illustrates the second substrate with patterned electrode and rubbed alignment layer (alignment layer uppermost) and direction of rubbing shown with a single-headed arrow, $\phi_2=0^\circ$.

With reference to Figures 5a and 5b, the first substrate (alignment layer uppermost) and second substrate (alignment layer lowermost) are then spaced a predetermined distance apart facing each other, with the respective alignment layer rubbing directions and orientated at 90° to each other. Note: the rubbing direction of the second substrate has been mirrored in a vertical plane because the alignment layer is now shown as the lowermost layer, so the rubbing direction, ϕ_2 , now appears be $\phi_2=180^\circ$ when viewed from above. The first substrate and second substrate, are then spaced a predetermined distance apart, **d**, and glued together (Norland Optical Adhesive 91) to form a cell and a liquid crystal material 2 is then injected into the cell. The thickness of the liquid crystal layer 2, **d** can be derived to a first approximation from the formula $\mathbf{d}=\mathbf{W}^2/(8*\mathbf{f}*\Delta\mathbf{n})$ where **W** is the lens width ($\mathbf{W}=\mathbf{P}_e$ for this example), **f** is the focal length

of the lens in air and Δn is the birefringence of the liquid crystal material. The focal length of the lens is arranged to be approximately at the plane of the pixels of the image display 43. The liquid crystal material is a mixture of liquid crystal and chiral dopant, for example, MDA-03-272A (Merck) and chiral dopant, for example R811 (Merck). The chiral pitch of the resulting liquid crystal mixture is generally significantly larger ($\sim \times 20$), than the thickness of the liquid crystal cell. The chirally doped liquid crystal mixture cooperates with the rubbed alignment layers in a standard fashion to form a uniform liquid crystal structure that twists through 90° from the first substrate 11 to the second substrate 12 when no voltage is applied to the electrodes 112, 122. Alternatively, a uniform liquid crystal structure that twists through 90° from the first substrate 11 to the second substrate 12 can be achieved using no chiral dopant and liquid crystal alignment layers on the first substrate 11 and the second substrate 12 that induces an appreciable surface pretilt ($> \sim 2^\circ$). This completes the fabrication of the switchable imaging optical device 1.

With reference to Figure 6, the switchable imaging optical device 1 is combined with an image display 4 to realise a first switchable 2D-3D display system 8a. An image display 4 that is comprised of a lower substrate 41, a pixel layer 43, an upper substrate 42 and a film for controlling polarisation

5 are arranged such that the light output from the image display 4 is linearly polarised and oriented parallel to the rubbing direction of the lower-most substrate of the switchable imaging optical device 1. The lower-most substrate of the switchable imaging optical device 1 (i.e. the substrate closest to the image display 4) may be either the first substrate 11 or the second substrate 12. The film for controlling polarisation 5 may be intrinsic or extrinsic to the operation of the image display 4. The switchable imaging optical device 1 is then adhered to the image display 4 using optical glue 6, for example, Norland Optical Adhesive 65 to form a 2D-3D switchable display system. For a 2-View 3D display system, the distance, **s**, between the pixels of the image display and the liquid crystal layer of the switchable imaging optical device is arranged according to the formula $\mathbf{s}=(\mathbf{V_d} \cdot \mathbf{P_i} \cdot \mathbf{n})/\mathbf{e}$ where **V_d** is the desired viewing distance of the display system, **P_i** is the pitch of the pixels on the image panel 4, **e** is the eye separation distance (typically e~65mm) and **n** is the average refractive index of the material between the pixels of the image display 4 and the liquid crystal layer 2 of the switchable imaging optical device 1 (typically n~1.52). For the viewing of autostereoscopic 3D images, the image panel 4 has pixel information for the left and right eye interlaced on alternate pixels. The lateral position of the switchable imaging optical device 1 relative to the image

display 4 is arranged so that an on-axis user receives right eye pixel information, R, with their right eye 9a and receives left eye pixel information, L, with their left eye 9b.

With reference to Figure 7, the switchable imaging optical device 1 is combined with an image display 4 to realise a second switchable 2D-3D display system 8b. The switchable 2D-3D display systems 8a and 8b are identical except for the addition of a linear polariser 7 adhered to the switchable 2D-3D display system 8b (Figure 7). The linear polariser 7 is adhered to the outer-most substrate of the switchable imaging optical device 1 (substrate furthest from the image display 4) such that the transmission axis of linear polariser 7 is oriented at 90° to the transmission axis of the linearly polarising element 5. The polarisation elements 5 and 7 are therefore crossed; the switchable imaging optical device 1 is therefore required to convert or rotate the polarisation state of light passing through it in order for light to exit the polariser 7. This completes the fabrication of the switchable 2D-3D display systems 8a and 8b.

With reference to Figure 8, a first driving scheme DS1 for the switchable imaging optical device 1 is proposed. With zero potential difference between the first electrode 112 and the second electrode layer 122, no imaging function is performed by the switchable imaging optical device 1 and consequently the display systems 8a and 8b enables viewing

of 2D images with the full native resolution of the image display 4. In practice, this is achieved by applying 0 volts to both the first electrode 112 and second electrode 122. To enable the viewing of 3D images on the display systems 8a and 8b, 3D image content must be addressed to the image display 4 and the switchable imaging optical device 1 must be switched to perform an imaging function. The imaging function is activated via the application of a potential difference between the first electrode 112 and the second electrode 122 of V_1 volts, where V_1 is the root mean square (rms) voltage. Typically, V_1 is typically between 2V and 15V with a preferred value of around 3-7V. The voltage V_1 can be tuned to optimize the 3D performance of a given display systems 8a and 8b in situ. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages (between 25Hz and 1000Hz) while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking.

With reference to Figure 9, a second driving scheme DS2 for the switchable imaging optical device 1 is proposed. The imaging function is activated via the application of a potential difference between the first electrode 112 and the second electrode 122 of V_2 volts for time T_1 followed by the application of a potential difference between the first electrode 112 and the second electrode 122 of V_1 volts. The

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voltages V1 and V2 are rms voltages. Typically, V2 is between 10V and 80V with a preferred value of around 50V. Typically, T1 is between 0.2 seconds and 6 seconds with a preferred value of around 2 seconds. Typically, V1 is between 2V and 15V with a preferred value of around 4-7V. The voltage V1 can be tuned to optimize the 3D performance of a given display systems 8a and 8b in situ. During the time T1, a new liquid crystal structure is nucleated. The nucleated LC structure is energetically stable at V1 volts. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages (between 25Hz and 1000Hz) while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking.

Microscopic analysis revealed that unwanted liquid crystal structures could form when liquid crystal cell gap gradients occur in the vicinity of fringing electric fields from electrode edges. Patterning of the edge seal (glue line) and/or patterning of the liquid crystal cell spacers may prevent liquid crystal cell gap gradients occurring in the vicinity of fringing electric fields from electrode edges.

To prevent the formation of unwanted liquid crystal structures, the edge seal (glue line) may optionally be positioned away from the vicinity of fringing electric fields that come from the edge of electrode 122. With reference to Figure 29, the edge seal 50 (dashed line) may be positioned on

top of the electrode 122 and away from the edges of the electrode 122. Alternatively, the edge seal (50) may be positioned not on top of the electrode 122 and away from the edges of the electrode 122, for example near the substrate boundary (the full line in fig 29).

Additionally or alternatively, to prevent the formation of unwanted liquid crystal structures, liquid crystal cell spacers may optionally be positioned away from the vicinity of fringing electric fields that come from the edge of electrode 122. With reference to Figure 30a and Figure 30b, the liquid crystal cell spacers 51 may be positioned away from the edge of the electrode 122. The liquid crystal cell spacers 51 may be positioned between the electrode fingers (Figure 30a) and/or the liquid crystal cell spacers 51 may be positioned on top of the electrode fingers (Figure 30b). The liquid crystal cell spacers may be patterned using a photolithographic technique. The shape of the liquid crystal cell spacers may be circular, cylindrical, rectangular etc. The shape of the liquid crystal cell spacers may regular and/or irregular. The distribution of the spacer may be uniform or non-uniform. The density distribution of the liquid crystal cell spacers should be high enough to ensure a reliable, uniform cell gap. The density distribution of the liquid crystal cell spacers should be low enough to ensure a good quality imaging of the optical element is still obtained. The area density of the liquid crystal

cell spacers may be in the range 10% to 0.01%.

The following switchable 2D-3D display system was constructed and driven using the following parameters: liquid crystal thickness, $d=20\mu\text{m}$, liquid crystal birefringence, $\Delta n=0.20$, chiral pitch of liquid crystal = $400\mu\text{m}$, electrode width $1221=16\mu\text{m}$, electrode pitch, $P_e=206.686\mu\text{m}$, pixel pitch, $P_i=103.5\mu\text{m}$, rubbing direction of the first substrate (alignment layer uppermost) $\phi_1=270^\circ$, rubbing direction of the second substrate (alignment layer uppermost) $\phi_2=0^\circ$, $s=950\mu\text{m}$, $V_1=5\text{V}$, $V_2=50\text{V}$, $T_1=3\text{s}$. Plots that record the optical response at $V_d \sim 400\text{mm}$ are shown in Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14.

With reference to Figure 6, Figure 7 and Figure 8, the angular dependant brightness of display system 8a (circles) and 8b (squares), driven with Drive Scheme 1 (DS1) is shown in Figure 10. The image displayed on image display 4 contains left eye pixels that are turned on and right eye pixels that are turned off. Between -4° and -5° , it is calculated from Figure 10 that the peak brightness of display system 8b (squares) is approximately $\sim 7\%$ darker than display system 8a (circles). Consequently, in terms of 3D mode brightness, there is little difference between display system 8a (circles) and 8b (squares) using Drive Scheme 1 (DS1).

A plot of self-normalised 3D crosstalk for display system 8a (circles) and 8b (squares), driven with Drive Scheme 1

(DS1) is shown in Figure 11. Figure 11 is derived from Figure 10 and illustrates the amount of left eye information that is seen with the right eye (3D Crosstalk). Between 3° and 6.5° , it is clear from Figure 11 that 3D crosstalk of display system 8b (squares) is lower than display system 8a (circles). Consequently, display system 8b (squares) exhibits a better quality 3D mode than display system 8a (circles).

With reference to Figure 6, Figure 7 and Figure 9, the angular dependant brightness of display system 8a (triangle) and 8b (diamond), driven with Drive Scheme 2 (DS2) is shown in Figure 12. The image displayed on image display 4 contains left eye pixels that are turned on and right eye pixels that are turned off. Between -4° and -5° , it is calculated from Figure 12 that the peak brightness of display system 8b (diamond) is approximately ~7% darker than display system 8a (triangle). Consequently, in terms of 3D mode brightness, there is little difference between display system 8a (triangle) and 8b (diamond) using Drive Scheme 2 (DS2).

A plot of self-normalised 3D crosstalk for display system 8a (triangles) and 8b (diamonds), driven with Drive Scheme 2 (DS2) is shown in Figure 13. Figure 13 is derived from Figure 12 and illustrates the amount of left eye information that is seen with the right eye (3D Crosstalk). Between 3° and 6.5° , it is clear from Figure 13 that 3D crosstalk of display system 8b (diamonds) is lower than display system 8a (triangles).

Consequently, display system 8b (diamonds) will exhibit a better quality 3D mode than display system 8a (triangles).

For completeness, a plot of self-normalised 3D crosstalk for display system 8b driven with Drive Scheme 1, DS1 (squares), and Drive Scheme 2, DS2, (diamonds) is shown in Figure 14. Between 3° and 6.5° , it is clear from Figure 14 that 3D crosstalk of Drive Scheme 2 (diamonds) is much lower than Drive Scheme 1 (squares). Consequently, display system 8b will exhibit a better quality 3D mode when driven with Drive Scheme 2 (DS2). However, Drive Scheme 1 has the advantage that it is simpler and cheaper to implement than Drive Scheme 2. Drive Scheme 1 also has the advantage that it is quicker to switch into the 3D mode than Drive Scheme 2. It is quite conceivable that further optimisation of LC cell parameters, such drive voltage, cell thickness, electrode width, rubbing conditions, LC material etc. would enable similar 3D performance to be achieved using Drive Scheme 1 and Drive Scheme 2.

With reference to Figure 15a, the liquid crystal layer 2 of the switchable optical imaging device 1 has been modelled. The width of the electrode 122 is $20\mu\text{m}$, the thickness of the liquid crystal layer is $20\mu\text{m}$, the birefringence (Δn) of the liquid crystal layer is 0.20. The surface alignment directions of the liquid crystal are as depicted in Figure 5. The electrode 112 has been set to 0V and the electrodes 122 have been set

to 4V (i.e. $V_1=4V$). The region of liquid crystal 23 that is situated beneath the electrodes 122 are substantially vertically aligned and parallel to the electric field lines produced by the electrodes 122, 112. Owing to the orientation of crossed polarisers as depicted in Figure 7 (the polariser axes are aligned with the surface liquid crystal alignment directions), the resulting on-axis optical transmission L1 of the liquid crystal layer 2 shows a drop in transmission 22 at the spatial location of the electrodes 122.

The switchable optical imaging device 1 therefore yields a switchable parallax barrier that absorbs light. The amount of light absorbed by the parallax barrier varies in the x direction, as shown by L1. The tilt angle, θ , of the liquid crystal molecules between the patterned electrodes 122 varies as a function of x, thus a Graded Refractive INDEX (GRIN) lens structure is also realised. The edge of the GRIN lens is situated beneath the electrodes 122 and the middle of the GRIN lens structure is situated between the electrodes 122. The imaging properties of the switchable optical imaging device 1 are a function of the switchable parallax barrier region and the switchable GRIN lens region. By removing the uppermost polariser 7, the parallax barrier part of the switchable optical imaging device 1 is also removed since there is no polariser to absorb light exiting from the switchable optical imaging device 1. With reference to Figure

6, switchable optical imaging device 1 is operating as a switchable GRIN lens only. With reference to Figure 7, switchable optical imaging device 1 is operating as a switchable GRIN lens and a switchable parallax barrier. With
5 reference to Figure 11 and Figure 13, the 3D crosstalk of display system 8b is superior to display system 8a and consequently, the switchable parallax barrier is a desirable, although optional, feature of the switchable optical imaging device 1.

10 Figure 15b depicts the same arrangement of optical components as shown in Figure 15a, except that the voltage on the electrodes 122 has increased to 6V (i.e. $V_1=6V$). The increase in voltage causes more liquid crystal molecules to align vertically 23 beneath the electrodes 122 which changes
15 the details of the on-axis transmission function L2 by increasing the lateral extent of the parallax barrier region 24. The increase in voltage also changes the tilt function form of the liquid crystal molecules situated between the electrodes 122, which in turn also changes the imaging properties of the
20 GRIN lens region. It has therefore been demonstrated that by varying the voltage V_1 , the imaging properties of the switchable optical imaging device 1, which are governed by a first spatial region of parallax barrier and a second spatial region of GRIN lens, can be controlled and therefore optimised
25 for a given display systems 8a and 8b. By studying Figures

15a and 15b, it is intuitively obvious that by changing the width of the electrode 122, the lateral extent of the parallax barrier region will also change. An increase in the width of the electrode 122 corresponds to an increase in the lateral
5 extent of the parallax barrier region 22, 24. The width of the electrode 122 can also affect the imaging properties of the switchable optical imaging device 1 and therefore be optimised for a given display systems 8a and 8b.

Figure 16 depicts, from top to bottom, modelling of the
10 liquid crystal layer 2 of the switchable optical imaging device 1, a lens array 21 and parallax barrier array 22, a micrograph of the GRIN lens focus 25 and micrograph of the parallax barrier 26. The objects 2, 21 and 22 have been aligned laterally (same x position), enabling the modelling of the
15 liquid crystal layer 2 to coincide with the depiction of the lens 21 and parallax barrier. The objects 2, 25 and 26 have also been aligned laterally (same x position), enabling the modelling of the liquid crystal layer 2 to coincide with the micrographs of the lens focus 25 and parallax barrier 26. The
20 liquid crystal beneath the electrode 122 is substantially vertically aligned by the applied electric field and the width of the resulting parallax barrier is shown by the micrograph 26. The micrograph shows that the focal position of the GRIN lens occurs between the parallax barrier regions. In order to aid
25 operational understanding of the switchable optical imaging

device 1, a schematic representation of a lens array 21 and parallax barrier array 22 are shown.

It will be noted that the two GRIN lens are shown in Figure 16 as just touching one another. Whether two adjacent GRIN lens touch one another or not will depend on the width of the electrodes 122, and if the electrodes 122 were wider adjacent GRIN lenses would not touch one another so that there would be a gap between adjacent GRIN lenses. The presence of a gap between adjacent GRIN lenses does not affect the optical performance, however, as the light-attenuating region will coincide with the gap between adjacent GRIN lenses thereby preventing optical cross-talk. (Increasing the width of the electrodes 122 will not affect the position of the apex of the GRIN lens, assuming that all electrodes 122 still have the same width as one another.)

With reference to Figures 5a and 5b, there are an infinite number of ways that the first substrate 11 (alignment layer uppermost) and second substrate 12 (alignment layer lowermost) can be orientated so that the alignment layer rubbing directions (shown with arrows) of the first substrate 11 and the second substrate 12 can be orientated at 90° to each other. Figure 17, Figure 18 and Figure 19 show a further 3 configurations that each have the rubbing direction of the first substrate 11 orientated at 90° to the second substrate 12 when assembled into a liquid crystal cell. The rubbing

directions described for Figure 17, Figure 18 and Figure 19 are in relation to the assembled switchable imaging optical device 1 when viewed from above. Figure 17 shows a rubbing direction of $\varphi_1=0^\circ$ on substrate 11 and a rubbing direction of $\varphi_2=270^\circ$ on substrate 12. Figure 18 shows a rubbing direction of $\varphi_1=45^\circ$ on substrate 11 and a rubbing direction of $\varphi_2=315^\circ$ on substrate 12. Figure 19 shows a rubbing direction of $\varphi_1=225^\circ$ on substrate 11 and a rubbing direction of $\varphi_2=135^\circ$ on substrate 12. It is desirable that the polarisation state of light entering the switchable optical imaging device 1 is arranged to be linearly polarised and in a direction that is parallel to the rubbing direction on the first substrate encountered (i.e. substrate closest to the image display 4). The first substrate encountered by light from the image display 4 may be the first substrate 11 or the second substrate 12 of the switchable optical imaging device 1. A linear polariser 7 can be adhered to the outer face of the substrate 1 such that the transmission axis is perpendicular (crossed) to the transmission axis of light from the polarisation element 5. The rubbing conditions described by Figure 18 were found to yield a switchable imaging optic device 1 with particularly good performance in terms of low optical 3D crosstalk, low switching voltage and fast 2D→3D switching and fast 3D→2D switching. The rubbing conditions described by Figure 18 yield a molecular orientation of the

liquid crystal molecules located in the centre of the liquid crystal layer (i.e. at $d/2$) that are parallel to the stripe electrodes 122. With zero potential difference applied across the liquid crystal layer, the rubbing conditions alone may
5 define the handedness of the twisted structure. Alternatively, a chiral dopant can be added to the liquid crystal material that further cooperates with the rubbing conditions to define the handedness of the twisted structure. With reference to Figure 18, a right handed chiral dopant should be used, for
10 example, R811 (Merck), so that the right handed chiral dopant cooperates with the rubbing conditions. The rubbing conditions described by Figure 18 enable the switchable imaging optic device 1 to be switched to a 3D mode with low 3D crosstalk using Drive Scheme 1 (DS1) as described by
15 Figure 8 with V_1 typically between 2V and 15V with a preferred value of around 2-5V. The use of Drive Scheme 1 (DS1) to achieve low crosstalk performance is preferable to the use of Drive Scheme 2 (DS2).

With reference to Figures 5a and 5b, there are an
20 infinite number of ways that the first substrate 11 (alignment layer uppermost) and second substrate 12 (alignment layer lowermost) can be rubbed and orientated so that the alignment layer rubbing directions (shown with arrows) of the first substrate 11 and the second substrate 12 can be
25 orientated at an angle of 90° to each other. Moreover,

although Figure 5a shows the alignment layer rubbing directions of the first substrate 11 and the second substrate 12 orientated at an angle of 90° to each other, the invention is not limited to this and the alignment layer rubbing directions of the first substrate 11 and the second substrate 12 may be orientated at an angle of less than 90° to each other. There are an infinite number of ways that the first substrate 11 (alignment layer uppermost) and second substrate 12 (alignment layer lowermost) can be rubbed and orientated so that the alignment layer rubbing directions of the first substrate 11 and the second substrate 12 can be orientated at an angle of less than 90° to each other. The use of a rubbing angle between the first substrate 11 (alignment layer uppermost) and second substrate 12 (alignment layer lowermost) of less than 90° , for example, 85° or 80° , will bias the handedness of the liquid crystal twist. If the rubbing angle between the first substrate 11 and second substrate of less than 90° is used, it is preferable to ensure that any liquid crystal pretilt and/or any liquid crystal chiral dopant co-operates with the biased handedness provided by the liquid crystal twist angle. The use of rubbing angles to enable the liquid crystal twist angle to be in the range $80^\circ < \phi < 90^\circ$ may help to prevent the formation of unwanted liquid crystal structures. The orientation of linearly polarised light incident on the LC layer 2 is preferably arranged to be aligned

substantially parallel to the rubbing direction on the lowermost substrate 11 while the orientation of the transmission axis of the exit polariser 7 is preferably arranged to be orientated substantially parallel to the rubbing
5 direction on the uppermost substrate 12.

With reference to Figures 3a and 3b, Figures 21a and 21b and Figures 22a and 22b, fabrication of a switchable imaging optical device 1b according to another embodiment of the invention will now be described. The switchable imaging
10 optical device 1b is comprised of a first substrate 11, as described previously and shown in Figures 3a and 3b, and a second substrate 12b, as shown in Figures 21a and 21b. The second substrate 12b is comprised of a first electrode 122a of width 1221a and a second electrode 122b of width 1221b. The
15 first electrode 122a and the second electrode 122b are interdigitated and electrically distinct from each other. The dashed line 124 in Figure 21a shows the approximate spatial extent of the pixelated area of the image display 4. As a general rule, setting the width of the second electrode 1221b
20 to be commensurate with the liquid crystal layer 2 thickness, **d**, was found to produce good 3D performance and provided a basis for subsequent optimisation. As a general rule, the gap 1221c between the first electrode 122a and the second electrode 122b within the region 124 is arranged to be
25 commensurate with the thickness, **d**, of the liquid crystal

layer 2 and provided a basis for subsequent optimisation. All other features of substrate 12b (alignment layer, rubbing conditions etc.) are identical to the second substrate 12 as shown in Figures 4a and 4b, the details of which have been described previously. The subsequent construction of the switchable imaging optical device 1b is shown in Figure 22. The first substrate 11 (alignment layer 113 uppermost) and second substrate 12b (alignment layer 123 uppermost) are spaced a predetermined distance, **d**, apart, with alignment layers facing each other and glued such that the respective rubbing directions are orientated at 90° to each other, in accordance to the fabrication procedure described previously. A liquid crystal material is then injected into the resulting cell and the switchable imaging optical device 1b is adhered to an image display 4 to yield a switchable 2D-3D display systems 8a and 8b, as shown in Figure 6 or Figure 7 respectively and in accordance to the fabrication procedure described previously. With reference to Figure 23, switching between the 2D mode and 3D mode will now be described. At time T_{on} , the switchable optical imaging device 1b is turned from a non-imaging state (2D mode) to an imaging state (3D mode). At time T_{on} , voltage V_{122a} is applied to electrode 122a and voltage V_{122b} is applied to electrode 122b and voltage V_{112} is applied to electrode 112. The potential difference between electrode 122a (substrate 12b) and electrode 112

(substrate 11) is set to be below the switching threshold (V_{TH}) of the liquid crystal. The switching threshold is typically between 1 and 2 volts. The potential difference between electrode 122a (substrate 12b) and electrode 112 (substrate 11) may be set to zero volts. Alternatively, the voltage on electrode 122a may not be set but allowed to have a floating value. The potential difference between electrode 122b (substrate 12b) and electrode 112 (substrate 11) can be in tuned in the range 2V to 40V to optimise performance, with a preferred value of around 5V. With reference to Figure 23, the imaging function of the switchable optical imaging device 1b can for example be activated by applying 800mV to electrode 122a, 5V to electrode 122b and 0V to electrode 112. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages, at a frequency of between 25Hz and 1000Hz, while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking. If a voltage of alternating polarity is applied to the electrode 122a and electrode 122b then it may be advantageous that the voltages applied to 122a and electrode 122b are in phase.

The device of Figures 21a and 21b again is selectively operable in a first, imaging mode in which the device comprises at least one region that performs a lensing action and at least one region that at least partially attenuates light

passing through the or each second region – and preferably comprises a plurality of regions that perform a lensing action and a plurality of regions that at least partially attenuates light so as to define a parallax barrier. For the drive scheme
5 of Figure 23, the light-attenuating regions are defined under the thin electrodes 122b and the apexes of the GRIN lens are under the wide electrodes 122a. As with the embodiment of Figures 5a and 5b, whether or not the edges of adjacent GRIN lenses meet one another depends on the width of the thin
10 electrodes 122b.

With reference to Figures 21a and 21b, Figures 24a and 24b, Figures 25a and 25b and Figures 26a and 26b fabrication of a switchable imaging optical device 1c according to another embodiment of the invention will now be
15 described. The switchable imaging optical device 1c is selectively operable in a first imaging mode in which it predominantly performs a lensing and parallax barrier action in a first orientation and in a second imaging mode in which it predominantly performs a lensing and parallax barrier
20 action in a second orientation as well as in a mode that performs no imaging or substantially no imaging for any orientation. The first orientation and second orientation can be arranged to be orthogonal to each other. Consequently, a switchable 2D-3D display system can be realised whereby the
25 display system is switchable between a 2D mode, a first 3D

mode and a second 3D mode. In the first 3D mode, 3D images are viewed when the image display 4 is in a portrait (vertical) orientation, see Figure 25a. In the second 3D mode, 3D images are viewed when the image display 4 is in a landscape (horizontal) orientation, see Figure 25b. With reference to Figure 21a and 21b, fabrication of the substrate 12b pertaining to the switchable imaging optical device 1c has been described previously. With reference to Figures 24a and 24b, the details of the substrate 11b (electrode arrangement, alignment layer, rubbing direction) are the same as substrate 12b. With reference to Figures 24a and 24b, the formation of a switchable imaging optical device 1c from substrate 11b (alignment layer uppermost) and substrate 12b (alignment layer uppermost) are shown and adhere to the same fabrication procedure as described previously. The subsequent integration of optical switchable imaging optical device 1c with an image display 4 to form a switchable 2D-3D display system (8a and 8b) is realised using the fabrication procedure as described previously. With reference to Figures 26a and 26b, switching between the 2D mode and 3D mode will now be described. At time T_{on} , the switchable optical imaging device 1c is turned from a non-imaging state (2D mode) to an imaging state (3D mode). Switching between a 2D mode and 3D mode of a first orientation (for example, portrait 3D mode) is illustrated by the driving scheme in Figure 26a.

At time T_{on} , voltage V_{122a} is applied to electrode 122a and voltage V_{122b} is applied to electrode 122b and voltage V_{112a} is applied to electrode 112a and voltage V_{112b} is applied to electrode 112b. The potential difference between electrodes 112a and 112b is zero volts (so that the electrodes 112a and 112b form a pseudo-planar electrode - that is, the electrodes 112a and 112b together effectively act as a single electrode that extends over the entire active area of the device). The potential difference between electrode 122a (substrate 12b) and electrodes 112a and 112b (substrate 11b) is set to be below the switching threshold (V_{TH}) of the liquid crystal. The switching threshold is typically between 1 and 2 volts and so a potential difference between electrode 122a (substrate 12b) and electrodes 112a and 112b (substrate 11b) of around 800mV was found to give good performance. The potential difference between electrode 122b (substrate 12b) and electrodes 112a and 112b (substrate 11b) can be in tuned in the range 3V to 40V to optimise performance, with a preferred value of around 5V. With reference to Figure 26a, the imaging function of the switchable optical imaging device 1c can therefore be activated by applying 800mV to electrode 122a, 5V to electrode 122b and 0V to electrode 112a and 0V to electrode 112b. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages (between 25Hz and 1000Hz) while maintaining the magnitude

of the applied voltage is advantageous in order to prevent image sticking. If a voltage of alternating polarity is applied to the electrode 122a and electrode 122b for a 3D mode in the Portrait orientation, then it may be advantageous that the

5 voltages applied to 122a and electrode 122b are in phase. This concludes the switching between a 2D mode and 3D mode of a first orientation (for example, portrait 3D mode) as illustrated by the driving scheme in Figure 26a. Switching between a 2D mode and 3D mode of a second orientation (for

10 example, landscape 3D mode) is illustrated by the driving scheme in Figure 26b. At time T_{on} , voltage V_{122a} is applied to electrode 122a and voltage V_{122b} is applied to electrode 122b and voltage V_{112a} is applied to electrode 112a and voltage V_{112b} is applied to electrode 112b. The potential difference

15 between electrode 122a and electrode 122b is zero volts (so that the electrodes 122a and 122b form a pseudo-planar electrode - that is, they together effectively act as a single electrode that extends over the entire active area of the device). The potential difference between electrode 112a

20 (substrate 11b) and electrodes 122a and 122b (substrate 12b) is set to be below the switching threshold (V_{TH}) of the liquid crystal. The switching threshold is typically between 1 and 2 volts and so a potential difference between electrode 112a (substrate 11b) and electrodes 122a and 122b (substrate 12b)

25 of around 800mV was found to give good performance. The

potential difference between electrode 112b (substrate 11b) and electrodes 122a and 122b (substrate 12b) can be in tuned in the range 3V to 40V to optimise performance, with a preferred value of around 5V. With reference to Figure 26b, 5 the imaging function of the switchable optical imaging device 1c can therefore be activated by applying 800mV to electrode 112a, 5V to electrode 112b, 0V to electrode 122a and 0V to electrode 122b. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages 10 (between 25Hz and 1000Hz) while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking. If a voltage of alternating polarity is applied to the electrode 112a and electrode 112b for a 3D mode in the Landscape orientation, then it may be advantageous that the 15 voltages applied to 112a and electrode 112b are in phase. This concludes the switching between a 2D mode and 3D mode of a second orientation (for example, landscape 3D mode) as illustrated by the driving scheme in Figure 26b.

Alternatively, the switchable imaging optical device 1c as 20 described previously may also be realised by using an uppermost substrate as illustrated in Figures 4a and 4b and lowmost substrate as illustrated in Figures 4a and 4b. Either Driving Scheme 1 (DS1) or Driving Scheme 2 (DS2) may be employed to yield an imaging mode in a first orientation (for 25 example, portrait orientation) and an imaging mode in a

second orientation (for example, landscape orientation).

With reference to Figures 21a and 21b, Figures 25a and 25b, Figures 27a and 27b and Figures 28a and 28b, fabrication of a switchable imaging optical device 1d according to another embodiment of the invention will now be described. The switchable imaging optical device 1d is selectively operable in a first imaging mode in which it predominantly performs a parallax barrier action in a first orientation and a second imaging mode in which it predominantly performs a lensing action and a parallax barrier action in a second orientation as well as in a mode that performs no imaging or substantially no imaging for any orientation. The first orientation and second orientation can be arranged to be orthogonal to each other. Consequently, a switchable 2D-3D display system can be realised whereby the display system is switchable between a 2D mode, a first 3D mode and a second 3D mode. In the first 3D mode, 3D images are viewed when the image display 4 is in a portrait (vertical) orientation. In the second 3D mode, 3D images are viewed when the image display 4 is in a landscape (horizontal) orientation. If the 3D mode for the landscape (horizontal) orientation is achieved when the switchable imaging optical device 1d predominantly performs a parallax barrier action, then the 3D mode for the portrait (vertical) orientation is achieved when the switchable imaging optical device 1d

predominantly performs a lensing action. If the 3D mode for the landscape (horizontal) orientation is achieved when the switchable imaging optical device 1d predominantly performs a lensing action, then the 3D mode for the portrait (vertical) orientation is achieved when the switchable imaging optical device 1d predominantly performs a parallax barrier action. If the image display 4 is comprised of a standard arrangement of colored sub-pixels such that in the portrait (vertical) orientation any given row of sub-pixels proceeds cyclically through red, green, blue, red etc. and given column of sub-pixels are of a single colour, then it is preferable that the switchable imaging optical device 1d predominantly performs a parallax barrier action in order to yield a 3D mode in the portrait (vertical) orientation since colour artefacts are minimised. With reference to Figures 21a and 21b, fabrication of the substrate 11b pertaining to the switchable imaging optical device 1d that predominantly performs a lensing action has been described previously, substrate 11b is essentially the same as substrate 12b. With reference to Figures 27a and 27b, fabrication of the substrate 12c pertaining to the switchable imaging optical device 1d that predominantly performs a parallax barrier action is comprised of a first electrode 122d of width 1221d and a second electrode 122e of width 1221e. The electrode 122d and 122e are interdigitated and distinct. The ratio of electrode width

122e to 122d (i.e. 1221e/1221d) is typically within the range 1 to 3. The gap 1221c between the electrodes 122d and 122e is subject to the same design constraints as discussed previously. With reference to Figures 27a and 27b, the formation of a switchable imaging optical device 1d from substrate 11b (alignment layer uppermost) and substrate 12c (alignment layer uppermost) are shown and adhere to the same fabrication procedure as described previously. The subsequent integration of optical switchable imaging optical device 1d with an image display 4 to form a switchable 2D-3D display system (8a and 8b) is realised using the fabrication procedure as described previously. With reference to Figures 28a and 28b, switching between the 2D mode and 3D mode will now be described. At time T_{on} , the switchable optical imaging device 1d is turned from a non-imaging state (2D mode) to an imaging state (3D mode). Switching between a 2D mode and 3D mode of a first orientation (for example, portrait 3D mode) is illustrated by the driving scheme in Figure 28a. At time T_{on} , voltage V_{122d} is applied to electrode 122d and voltage V_{122e} is applied to electrode 122e and voltage V_{112a} is applied to electrode 112a and voltage V_{112b} is applied to electrode 112b. The potential difference between electrode 112a and electrode 112b is zero volts. The potential difference between electrode 122d and electrode 112a (and electrode 112b) is zero volts. The potential difference between electrode

122e and electrodes 112a and 112b is within the range 2V to 40V. With reference to Figure 28a, the imaging function of the switchable optical imaging device 1d can therefore be activated by applying, for example, 20V to electrode 122e, 0V to electrode 122d, 0V to electrode 112a and 0V to electrode 112b. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages (between 25Hz and 1000Hz) while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking.

10 This concludes the switching between a 2D mode and 3D mode of a first orientation (for example, portrait 3D mode) as illustrated by the driving scheme in Figure 28a. Switching between a 2D mode and 3D mode of a second orientation (for example, landscape 3D mode) is illustrated by the driving

15 scheme in Figure 28b. At time T_{on} , voltage V_{112a} is applied to electrode 112a and voltage V_{112b} is applied to electrode 112b and voltage V_{122d} is applied to electrode 122d and voltage V_{122e} is applied to electrode 122e. The potential difference between electrode 122d and 122e is zero volts. The potential

20 difference between electrode 112a and electrodes 122d and 122c (substrate 12c) is set to be below the switching threshold (V_{TH}) of the liquid crystal. The switching threshold is typically between 1 and 2 volts. The potential difference between electrode 112a (substrate 11b) and electrodes 122d

25 and 122e (substrate 12c) may be set to zero volts.

Alternatively, the voltage on electrode 122a may not be set but allowed to have a floating value. The potential difference between electrode 112b (substrate 11b) and electrodes 122d and 122e (substrate 12c) can be tuned in the range 2V to 40V to optimise performance, with a preferred value of around 5V. With reference to Figure 28b, the imaging function of the switchable optical imaging device 1d can for example be activated by applying 800mV to electrode 112a, 5V to electrode 112b, 0V to electrode 122d and 0V to electrode 122e. As according to standard liquid crystal drive schemes, changing the polarity of the applied voltages (between 25Hz and 1000Hz) while maintaining the magnitude of the applied voltage is advantageous in order to prevent image sticking. This concludes the switching between a 2D mode and 3D mode of a second orientation (for example, landscape 3D mode) as illustrated by the driving scheme in Figure 28b.

With reference to Figure 9, it is desirable that the liquid crystal nucleation time T_1 be as short as possible to facilitate fast switching between the non-imaging function and the imaging function of the switchable imaging optical device 1. With reference to Figure 9, it is also desirable that the nucleation voltage V_2 is as low as possible. Various nucleation schemes have been previously described in the literature and so will only be described here briefly. The nucleation time T_1 and voltage V_2 may be optimised via the

use of patterned surface alignment on the layers 113 and 123. A first example; layer 113 and/or layer 123 may be patterned to induce both planar liquid crystal alignment (low liquid crystal pretilt) and vertical liquid crystal alignment (high liquid crystal pretilt) – this is known as patterned zenithal alignment. A second example; layer 113 and/or layer 123 may be patterned to induce patterned planar alignment for at least 2 different directions (i.e. patterned azimuth alignment). A specific example of patterned azimuth alignment is shown in Figure 20a (plan view 1) and Figure 20b (plan view 2), where the surface alignment of the first substrate 11 (alignment layer uppermost) and the second substrate 12 (alignment layer lowermost) have been patterned, the pitch of the patterning equal to half the electrode pitch on substrate 12 (as denoted by the dashed line). The two patterned rubbing directions on the first substrate 11 are at $\phi_{11}=315^\circ$ and $\phi_{12}=225^\circ$. The two patterned rubbing directions on the second substrate 12 are at $\phi_{21}=225^\circ$ and $\phi_{22}=315^\circ$. The lateral alignment of the first substrate 11 and second substrate 12 is also shown in Figure 20, such that $\phi_{11}=315^\circ$ and $\phi_{21}=225^\circ$ form a first liquid crystal alignment region and $\phi_{12}=225^\circ$ and $\phi_{22}=315^\circ$ form a second liquid crystal alignment region. It may be desirable not to add a chiral dopant to the liquid crystal material when a patterned surface alignment treatment is undertaken.

With reference to Figure 9, nucleation time T1 and voltage V2 may be optimized via patterning the thickness of the liquid crystal layer 2. Nucleation time T1 and voltage V2 may be optimized via the use polymer networks. For example, a reactive mesogen (RM 84, Merck) is added to the liquid crystal 2 at a low concentration (~1%-5%). Liquid crystal nucleation is undertaken for T1 at V2. After the initial nucleation period T1, the liquid crystal and reactive mesogen mixture are exposed to UV light and a polymer network is formed within the liquid crystal layer. Subsequent nucleation is then achieved at a reduced value of T1 and/or V2.

Another method of reducing T1 and V2 is by choosing an liquid crystal material with a higher $\Delta\epsilon$ and by minimising the thickness of the liquid crystal layer, **d**.

With reference to Figure 6 and Figure 7, the embodiments thus far described pertain to a 2-View display system. In a 2-View display system, 2 different images are imaged by an optical device towards the user who is situated in the optical far field. In general, the switchable imaging optical device 1 described in the preceding embodiments can be designed to operate for multi-view display system where n images are imaged towards the user who is situated in the optical far field.

With reference to Figure 6, Figure 7, Figure 25a, Figure 25a, the embodiments thus far described pertain to a

switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components whereby the lens 21 and parallax barrier 22 components are substantially aligned parallel to the rows or columns of the pixels 43 of the image display 4 as shown in Figure 31a or Figure 31b. If lens 21 and parallax barrier 22 components are substantially aligned parallel the columns of pixels 43 of the image display 4, then an imaging function is performed on the pixels in a plane that is substantially perpendicular to the columns of pixels 43 and parallel to the rows of the pixels 43. For viewing multi-view images, such as 3D, a user's eyes must be substantially positioned within the plane that is substantially perpendicular to the columns of pixels 43 and substantially parallel to the rows of the pixels.

With reference to Figure 31b, a switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components is substantially aligned with columns of pixels 43 of an image display 4. The spatial extent of the optical element is indicated by the dashed line. The pixels 43 of the image display 4 have been ascribed an upper index of R, G or B to indicate the sub-pixel's colour (R=Red, G=Green, B=Blue) and have been ascribed a lower index of either L or R to indicate whether the sub-pixel is imaged to the Left eye or Right eye respectively. An image display 4 with a Landscape orientation (as shown in Figure 25b) may have rows of pixels

(as illustrated in Figure 31b) that contain sub-pixels of the same colour and columns of sub-pixels (as illustrated in Figure 31b) that contain a cyclic arrangement of coloured sub-pixels (red, green and blue for example). The arrangement of the switchable imaging optical device 1 with respect the pixels 43 as shown in Figure 31b illustrates that all coloured sub-pixels are imaged to all angles in the viewing plane which is substantially perpendicular to columns and parallel to the rows. Consequently, with the user's eyes positioned in the plane for the observing multi-view images, the user will therefore see every colour of sub-pixel regardless of the viewing angle. Thus Figure 31b enables a good quality multi-view display.

With reference to Figure 31a, a switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components is substantially aligned with columns of pixels 43 of an image display 4. The spatial extent of the optical element is indicated by the dashed line. The pixels 43 of the image display 4 have been ascribed an upper index of R, G or B to indicate a sub-pixel's colour (R=Red, G=Green, B=Blue) and have been ascribed a lower index of either L or R to indicate whether the sub-pixel is imaged to the Left eye or Right eye respectively. An image display 4 with a Portrait orientation (as shown in Figure 25a) may have rows of pixels (as illustrated in Figure 31a) that contain a cyclic

arrangement of coloured sub-pixels (red, green and blue for example) and columns of sub-pixels of the same colour (as illustrated in Figure 31a). The arrangement of the switchable imaging optical device 1 with respect the pixels 43 as shown in Figure 31a illustrates that specific coloured sub-pixels are imaged to specific angles in the viewing plane which is substantially perpendicular to columns and parallel to the rows. Consequently, with the user's eyes positioned in the plane for the observing multi-view images, the user will therefore see sub-pixel colour of a specific colour at a specific viewing angle. The resulting multi-view display may therefore exhibit angular dependent colour artefacts and therefore may not enable a good quality multi-view display. In order to lessen the described colour artefact problem, the switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components may be orientated at an oblique angle with respect to the rows and columns so that the lens 21 and parallax barrier 22 components are no longer substantially aligned parallel/perpendicular to the rows/columns.

With reference to Figure 31c, a switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components is aligned at an angle of approximately 20° (assuming a white pixel is square) with respect to the columns of pixels 43 of an image display 4. (By stating that a white pixel is "square", is meant that the sub-pixels making

up a white pixel (eg, a red sub-pixel, a green sub-pixel and a blue sub-pixel for an RGB display) combine to give a white pixel that is a square.) The alignment angle is derived from the fact that 1/3 of a white pixel is traversed horizontally while a whole white pixel is traversed vertically by the lens array 21 and parallax barrier array 22. Consequently, the alignment angle of the lens 21 and parallax barrier 22 components is substantially $\tan^{-1}\left(\frac{1}{3}\right)$. The pitch of the switchable imaging optical device 1 substantially covers 5 sub-pixels. The arrangement of the switchable imaging optical device 1 with respect the pixels 43 as shown in Figure 31c coupled with the image data (sub-pixel=Left eye image data OR sub-pixel=Right eye image data OR sub-pixel=OFF) addressed to the sub-pixels illustrates that with user's eyes positioned in the plane for observing multi-view images, the user will therefore see every colour of sub-pixel regardless of the viewing angle. Thus Figure 31c lessens the aforementioned colour artefact problem and enables a good quality multi-view display.

With reference to Figure 31d, a switchable imaging optical device 1 comprised of lens 21 and parallax barrier 22 components is aligned at an angle of approximately 12° (assuming a white pixel is square) with respect to the columns of pixels 43 of an image display 4. The alignment angle is derived from the fact that 2/3 of a white pixel is

traversed horizontally while 3 white pixels is traversed vertically by the lens array 21 and parallax barrier array 22. Consequently, the alignment angle of the lens 21 and parallax barrier 22 components is substantially $\tan^{-1}\left(\frac{2}{9}\right)$. The pitch of the switchable imaging optical device 1 substantially covers 5 sub-pixels. The arrangement of the switchable imaging optical device 1 with respect the pixels 43 as shown in Figure 31d coupled with the image data (sub-pixel=Left eye image data OR sub-pixel=Right eye image data OR sub-pixel=OFF) addressed to the sub-pixels illustrates that with user's eyes positioned in the plane for observing multi-view images, the user will therefore see every colour of sub-pixel regardless of the viewing angle. Thus Figure 31d lessens the aforementioned colour artefact problem and enables a good quality multi-view display.

With reference to Figure 32a and Figure 32b, a switchable imaging optical device 1 comprised of a first substrate 11 with unpatterned electrode 112 (alignment layer omitted for clarity) and second substrate 12 with patterned electrode 122 (alignment layer omitted for clarity) creates a lens region and a parallax barrier region. The width of the lens region is approximately commensurate with the gap between successive electrodes 122 and is located substantially between the electrodes 122. The width of the parallax barrier region is approximately commensurate with

the width of the electrodes 122 and is located substantially under the electrodes 122. The lens region and parallax barrier region may be distinct or may overlap. With reference to Figure 32a and Figure 32b, controlling the width of the lens region (LW1 or LW2) and the width of the parallax barrier region (BW1 or BW2) is determined substantially by the predetermined width of the electrode 122. Figure 32a illustrates a switchable imaging optical device 1 with a narrow width parallax barrier region relative to the width of the lens region ($LW1 \gg BW1$ or $LW1 > BW1$). Figure 32b illustrates a switchable imaging optical device 1 with a parallax barrier region and a lens region of commensurate width ($LW2 \sim BW2$). For a given image display 4 and multi-view application, there are various advantages and disadvantages to the designs illustrated by Figure 32a and Figure 32b. An advantage of the design illustrated in Figure 32a over Figure 32b is that multi-view images, such as autostereoscopic 3D images, will be brighter since the lateral extent of parallax barrier in Figure 32a is less than the lateral extent of parallax barrier in Figure 32b. An advantage of the design illustrated in Figure 32b over Figure 32a is that the liquid crystal layer thickness $d2$ will be less than the liquid crystal layer thickness $d1$ (in general, the thickness of the liquid crystal layer 2, d can be derived to a first approximation from the formula $d = W^2 / (8 * f * \Delta n)$ where W is the lens width, f is the

focal length of the lens in air and Δn is the birefringence of the liquid crystal material - the focal length of the lens is arranged to be approximately at the plane of the pixels of the image display). Consequently, the switchable imaging optical
5 device 1 has great design flexibility since the proportion of parallax barrier 22 to GRIN lens 21 ratio can be varied and customised for any given application.

With reference to Figure 33a and Figure 33b, a switchable imaging optical device 1 comprised of a first
10 substrate 11 with unpatterned electrode 112 (alignment layer omitted for clarity) and second substrate 12 with patterned electrode 122 (alignment layer omitted for clarity) creates a lens region and a parallax barrier region. The width of the lens region is approximately commensurate with the gap
15 between successive electrodes 122 and is located substantially between the electrodes 122. The width of the parallax barrier region is approximately commensurate with the width of the electrodes 122 and is located substantially under the electrodes 122. The lens region and parallax barrier
20 region may be distinct or may overlap. With reference to Figure 33a and Figure 33b, controlling the width of the lens region (LW3 or LW4) and the width of the parallax barrier region (BW3 or BW4) is determined substantially by the predetermined width of the electrode 122. Figure 33b
25 illustrates a switchable imaging optical device 1 with a

narrow width parallax barrier region relative to the width of the lens region ($LW4 \gg BW4$ or $LW4 > BW4$). Figure 33a illustrates a switchable imaging optical device 1 with a parallax barrier region and a lens region of commensurate width ($LW3 \sim BW3$). When a voltage is applied between electrodes 122 and electrode 112, the LC molecules (not shown) in the region directly beneath the electrode 122 are reoriented to align with the electric field and define, in conjunction with polarising elements (not shown), the parallax barrier region. When a voltage is applied across electrodes 122 and electrode 112, the LC molecules in the region between the successive electrodes 122 (but not directly beneath the electrode 122) are reoriented by a fringing electric field and define the GRIN lens region. Re-orientation of the LC molecules in the lens region is most pronounced for LC molecules in close proximity to the electrode 122. The effect is also illustrated by LC modelling in Figure 16. For a given LC layer thickness $d3$ and a lens region width $LW3$, the fringing electric field may re-orientate LC molecules at least to some extent from the edge of the lens region to the centre of the lens region. This re-orientation of the LC molecules is represented by the picture of a physical planar convex lens 21b in Figure 33a representing the imaging function of the LC GRIN lens, since the LC lens imaging is approximated by the physical lens shape 21b. For a given LC layer thickness $d3$

and a lens region width LW_4 , the fringing electric field may re-orientate LC molecules in close proximity to the electrode 122 but not re-orientate LC molecules in the centre of the lens region. This re-orientation of the LC molecules is represented by the picture of the lens 21c in Figure 33a since the LC lens imaging is approximated by the physical lens shape 21c shown in Figure 33a. The lens shape 21c of Figure 33b has a curved region in proximity to the electrode 122 and a non-curved region in the centre of the lens. The lens shape 21c of Figure 33b may be transformed into the lens shape 21b by increasing the thickness of the LC layer d_3 by an appropriate amount and/or by increasing the voltage between electrodes 122 and 112. For a given imaging application, it is usually desirable to minimise the LC layer thickness d_3 . Consequently, the width of the electrode 122 may be chosen so as to achieve the desired imaging effect while the LC layer thickness d_3 is minimised. The LC lens may have an equivalent physical lens shape similar to 21b or 21c or somewhere in between 21b and 21c. Consequently, the switchable imaging optical device 1 has great design flexibility since the proportion of parallax barrier 22 to GRIN lens 21 ratio and the physical equivalent of the GRIN lens shape can be varied and customised for any given application.

With reference to Figure 4a and Figure 5a, the switchable imaging optical device 1 may be formed using a

single patterned electrode 122 on one substrate that acts as a substrate of a liquid crystal cell. With reference to Figure 21a and Figure 22a, the switchable imaging optical device 1 may be formed using two patterned electrodes 1221a, 1221b on one substrate that acts as a substrate of a liquid crystal cell. With reference to Figure 24a, the switchable imaging optical device 1 may be formed using a first pair of patterned electrodes 112b, 112b on a first substrate 11b that acts as a substrate of a liquid crystal cell, and a second pair of patterned electrodes 122a, 122b on a second substrate 12b that acts as a substrate of a liquid crystal cell. It will be appreciated to persons skilled in the art of liquid crystal lens technology that multiple, independently addressable electrodes can be employed on either a single substrate or both substrates that act(s) as a substrate of a liquid crystal cell in order to form a standard liquid crystal GRIN lens. Therefore it will be appreciated to persons skilled in the art of liquid crystal lens technology that multiple, independently addressable electrodes can be can be used to form a novel switchable imaging optical device 1 comprised of both lens 21 and parallax barrier 22 components.

Although the invention has been shown and described with respect to a certain embodiment or embodiments, equivalent alterations and modifications may occur to others skilled in the art upon the reading and understanding of this

specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to
5 describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the
10 function in the herein exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several embodiments, such feature may be combined with one or more other features of the other
15 embodiments, as may be desired and advantageous for any given or particular application.

For example, in the embodiments described above it is intended that the entire active area of the device is switched. The invention is not however limited to this, and it is possible
20 for different spatial areas of an imaging device of the invention to be switched independently of one other. The use of patterned electrodes, with direct addressing, passive addressing or active addressing are standard addressing schemes used in image displays so that different spatial areas
25 of an image display can be switched independently of each

other. The smallest independently addressable area of an image display 4 is a sub-pixel. Such addressing techniques may be applied to a switchable imaging device of the present invention, to allow a spatial area of the device to be switched
5 independently of other spatial area(s) of the device. Thus, via the use of standard addressing schemes, such as patterned electrodes, passive addressing or active addressing, a switchable imaging optical device of the invention may be configured to have at least a first area that can be switched to
10 an imaging mode and at least a second area that may be switched, independently of the first area, to a non-imaging mode. Consequently, a 2D-3D switchable display device can be realised where at least a first area of the device may yield a high quality 2D image while at least a second area of the
15 device may yield a high quality 3D image. A switchable imaging optical device that has a twist angle of around 270° may be particularly suitable for area switching via a standard passive addressing scheme.

In the first mode of operation, the device may comprises
20 a plurality of second regions and the polarising element may, in co-operation with the second regions, act to at least partially absorb light passing through each second region thereby defining a parallax barrier. This prevents optical cross-talk and, in combination with the lensing action,
25 provides a good directional display mode.

In the first mode of operation, the or each first region may comprise a GRIN lens.

The second mode of operation may be a non-imaging mode, for example a 2-D display mode. In a non-imaging
5 mode no lensing regions or parallax barrier regions are defined in the device.

In the first mode, the first region or at least one first region may overlap the second region or the at least one second region. Alternatively, in the first mode, the or each
10 first region may not overlap the or each second region.

The device may be electrically switchable between the first mode and the second mode.

The electro-optic layer may comprise a liquid crystal material.

15 The or each second regions may act to at least partially attenuate light passing through the/each second region by arranging for light exiting a second region to have the plane of polarisation (or the major plane of polarisation) that is substantially not aligned with the transmission axis of the
20 exit polariser. (The "major plane of polarisation refers to a case where light leaving the electro-optic layer is elliptically polarised rather than linearly polarised; in this case the light has both major and minor planes of polarisation, and it is the major plane of polarisation of light exiting a second region
25 that should be substantially not aligned with the

transmission axis of the exit polariser.)

Operation of the device requires that light incident on the electro-optic layer is substantially plane polarised and is preferably completely plane polarised. The plane polarised light incident on the electro-optic layer is arranged to be oriented substantially parallel, and preferably to be oriented completely parallel, to the liquid crystal alignment direction on the first substrate. To ensure this is the case, the device may comprise another polariser disposed in the path of light to the electro-optic layer, so that the electro-optic layer is disposed between the two polarisers which form an input polariser and an exit polariser (although provision of the input polariser may in principle be unnecessary if the device is illuminated with light that is substantially linearly polarised). The input polariser (if present) must be arranged to provide linearly polarised light to the electro-optic layer - however, the input polariser does not have to be a linear polariser, and may for example be a circular polariser. As an example, where the device is illuminated by light from an image display panel that is clad with circular polarisers, the light exiting the uppermost circular polariser (circular polariser adjoining the device) is linearly polarised. If necessary, a half-wave retarder may also be provided between the display and the electro-optic layer to rotate the linearly polarised light exiting the uppermost circular polariser to an

appropriate angle for the correct operation of the device, i.e. parallel to the liquid crystal alignment direction on the first substrate. As a further example, where the device is illuminated by light from an image display panel that is clad
5 with linear polarisers, a half-wave retarder may also be provided between the display and the electro-optic layer to rotate the linearly polarised light exiting the uppermost linear polariser to an appropriate angle for the correct operation of the device, i.e. parallel to the liquid crystal alignment
10 direction on the first substrate.

The electro-optic layer may be disposed between a first electrode layer and a second electrode layer, the first electrode layer comprising a planar electrode layer and the second electrode layer comprising a plurality of second
15 electrodes extending in a first direction and spaced apart in a second direction crossed with the first direction, wherein each second electrode substantially corresponds to a respective second region of the device.

The second electrode layer may further comprise a
20 plurality of third electrodes extending in the first direction and spaced apart in the second direction, the second electrodes being interdigitated with the third electrodes.

The device may be in the second mode when no voltage is applied across the electro-optic layer by the first and
25 second electrode layers.

Alternatively, the electro-optic layer may be disposed between a first electrode layer and a second electrode layer, the first electrode layer comprising a plurality of first electrodes extending in a first direction and spaced apart in a second direction crossed with the first direction, and the second electrode layer comprising a plurality of second electrodes extending in the second direction and spaced apart in the first direction. This provides a switchable imaging device that may additionally be operated in a third mode, which is another imaging mode (different from the first mode). For example the device may perform imaging along different directions in the first and third modes.

The first electrode layer may further comprise a plurality of third electrodes extending in the first direction, the third electrodes being interdigitated with the first electrodes.

The second electrode layer may further comprise a plurality of fourth electrodes extending in the second direction, the fourth electrodes being interdigitated with the second electrodes.

The electro-optic layer may be disposed between a first electrode layer and a second electrode layer, the second electrode layer comprising a plurality of second electrodes and third electrodes extending in the first direction and spaced apart in the second direction, the second electrodes being interdigitated with the third electrodes.

Alternatively, the electro-optic layer may be disposed between a first electrode layer and a second electrode layer, the first electrode layer comprising a plurality of first electrodes and fourth electrodes extending in a second direction and spaced apart in a first direction crossed with the second direction, the first electrodes being interdigitated with the fourth electrodes, and the second electrode layer comprising a plurality of second electrodes and third electrodes extending in the first direction and spaced apart in the second direction, the second electrodes being interdigitated with the third electrodes. This provides a switchable imaging device that may additionally be operated in a third mode, which is another imaging mode (different from the first mode). For example the device may perform imaging along different directions in the first and third modes.

The liquid crystal layer may have a twist alignment when the device is in the second mode. In one advantageous embodiment, the exit polariser is oriented with its transmission axis at φ° to the plane of polarisation of linearly polarised light incident on the electro-optic layer (for example at φ° to the transmission axis of an input linear polariser if one is present). If the liquid crystal layer has a twist alignment in which the twist angle across the liquid crystal layer is φ° so that, when the device is in the second mode, the liquid crystal layer rotates the plane of polarisation of linearly

polarised light by approximately an angle φ° the rotation of the plane of polarisation as the light passes through the liquid crystal layer will mean that the plane of polarisation of the light exiting the liquid crystal layer is aligned with the transmission axis of the exit polariser - so that the device is maximally transmissive over its entire area, giving a non-imaging mode. The effect of switching the device to an imaging mode is that light passing through a second region of the liquid crystal layer no longer has its plane of polarisation rotated by φ° as the light passes through the liquid crystal layer, so that the plane of polarisation (or the major plane of polarisation) of the light exiting a second region of the liquid crystal layer is not substantially aligned with the transmission axis of the exit polariser and a light-attenuating region is defined.

Preferably the device is arranged such that, when it is in the second mode the plane of polarisation (or the major plane of polarisation) of light exiting the liquid crystal layer is aligned with the transmission axis of the exit polariser so that the device is maximally transmissive over its entire area, and such that in an imaging mode light exiting a second region of the liquid crystal layer has its plane of polarisation (or the major plane of polarisation) substantially orthogonal to the transmission axis of the exit polariser - so that the device is maximally light-attenuating in the second region of the liquid

crystal layer in the imaging mode. As one way to achieve this, the twist alignment of the liquid crystal layer may have a twist angle of approximately 90° (or $90^\circ + n \times 180^\circ$, where $n = 0, 1, 2$ etc). If $n > 0$, then a chiral dopant must be used to
5 achieve the desired twist angle. If the twist state of the liquid crystal layer rotates the plane of polarisation of linearly polarised light by an angle 90° (or $90^\circ + n \times 180^\circ$) as the light passes through the liquid crystal layer and the exit polariser is oriented with its transmission axis at 90° to the plane of
10 polarisation of linearly polarised light incident on the electro-optic layer then, if the effect of switching the device to the first mode is that the liquid crystal in the/a second region of the liquid crystal layer is switched to a state in which it does not significantly rotate the plane of polarisation (or the major
15 plane of polarisation) of light, this means that the plane of polarisation (or the major plane of polarisation) of light exiting the liquid crystal layer is substantially orthogonal to the transmission axis of the exit polariser and a light-attenuating action is realised.

20 Moreover, the input polariser (if present) may be arranged to illuminate the device with linearly polarised light that has a plane of polarisation aligned substantially parallel to the rubbing direction on the lowermost substrate of the device.

25 Moreover, the exit polariser may be arranged such that

the transmission axis is aligned substantially parallel to the rubbing direction on the uppermost substrate of the device.

The liquid crystal layer may have a substantially vertically-aligned state in the bulk of the liquid crystal layer
5 away from the surfaces of the liquid crystal layer and situated under each second electrode, while the twist state is compressed to the centre of the liquid crystal layer in the second regions when the device is in the first mode.

The device may have a first electrode 112 and an array
10 of second electrodes 122, the liquid crystal layer being disposed between the first electrode and the second electrodes, a second electrode defining, upon application of a non-zero voltage across the liquid crystal layer, an edge of a first GRIN lens and an edge of a second GRIN lens. This is illustrated in,
15 for example, Figure 16, which shows an electrode defining the right edge of a first GRIN lens and the left edge of a second GRIN lens. (Preferably the array of second electrodes is wider than the active area of the display, so that any edge effects occurring at the edges of the array of second electrodes are
20 outside the active area of the display and so do not affect the optical quality of the display.)

The second LC alignment may be a substantially vertical LC alignment state in the bulk of the liquid crystal layer away from the surfaces of the liquid crystal layer and situated
25 under each second electrode, while the twist state is

compressed to the centre of the liquid crystal layer in the second regions when the device is in the first mode.

The liquid crystal layer may be disposed between first and second alignment layers, the alignment direction of the first alignment layer being crossed with the alignment direction of the second alignment layer thereby to define twisted liquid crystal alignment in the absence of an applied voltage across the liquid crystal layer.

The twisted liquid crystal alignment may be a substantially 90° twist alignment.

The device may have a first electrode and an array of second electrodes, the liquid crystal layer being disposed between the first electrode and the second electrodes, each second electrode defining a respective second region of the liquid crystal layer. Moreover, each second electrode also defines, at least partially, a respective first region of the liquid crystal layer. For example, in the embodiment of Figure 16 the second electrodes 122 are responsible for forming the parallax barrier and the lens array. The region of the liquid crystal layer under one of the second electrodes 122 form an non-transmissive (or low-transmissive) region of the parallax barrier, but the fringing fields from two neighbouring second electrodes 122 form the GRIN lens between the two second electrodes 122.

A device of the first or second aspect may comprise a

plurality of independently addressable areas, each area being switchable between the first mode of operation and the second mode of operation independent of the other area(s). This allows, for example, at least a first area of the device to yield
5 a high quality 2D image (by being switched to a non-imaging mode) at the same time as at least a second area of the device yields a high quality 3D image (by being switched to an imaging mode).

10 INDUSTRIAL APPLICABILITY

A 2D-3D switchable display system suitable for mobile phones, handheld games consoles, portable PCs, photo-frames and multi-view television.

CLAIMS

1. A switchable imaging device, the device having a first mode of operation in which the device performs an imaging function and a second mode of operation different
5 from the first mode;

wherein the device comprises an electro-optic layer and a polarising element disposed in the path of light through the electro-optic layer, wherein in the first mode of operation the electro-optic layer comprises at least one first region that
10 performs a lensing action and at least one second region; and wherein the polarising element acts in co-operation with the second region(s) to at least partially absorb light passing through the or each second region.

15 2. A device as claimed in claim 1 wherein, in the first mode of operation, the device comprises a plurality of second regions, and wherein the polarising element acts, in co-operation with the second regions, to at least partially absorb light passing through each second region thereby defining a
20 parallax barrier.

3. A device as claimed in claim 1 or 2 wherein, in the first mode of operation, the or each first region comprises a GRIN lens.

4. A device as claimed in claim 1, 2 or 3 wherein the second mode of operation is a non-imaging mode.

5. A device as claimed in any of claims 1 to 4, wherein,
5 in the first mode, the first region or at least one first region overlaps the second region or the at least one second region

6. A device as claimed in any of claims 1 to 4, wherein,
in the first mode, the or each first region does not overlap the
10 or each second region.

7. A device as claimed in any preceding claim, the device being electrically switchable between the first mode and the second mode.
15

8. A device as claimed in any preceding claim wherein the electro-optic layer comprises a liquid crystal material.

9. A device as claimed in any preceding claim wherein
20 the electro-optic layer is disposed between a first electrode layer and a second electrode layer, the first electrode layer comprising a planar electrode layer and the second electrode layer comprising a plurality of second electrodes extending in a first direction and spaced apart in a second direction
25 crossed with the first direction, wherein each second

electrode corresponds to a respective second region of the device.

10. A device as claimed in claim 9 wherein the second
5 electrode layer further comprises a plurality of third electrodes extending in the first direction and spaced apart in the second direction, the second electrodes being interdigitated with the third electrodes.

10 11. A device as claimed in claim 9 or 10 wherein the device is in the second mode when no voltage is applied across the electro-optic layer by the first and second electrode layers.

15 12. A device as claimed in any one of claims 1 to 8 wherein the electro-optic layer is disposed between a first electrode layer and a second electrode layer, the first electrode layer comprising a plurality of first electrodes extending in a first direction and spaced apart in a second
20 direction crossed with the first direction, and the second electrode layer comprising a plurality of second electrodes extending in the second direction and spaced apart the first direction.

25 13. A device as claimed in claim 12, wherein the first

electrode layer further comprising a plurality of third electrodes extending in the first direction, the third electrodes being interdigitated with the first electrodes.

5 14. A device as claimed in claim 12 or 13, wherein the second electrode layer further comprising a plurality of fourth electrodes extending in the second direction, the fourth electrodes being interdigitated with the second electrodes.

10 15. A device as claimed in any one of claims 8 to 14 wherein the liquid crystal layer has a twist alignment when the device is in the second mode.

15 16. A device as claimed in claim 15 wherein the twist alignment of the liquid crystal layer has a twist angle of approximately 90°.

20 17. A device as claimed in claim 15 or 16 wherein the liquid crystal layer has substantially vertically-aligned state in the second regions in the first mode,

25 18. A switchable optical device comprising a liquid crystal layer, the liquid crystal layer having, in a first mode of operation of the device, a twisted liquid crystal alignment; wherein at least one first region of the liquid crystal layer is

switchable by application of a non-zero voltage across the liquid crystal layer to have, in a second mode of operation of the device, a second liquid crystal alignment different from the twisted liquid crystal alignment thereby to define at least
5 one GRIN lens in the liquid crystal layer.

19. A device as claimed in claim 18 wherein the device has first electrode and an array of second electrodes, the liquid crystal layer being disposed between the first electrode
10 and the second electrodes, a second electrode defining, upon application of a non-zero voltage across the liquid crystal layer, an edge of a first GRIN lens and an edge of a second GRIN lens adjacent to the first GRIN lens.

15 20. A device as claimed in claim 18 or 19 wherein the second liquid crystal alignment is a substantially vertical LC alignment

21. A device as claimed in claim 18, 19 or 20 and
20 wherein the liquid crystal layer is disposed between first and second alignment layers, the alignment direction of the first alignment layer being crossed with the alignment direction of the second alignment layer thereby to define twisted liquid crystal alignment in the absence of a voltage across the liquid
25 crystal layer.

22. A device as claimed in any one of claims 18 to 21 wherein the twisted liquid crystal alignment is a substantially 90° twist alignment.

5

23. A device as claimed in any preceding claim and comprising a plurality of independently addressable areas, each area being switchable between the first mode of operation and the second mode of operation independent of
10 the other area(s).

24. A display comprising an image display panel and a switchable imaging device as defined in any one of claims 1 to 23 disposed in path of light after passing through the image
15 display panel.

FIG. 1a

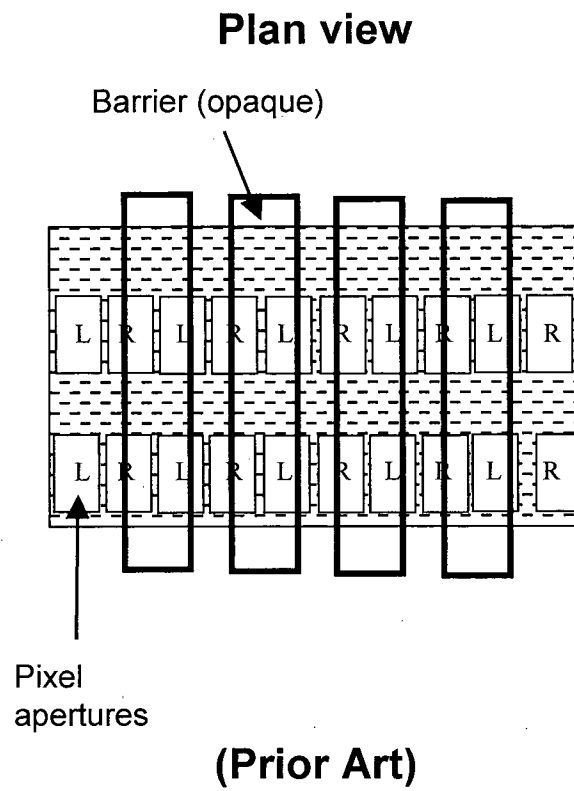
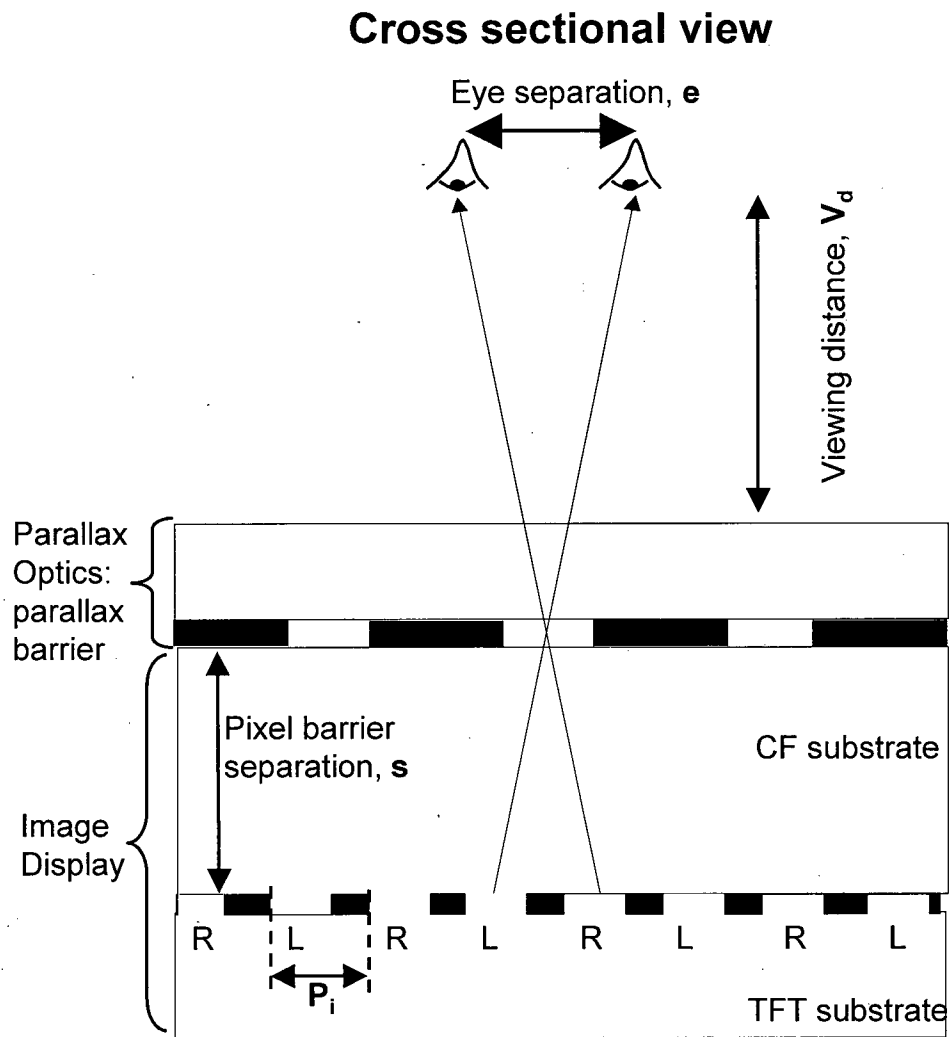


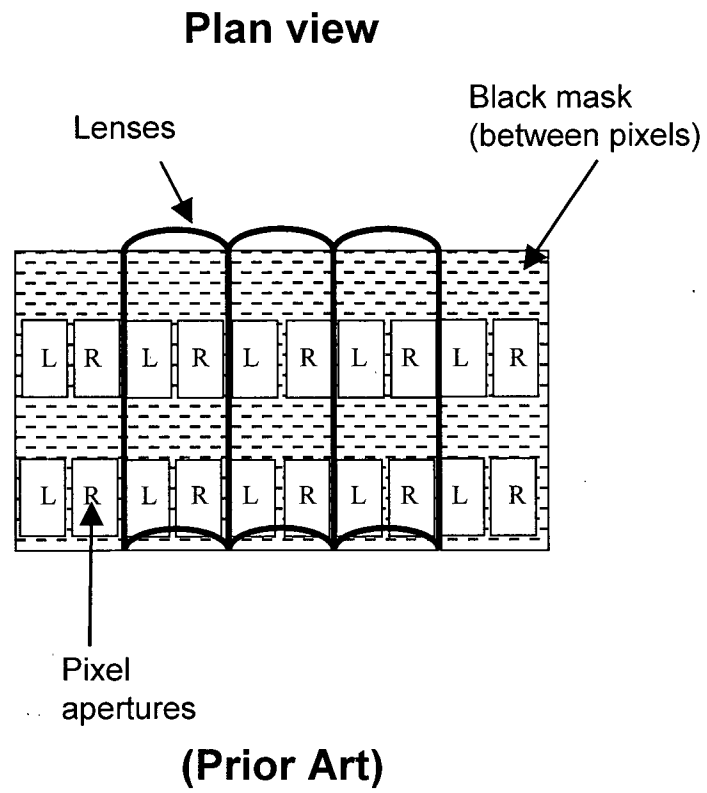
FIG. 1b



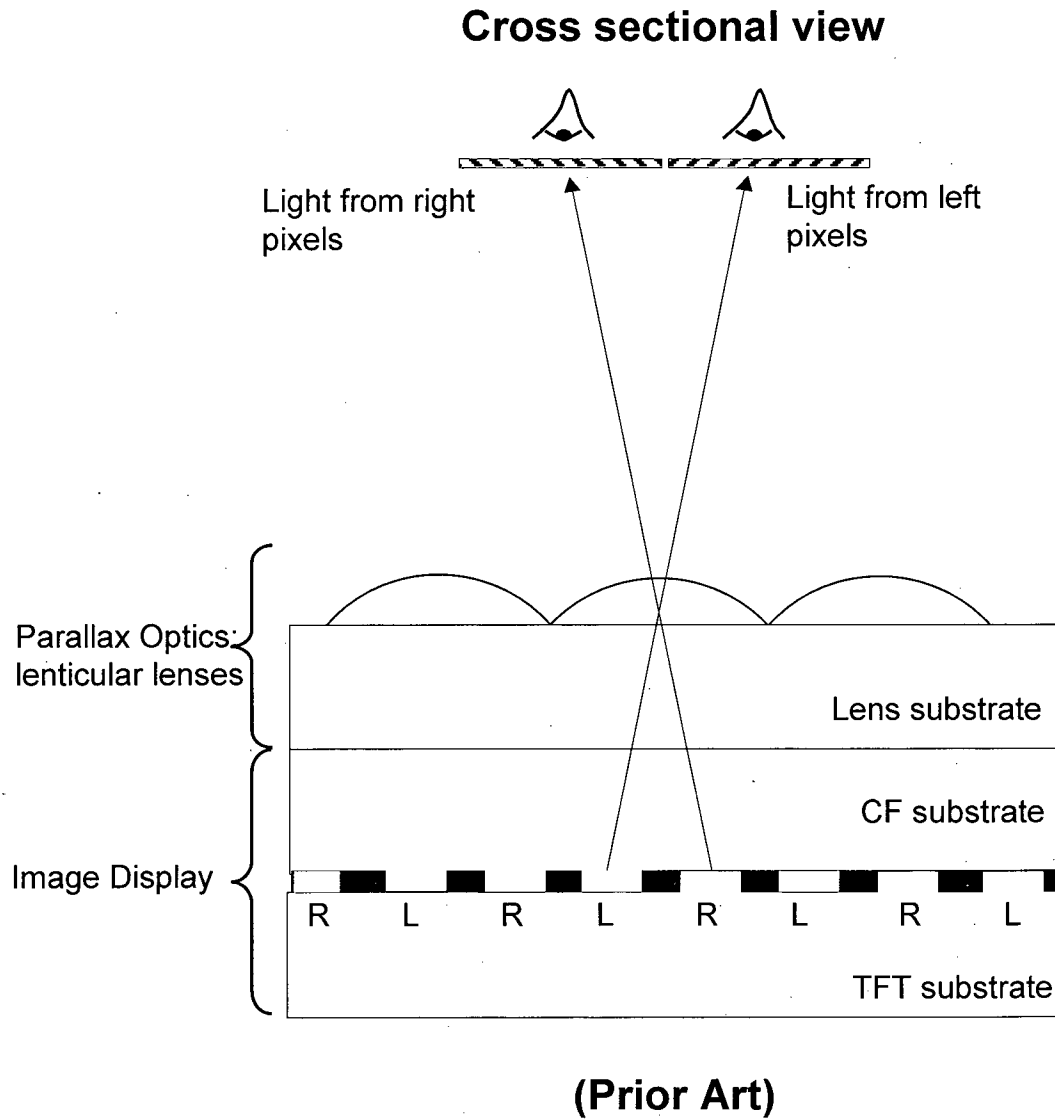
(Prior Art)

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FIG. 2a



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FIG. 2b

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FIG. 3a

Plan View

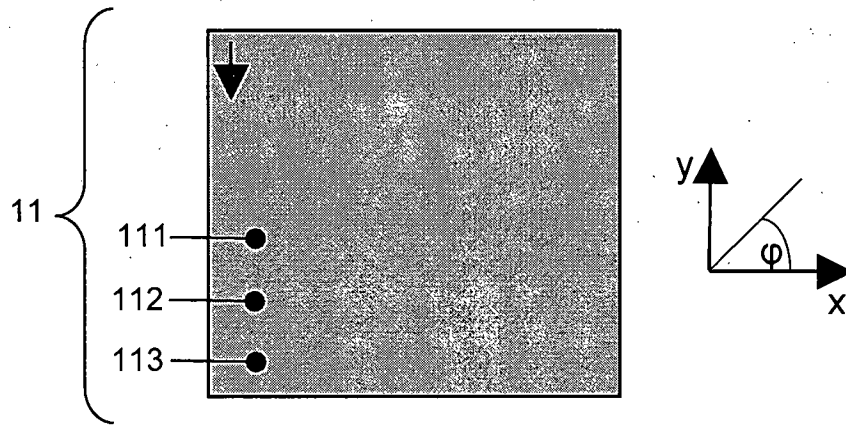
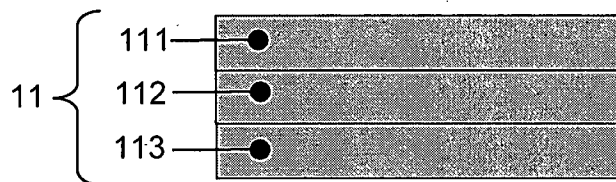


FIG. 3b

Side View



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FIG. 4a

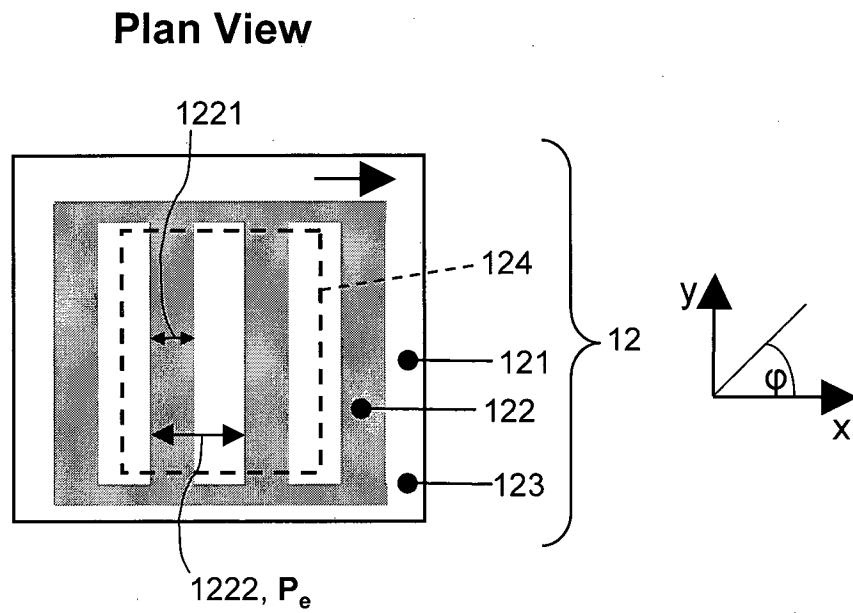
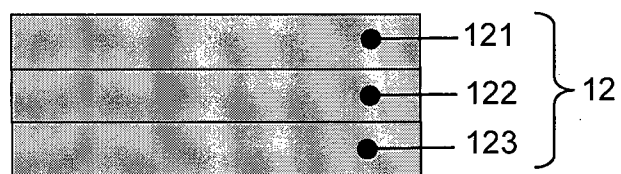


FIG. 4b

Side View

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FIG. 5a

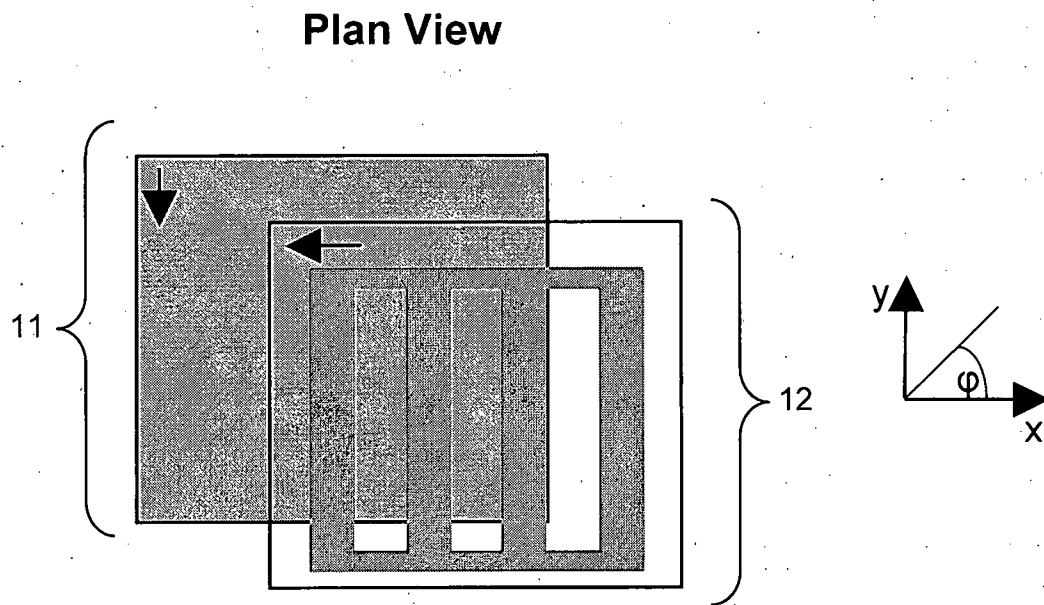


FIG. 5b

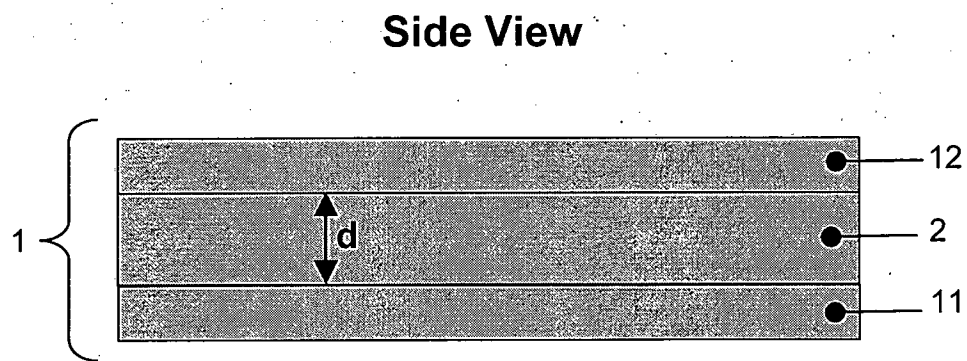


FIG. 6

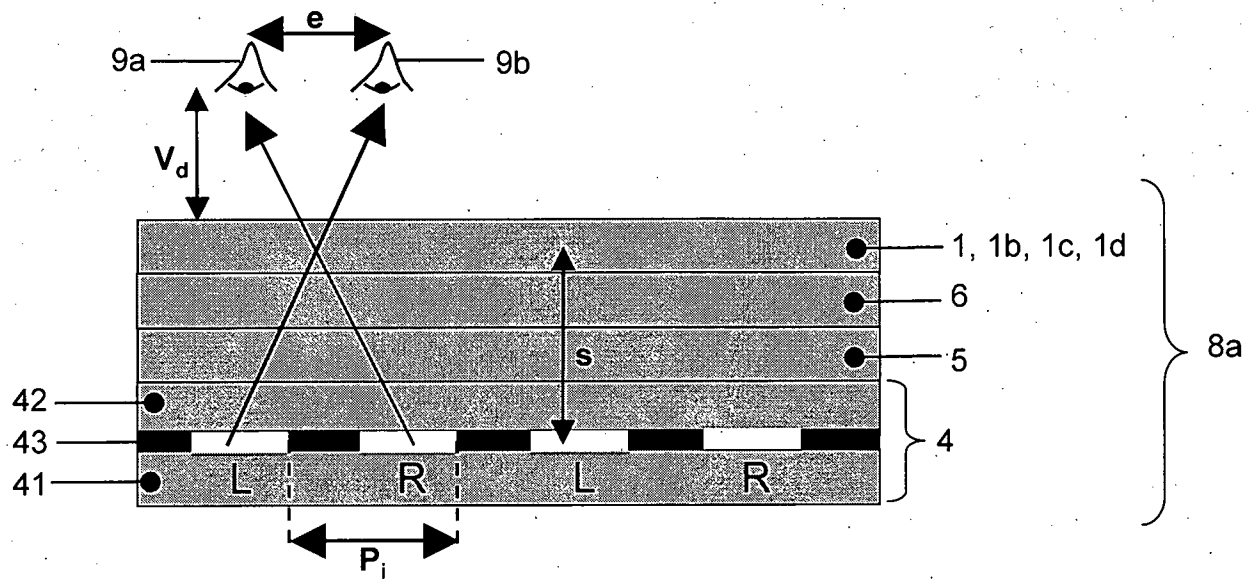
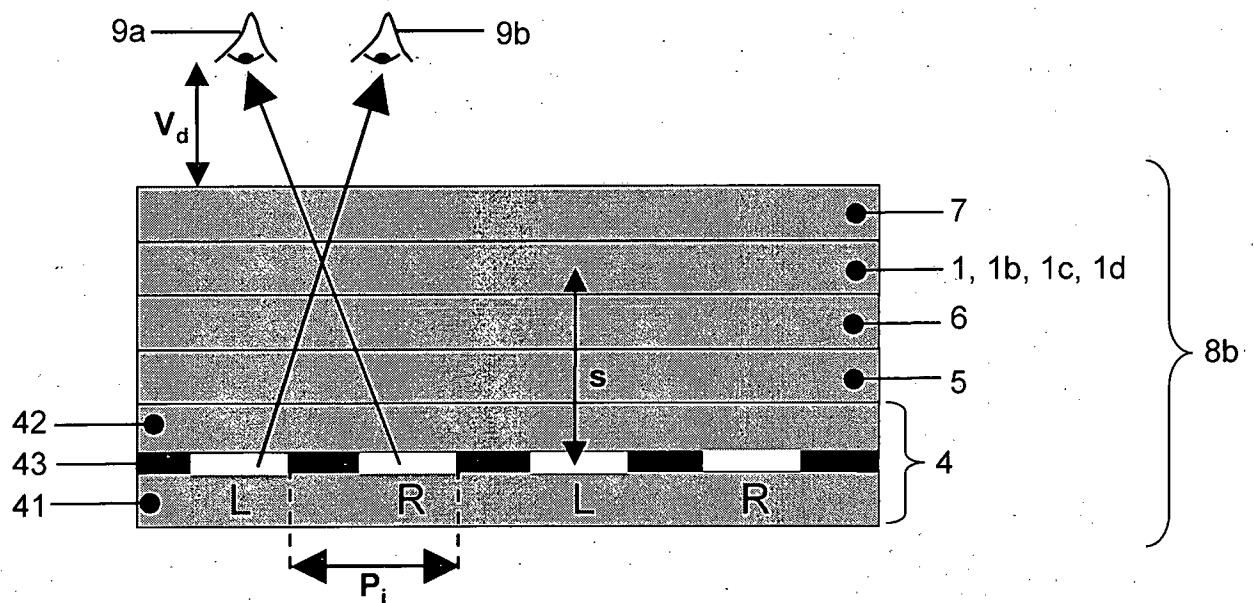


FIG. 7



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FIG. 8

Drive Scheme 1

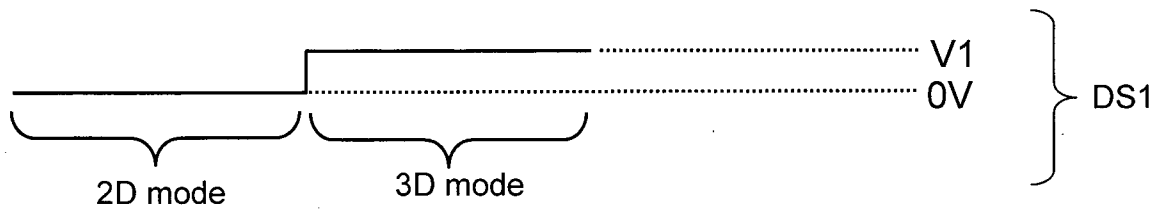
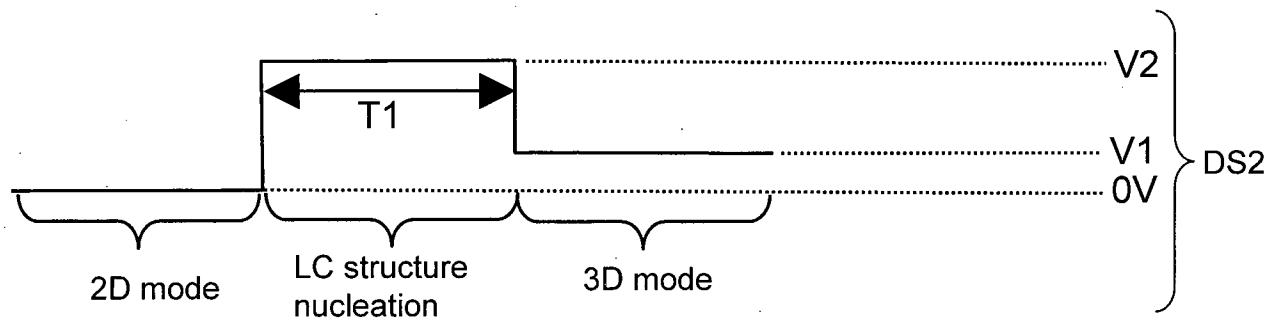


FIG. 9

Drive Scheme 2



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FIG. 10

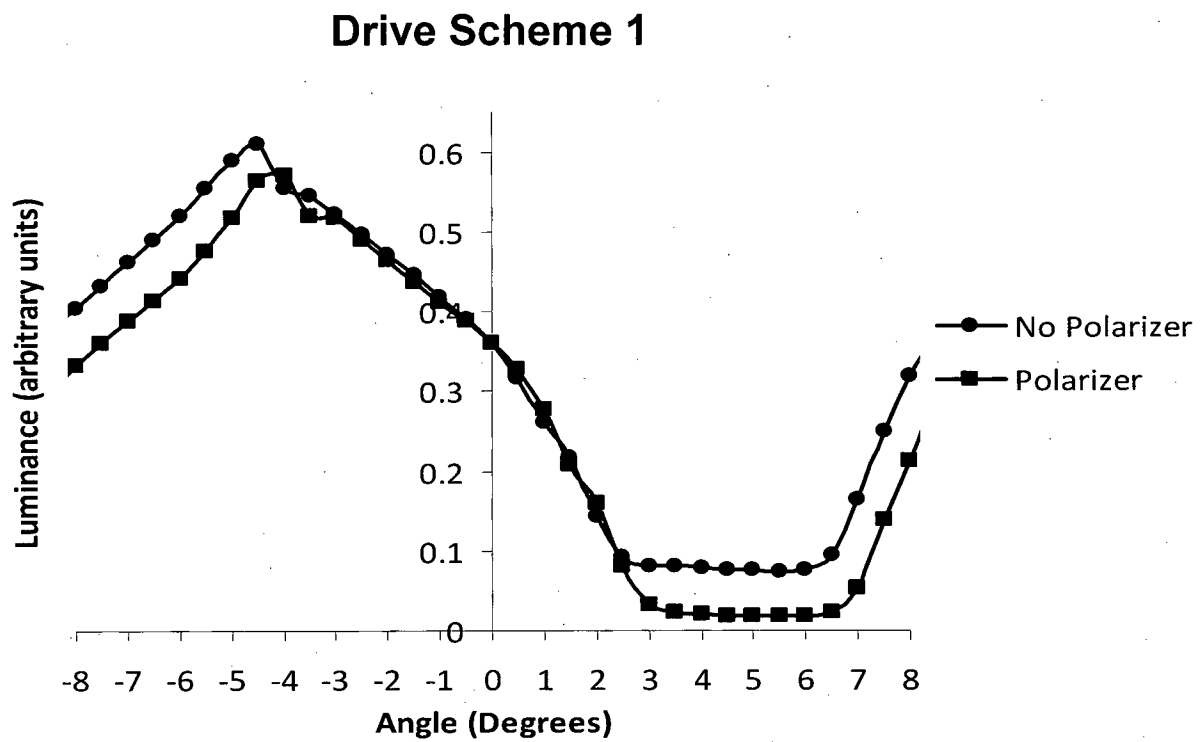
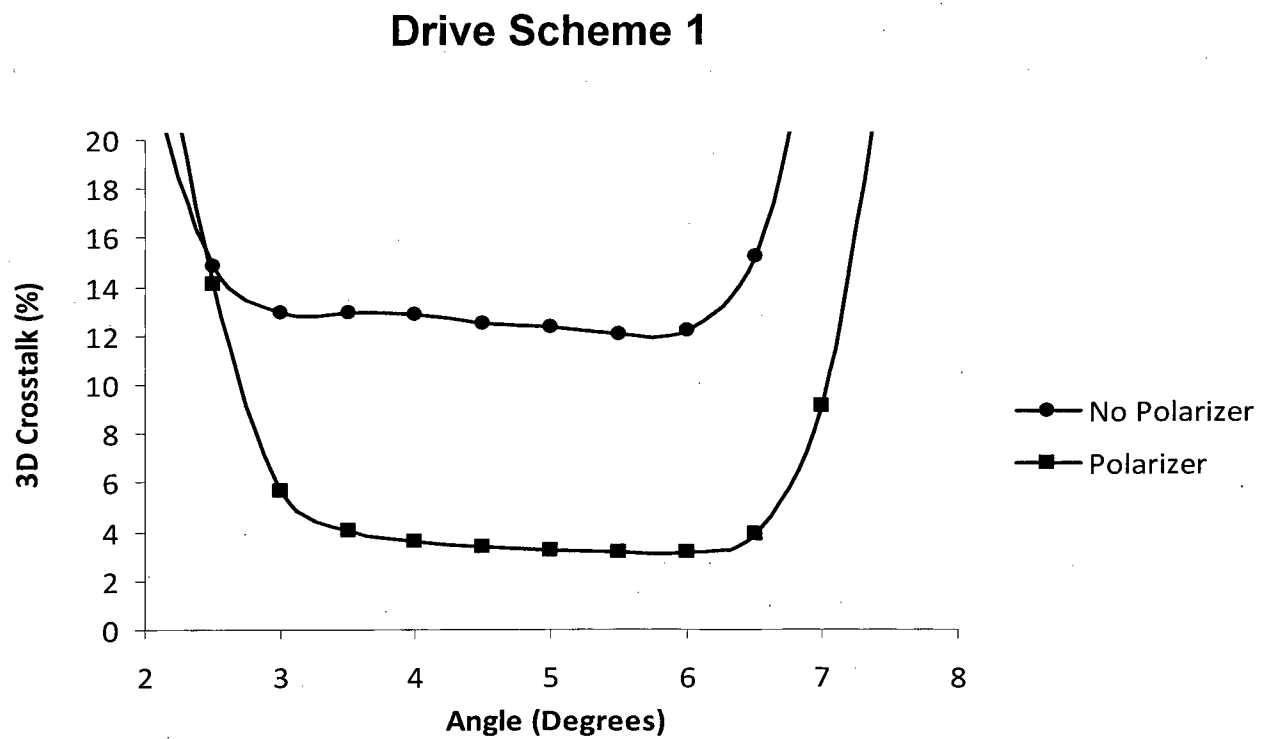


FIG. 11



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FIG. 12

Drive Scheme 2

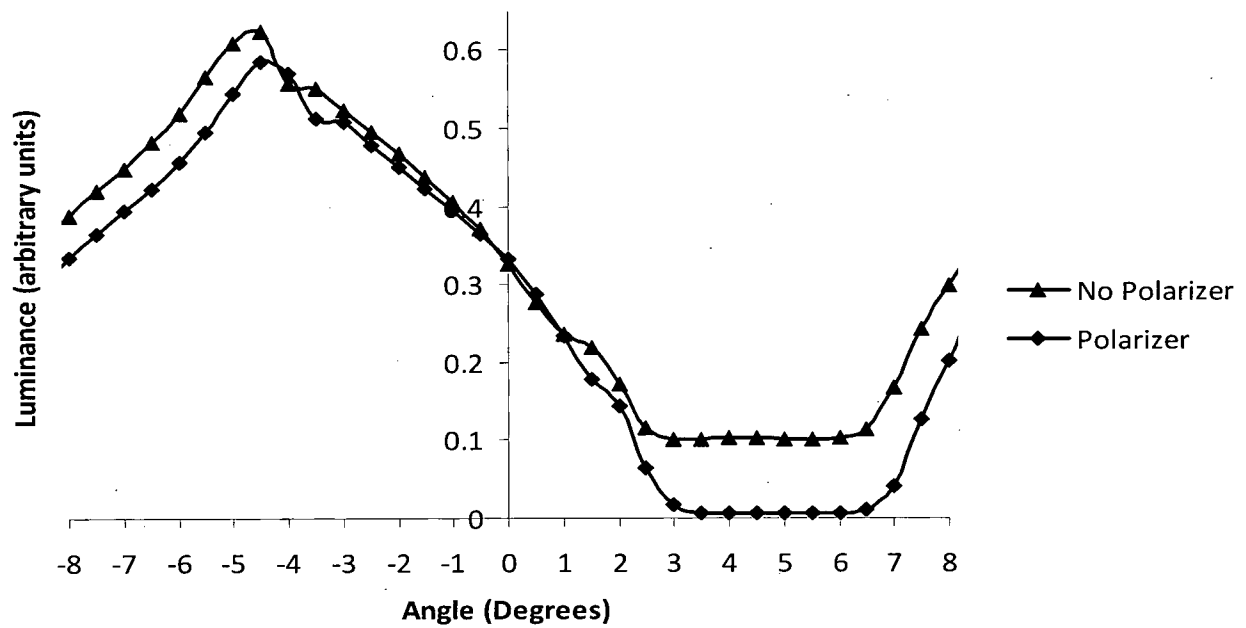
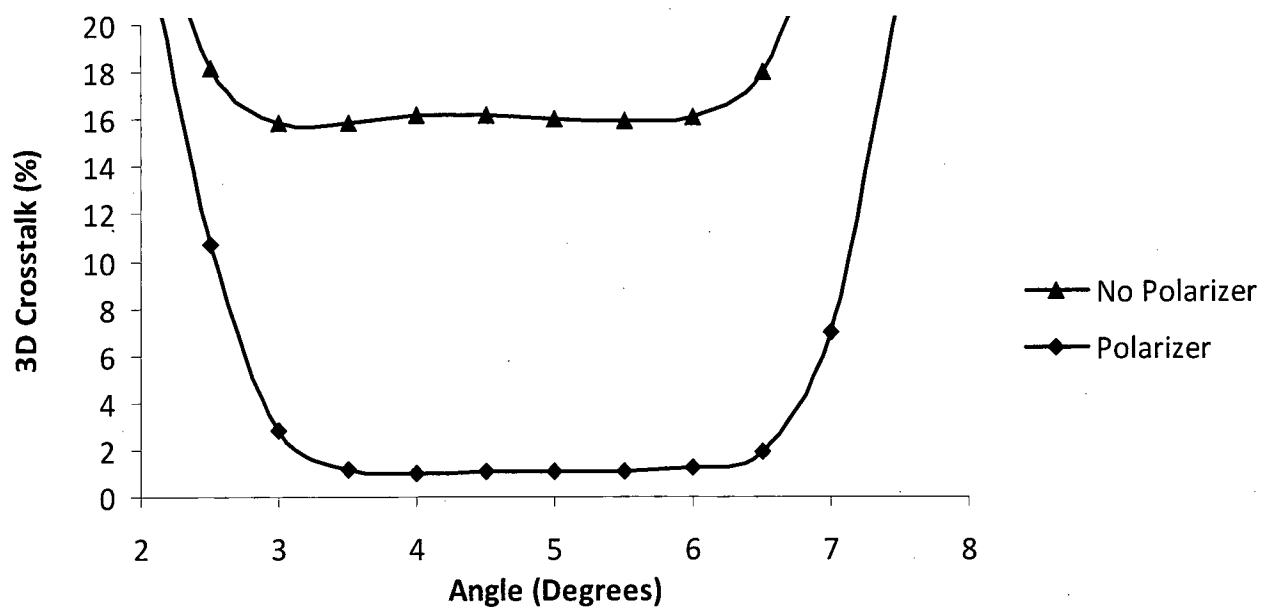


FIG. 13

Drive Scheme 2



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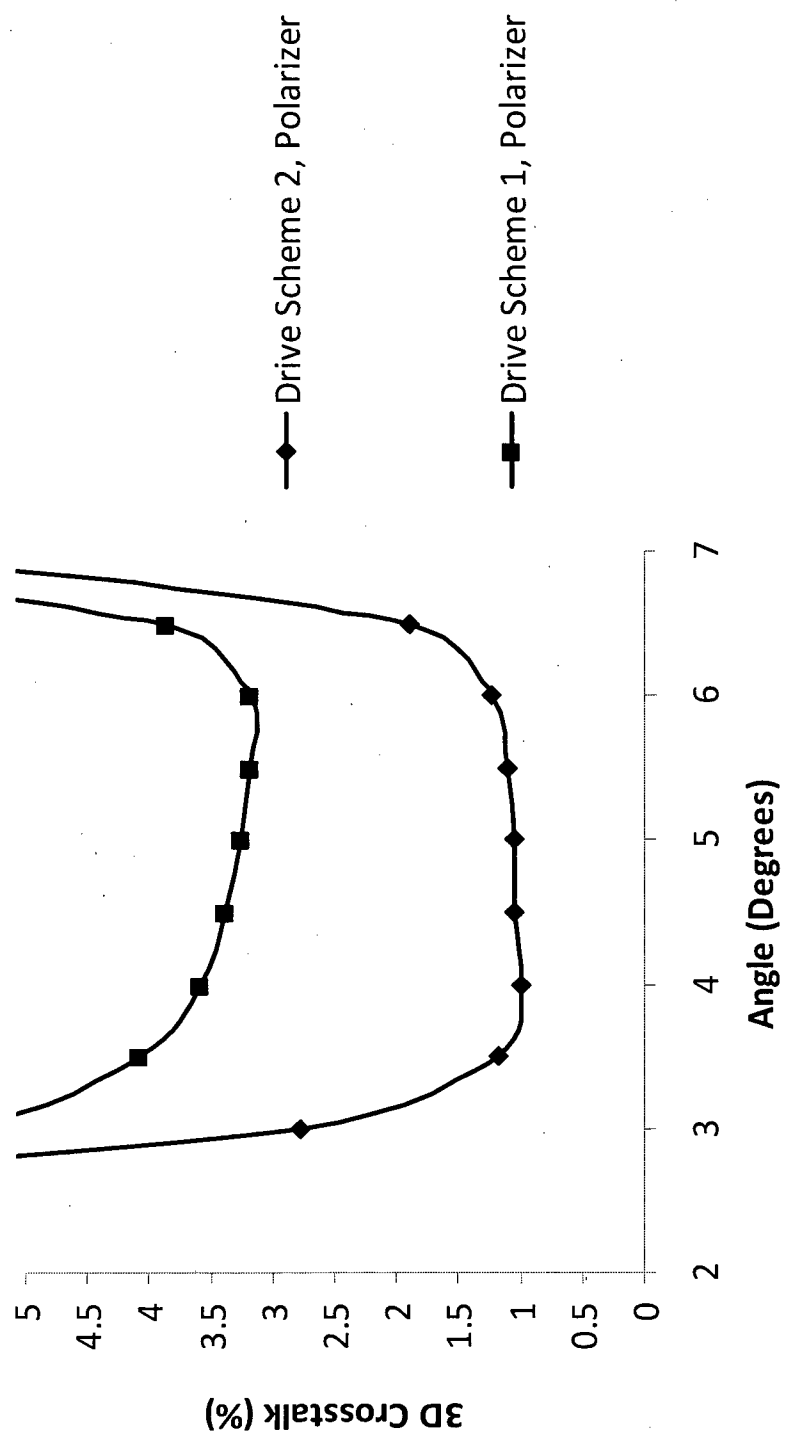


FIG. 14

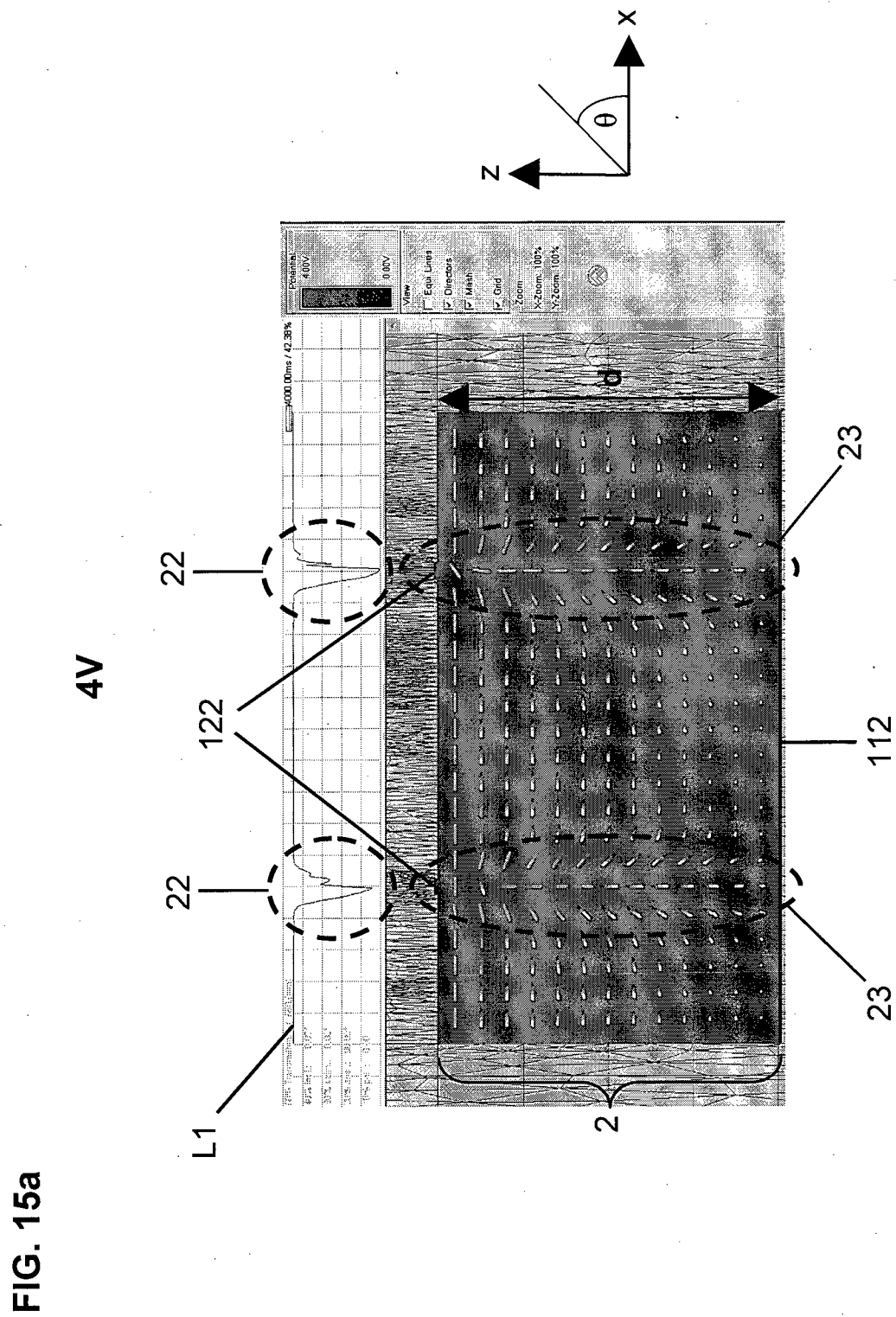
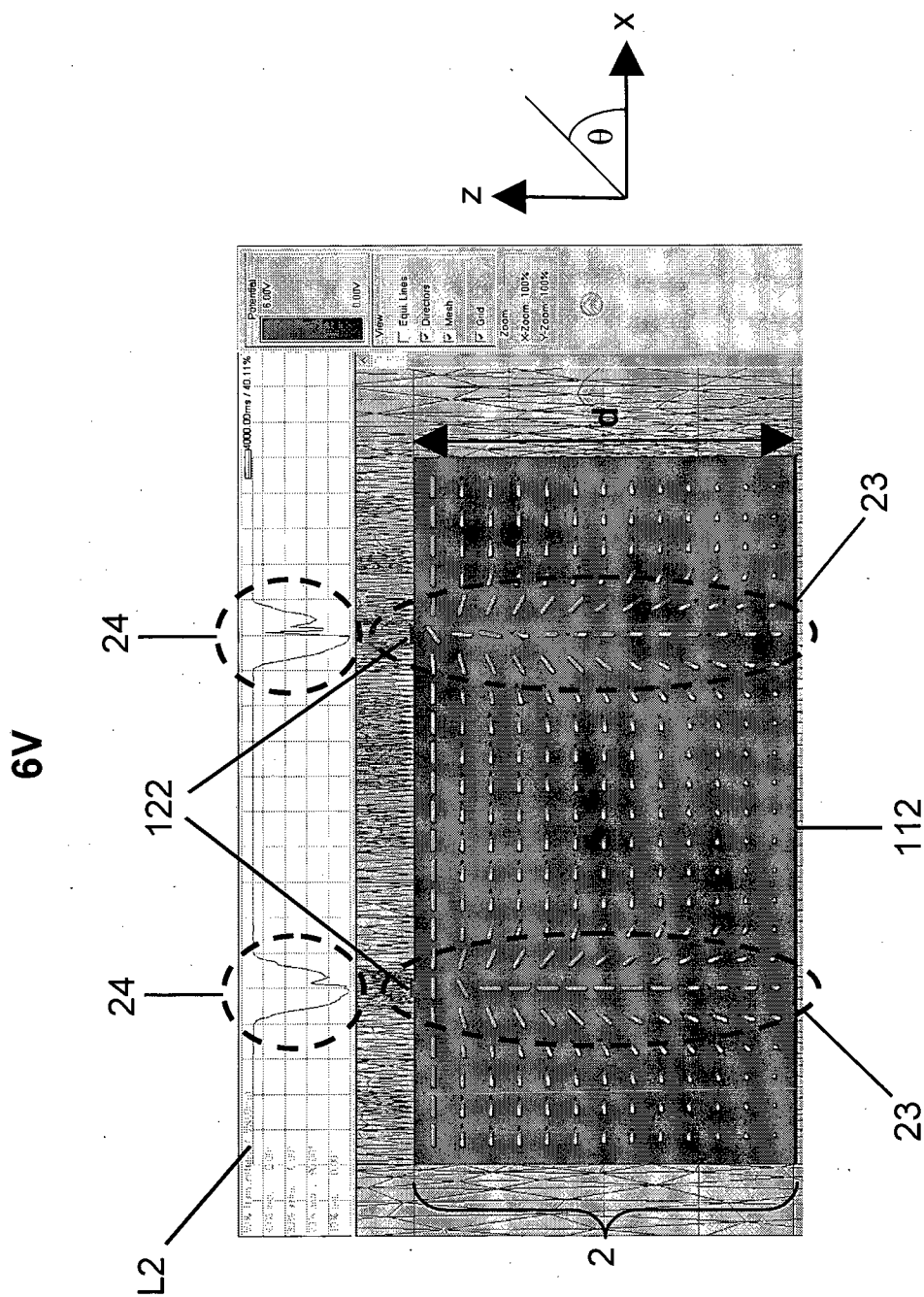
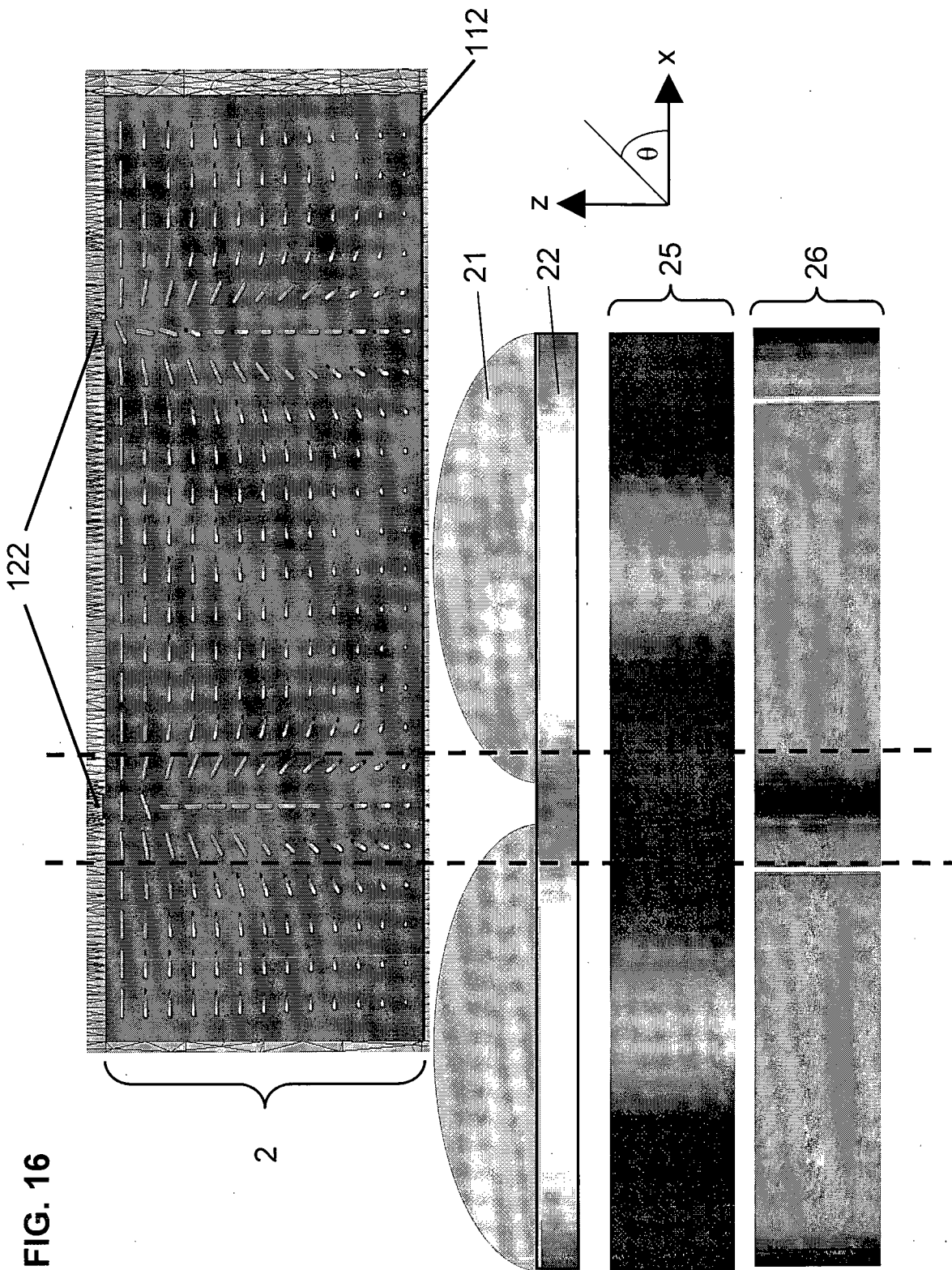


FIG. 15b





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FIG. 17

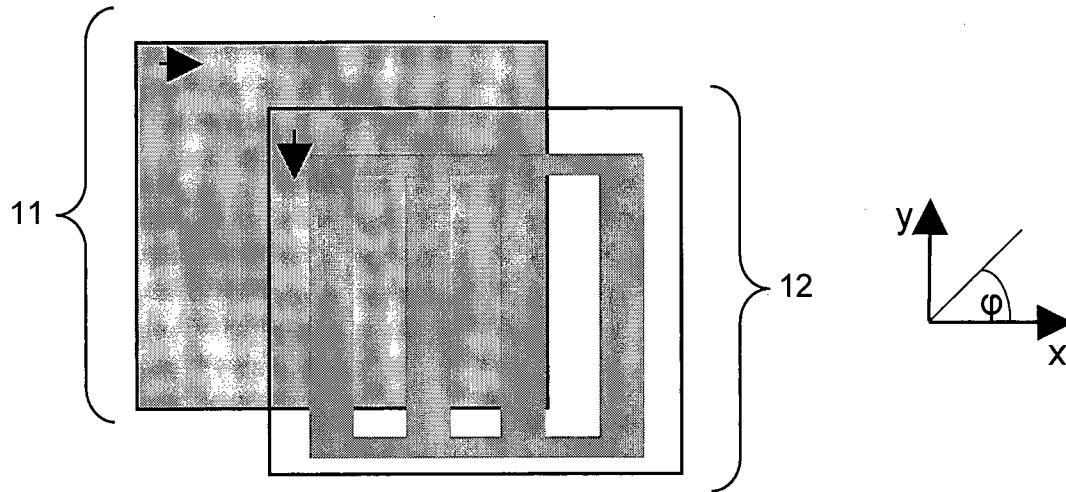
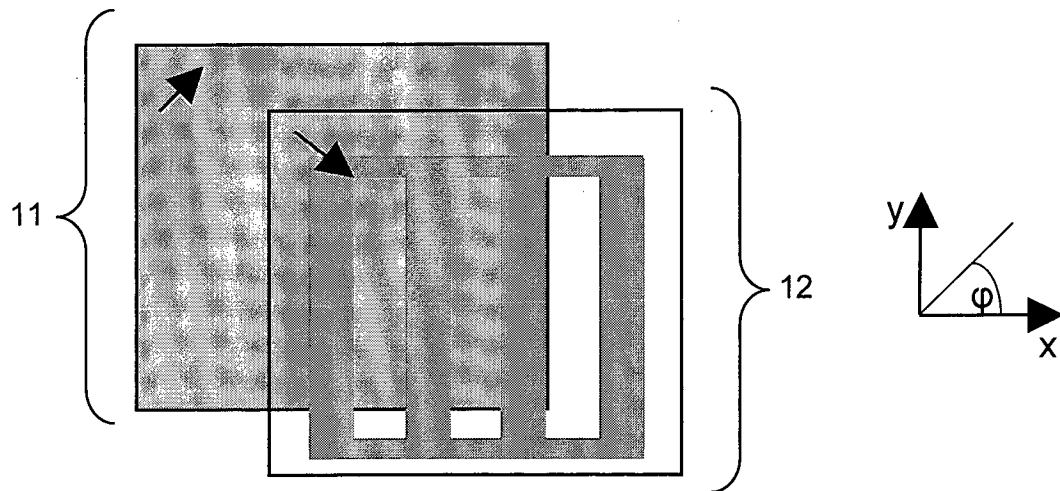


FIG. 18



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FIG. 19

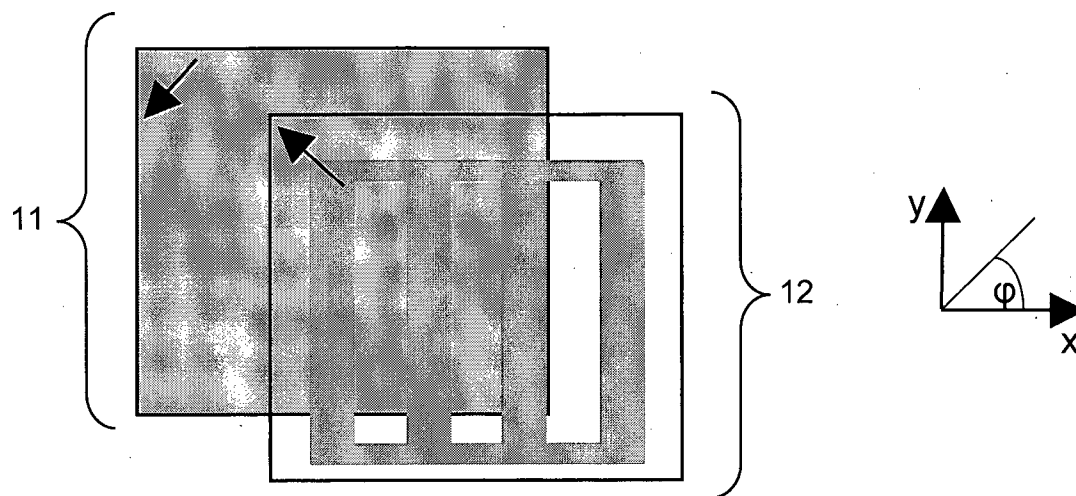
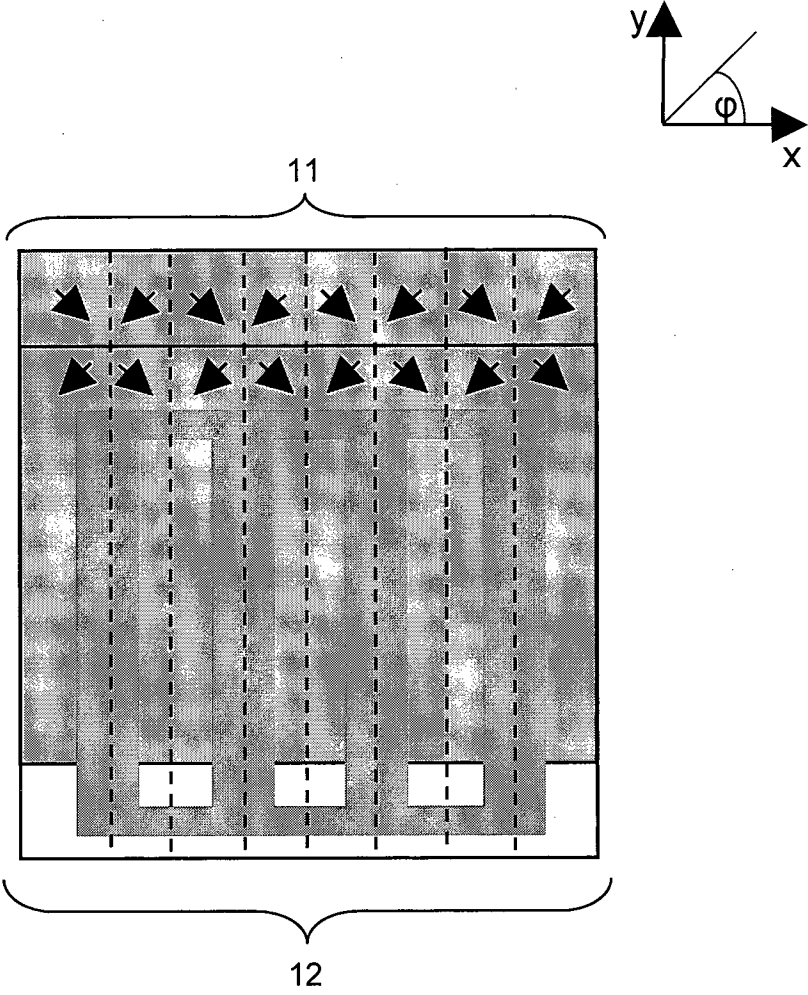


FIG. 20a



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FIG. 20b

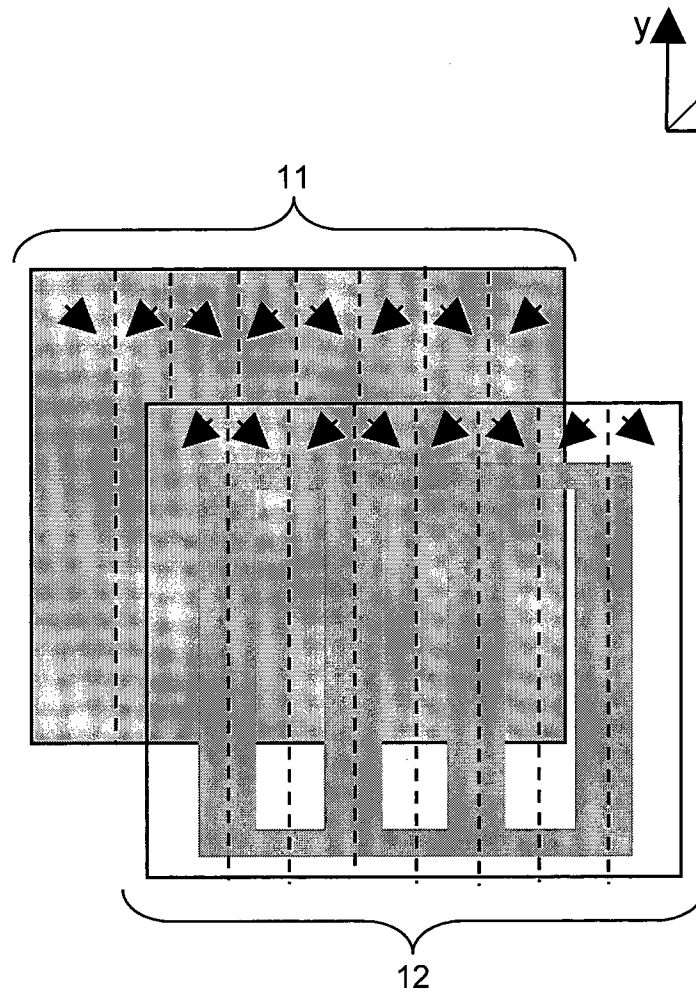


FIG. 21a

Plan View

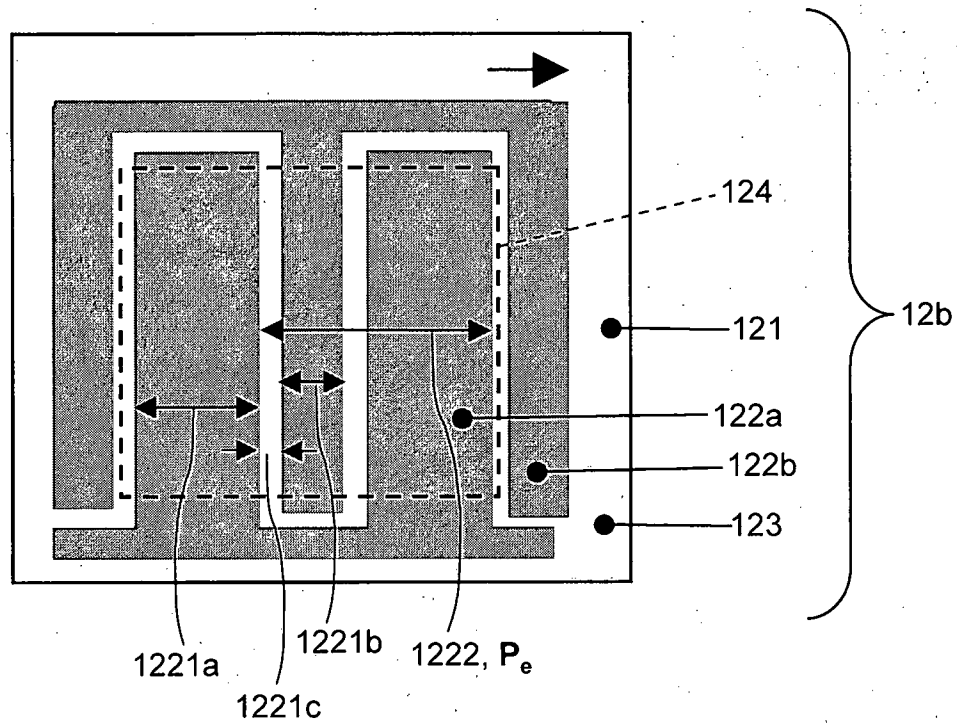


FIG. 21b

Side View

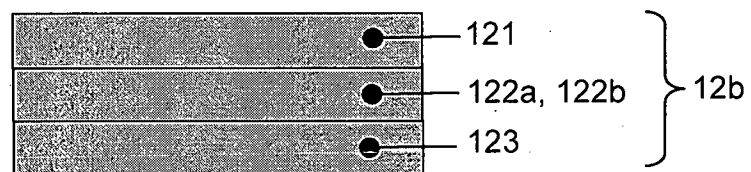
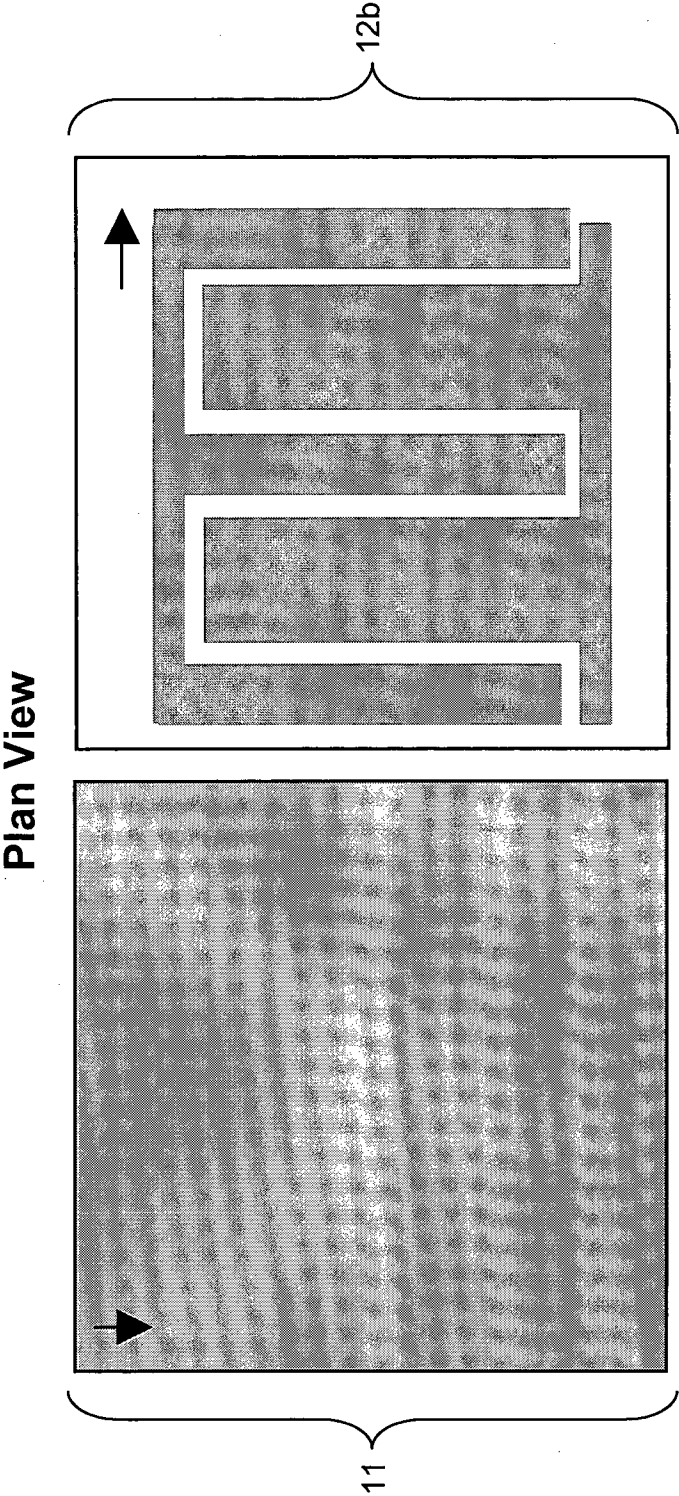


FIG. 22a



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FIG. 22b

Side View

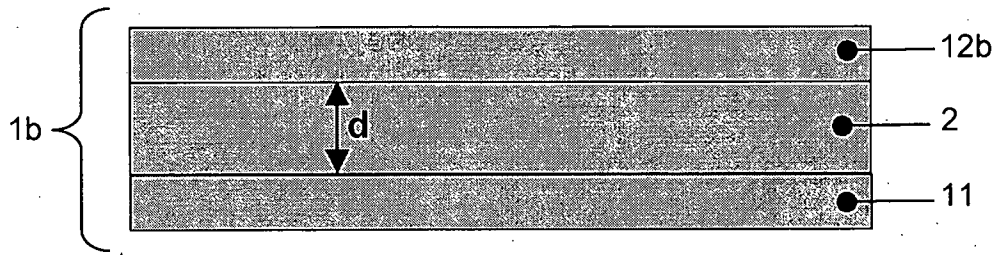


FIG. 23

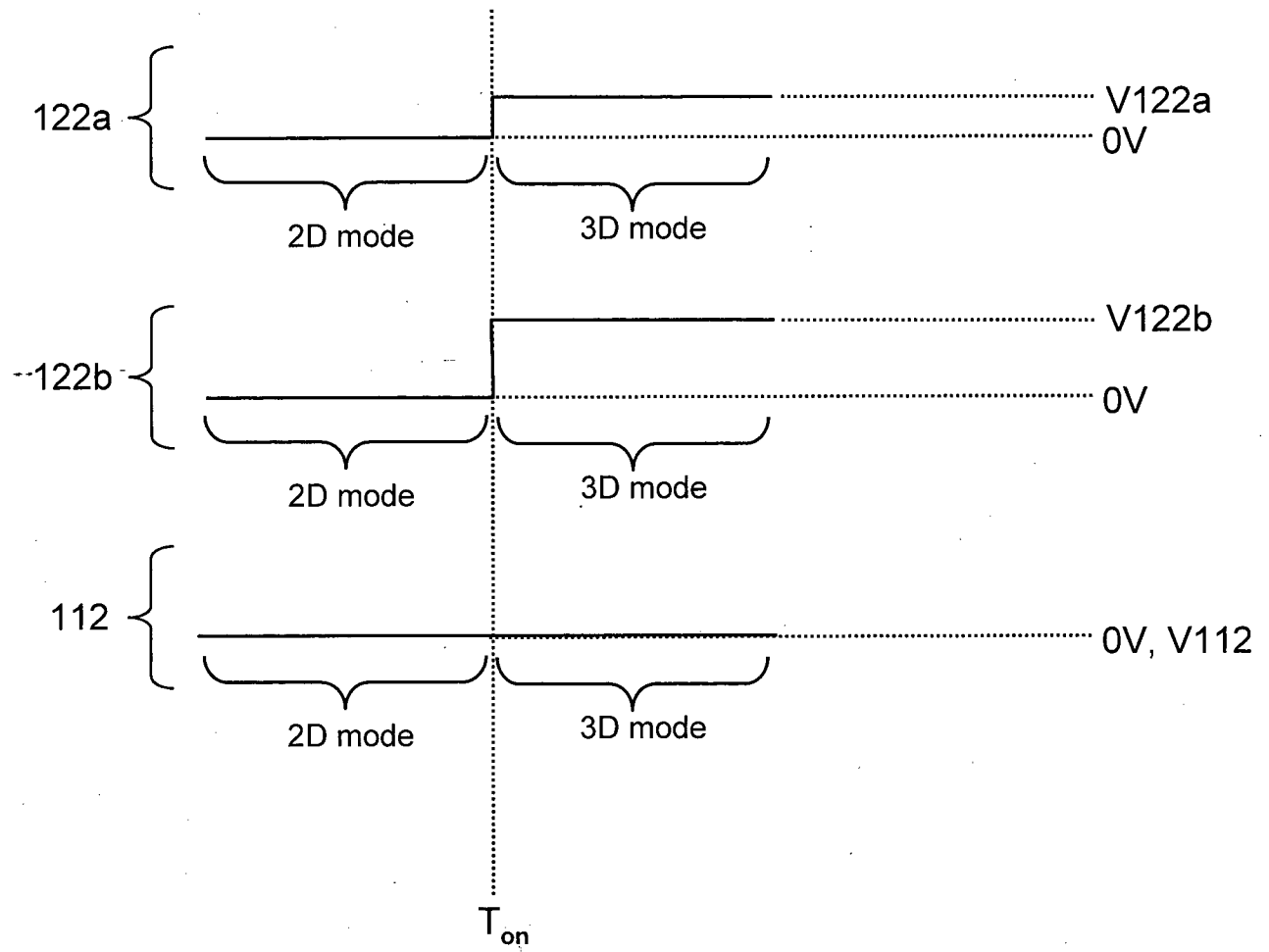


FIG. 24a

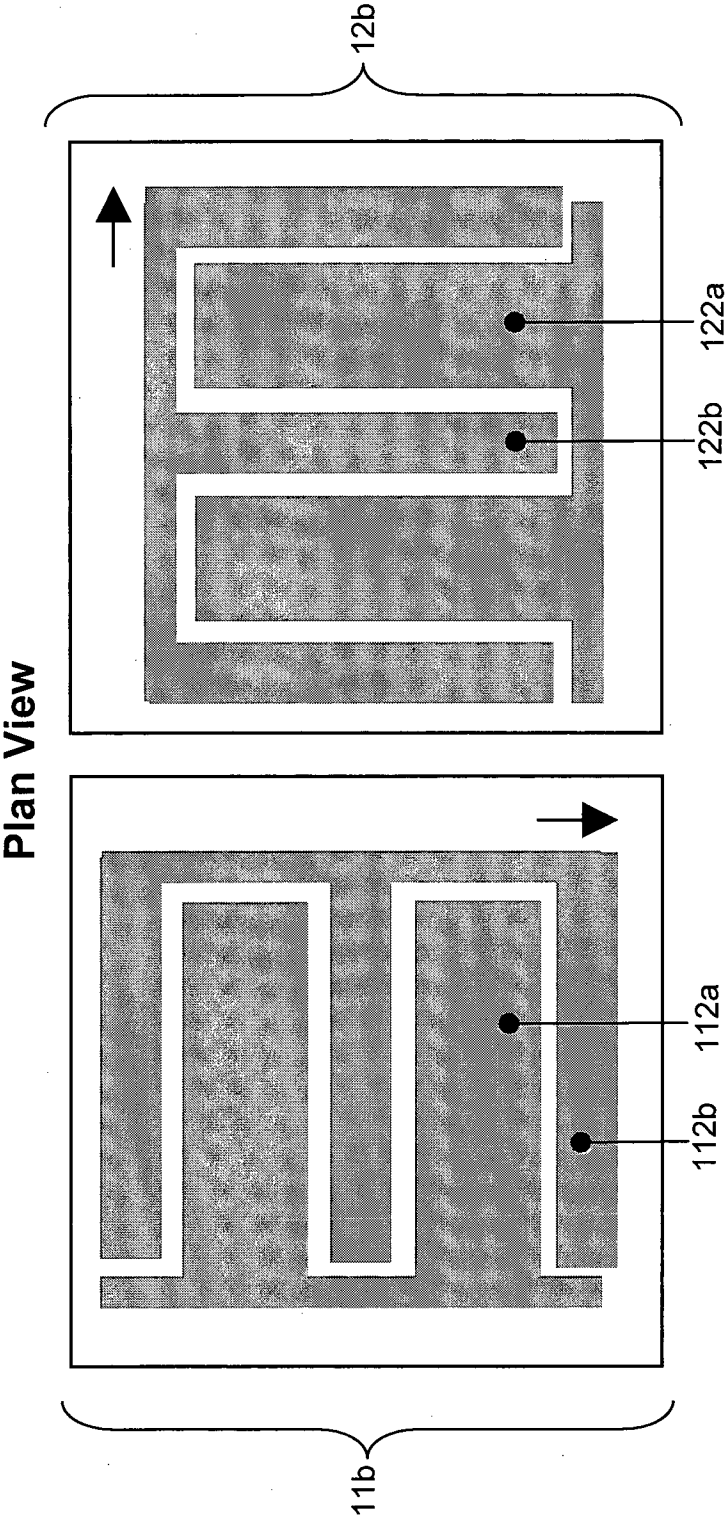
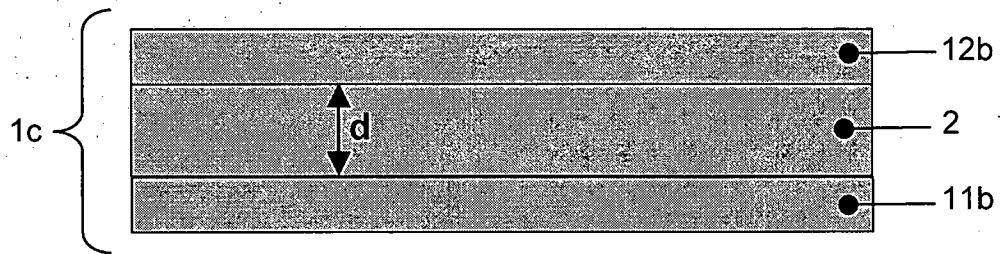


FIG. 24b

Side View



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FIG. 25a

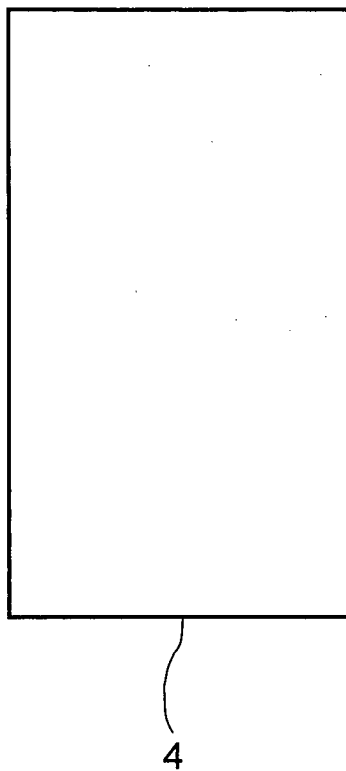
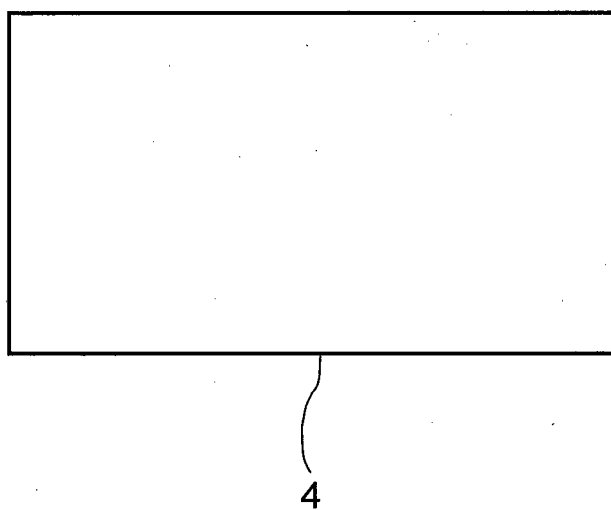


FIG. 25b



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FIG. 26a

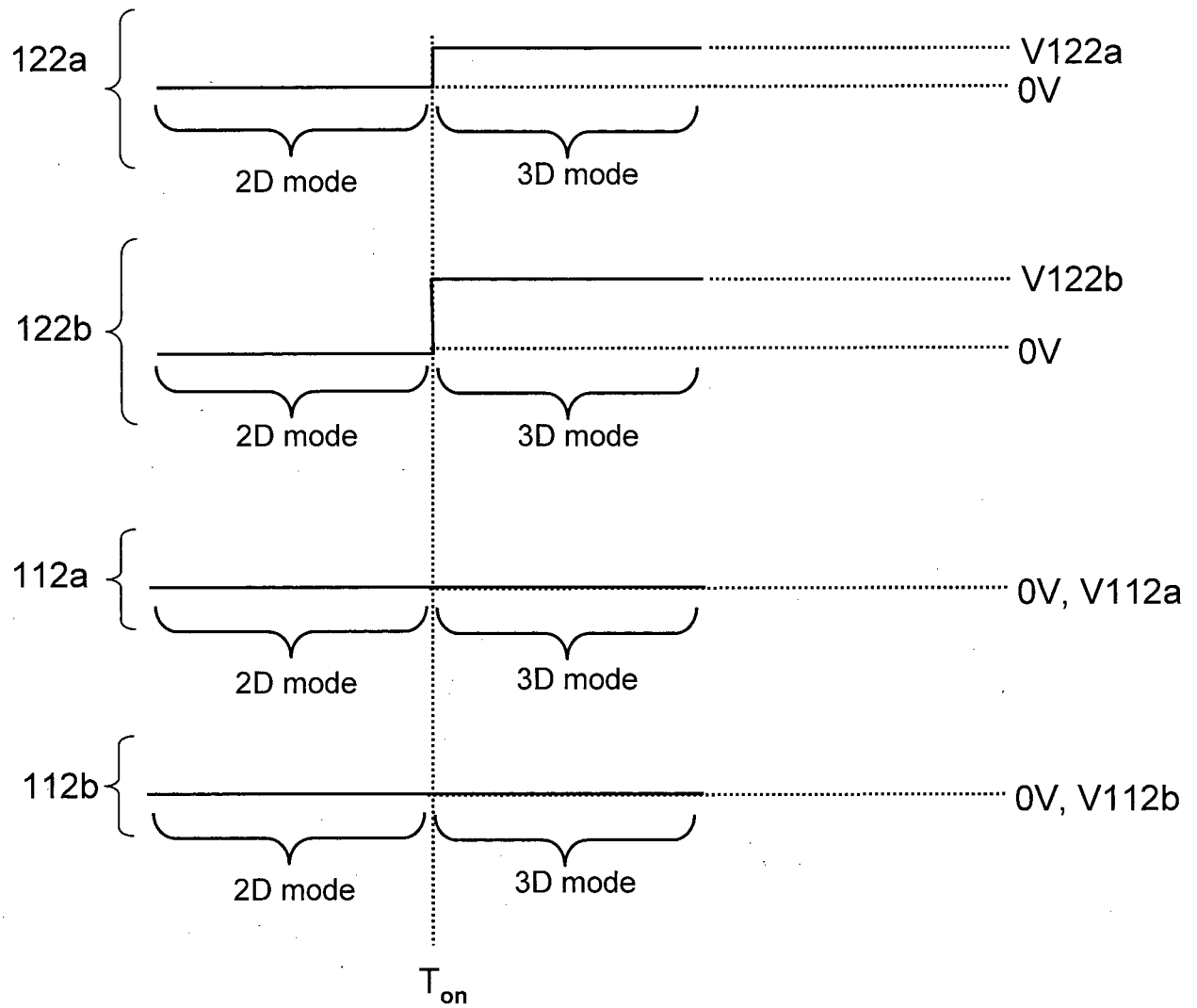


FIG. 26b

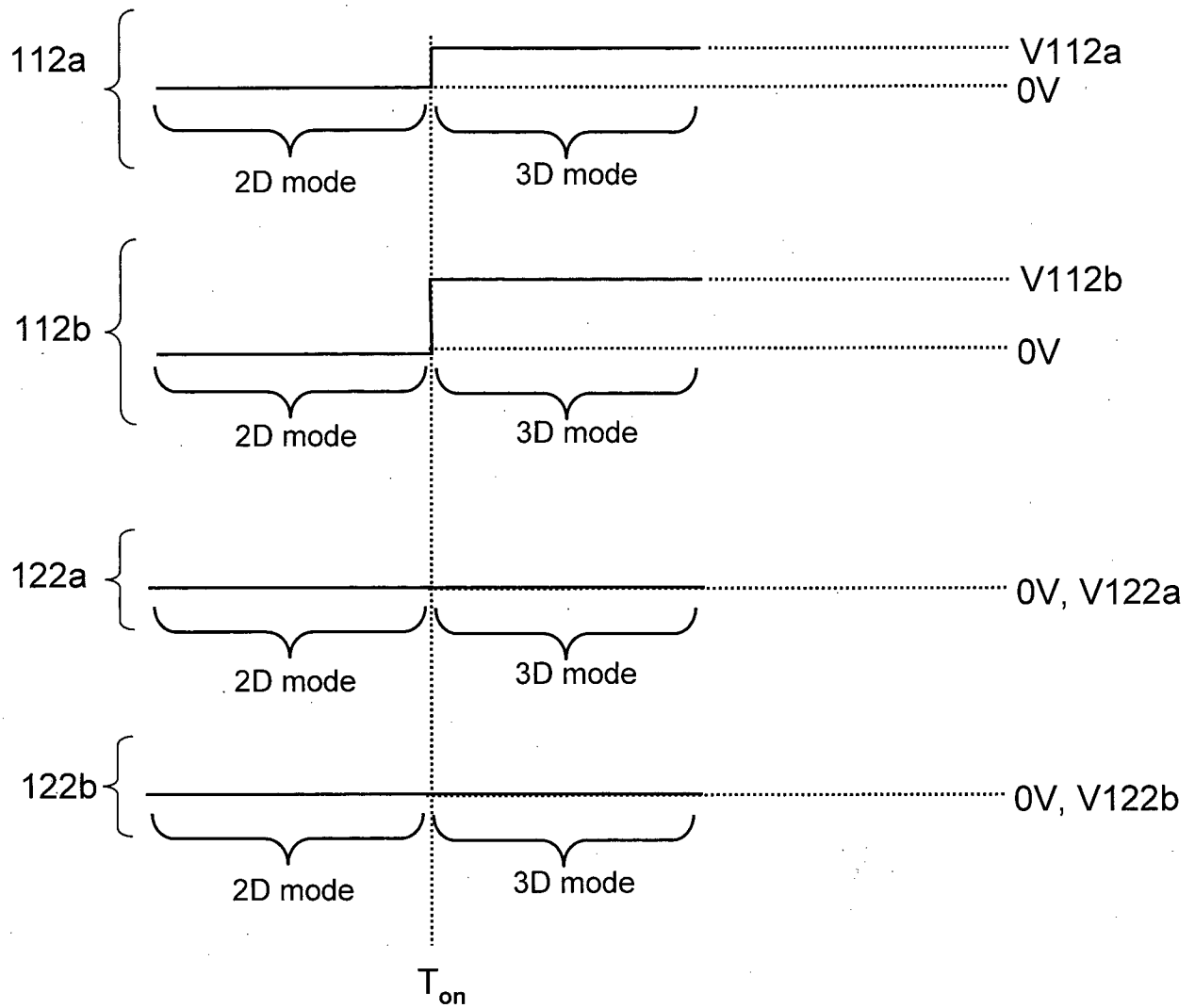


FIG. 27a

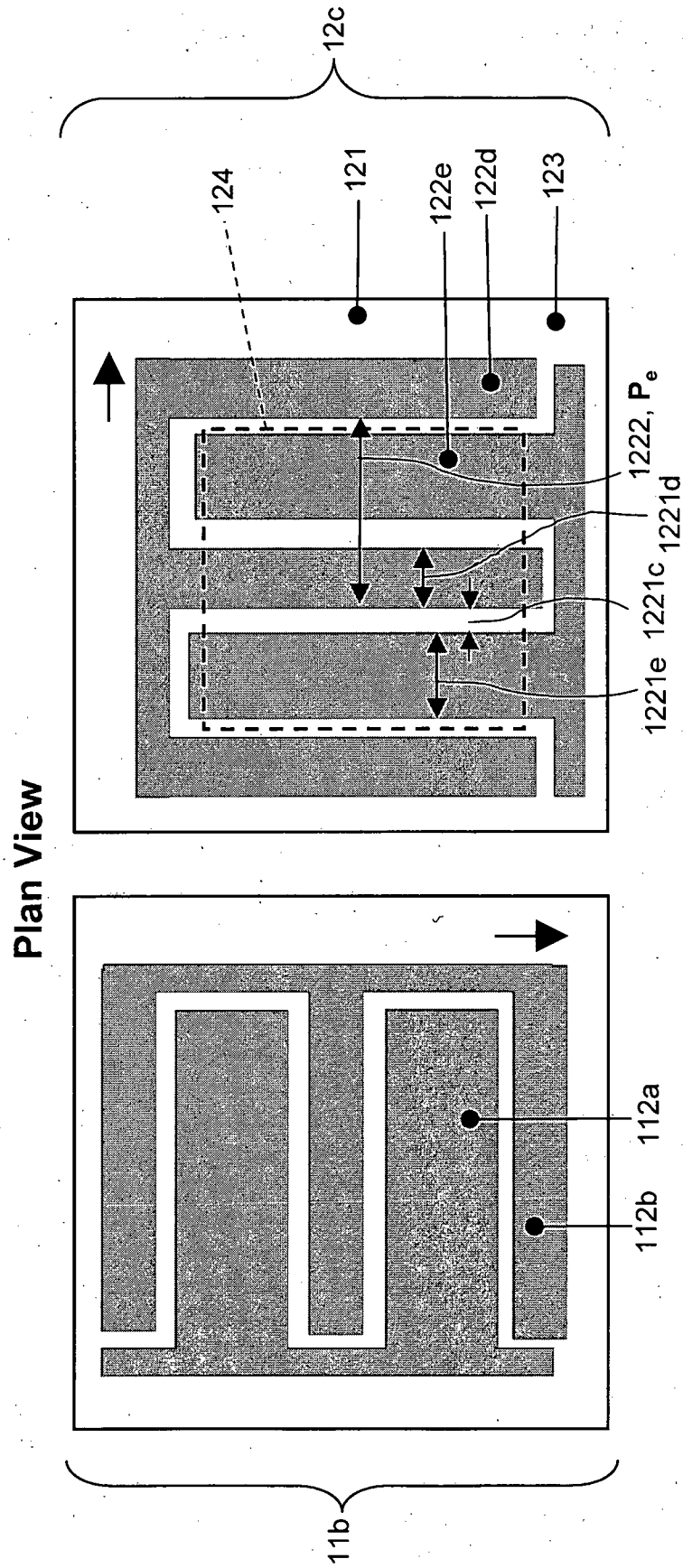


FIG. 27b

Side View

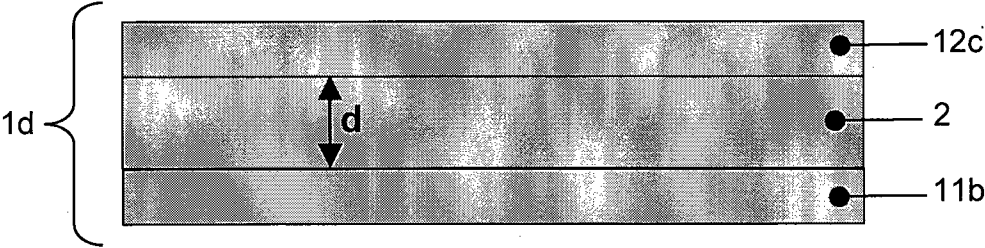
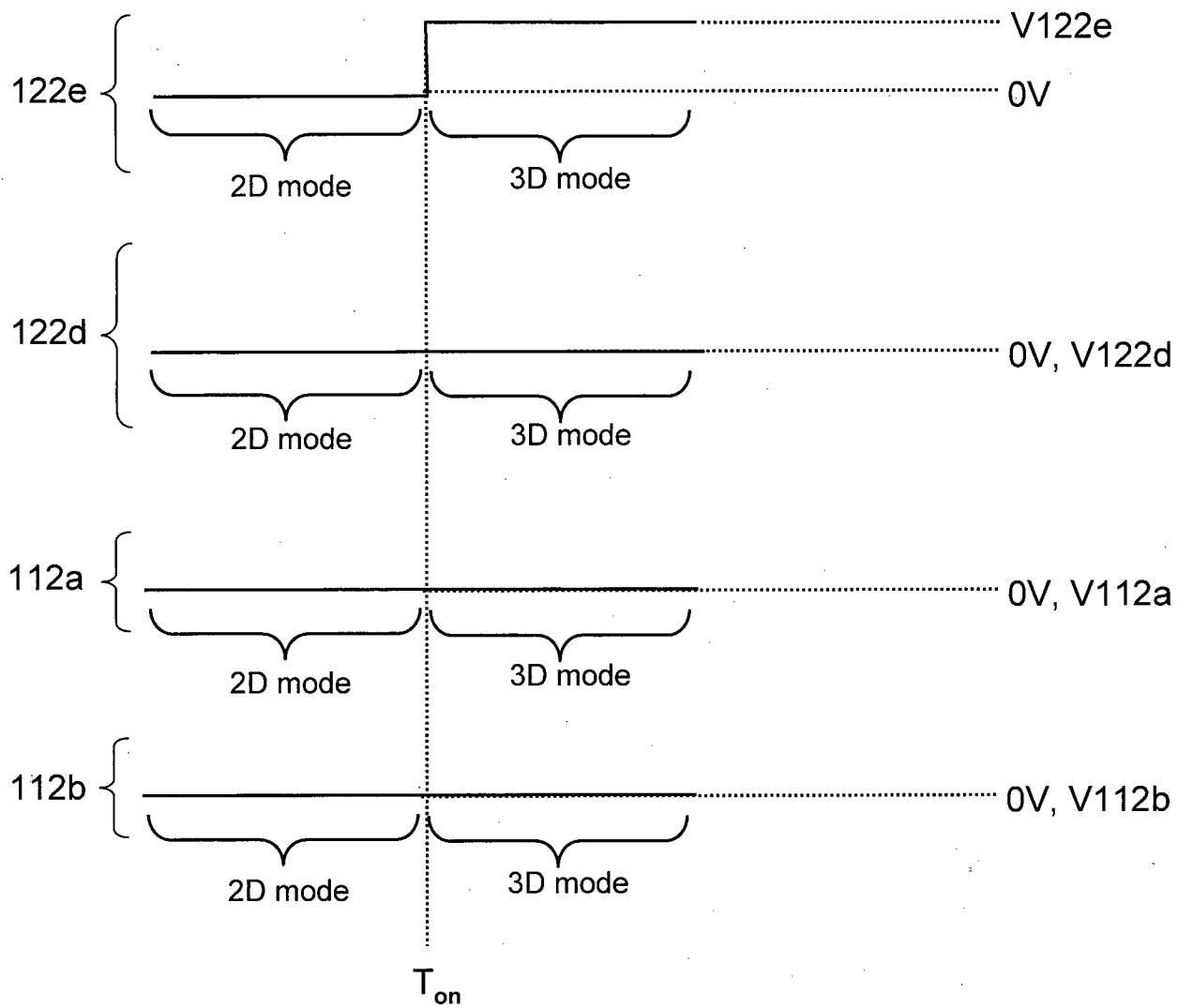


FIG. 28a



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FIG. 28b

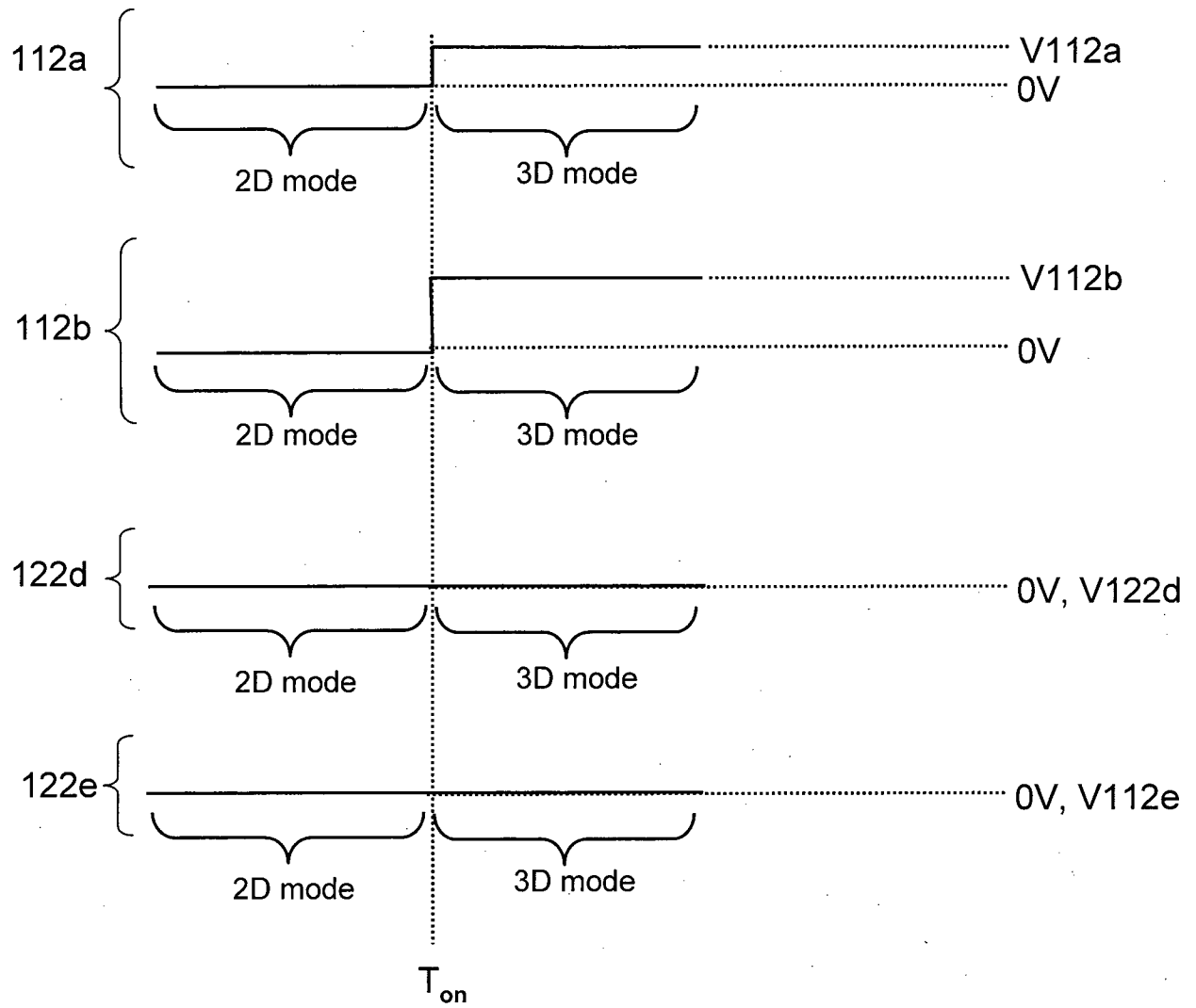
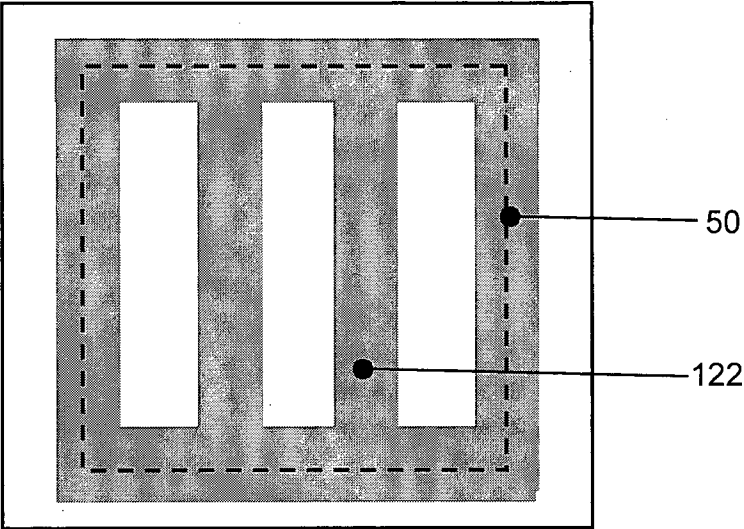


FIG. 29



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FIG. 30a

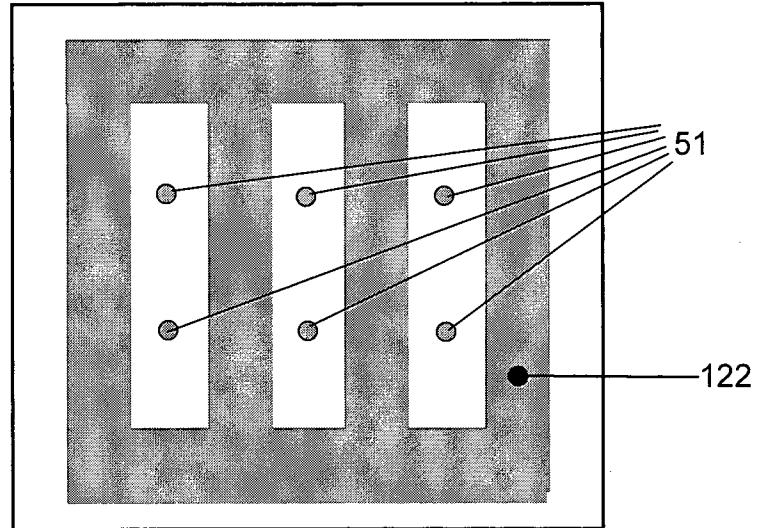


FIG. 30b

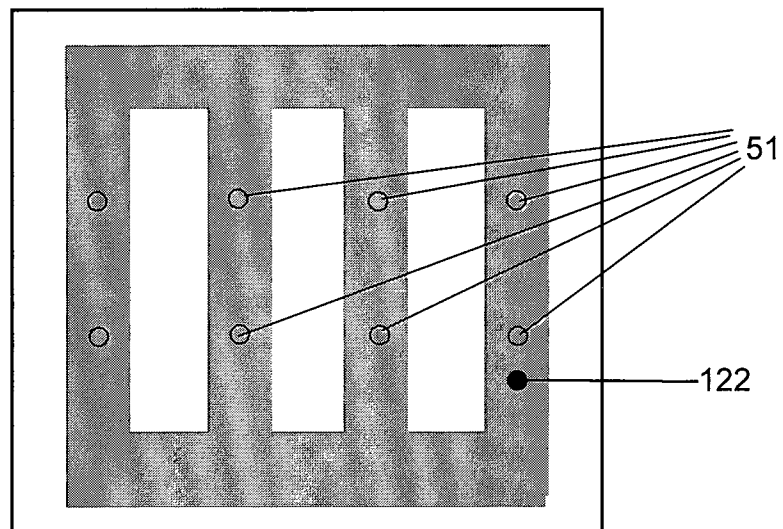


FIG. 31a

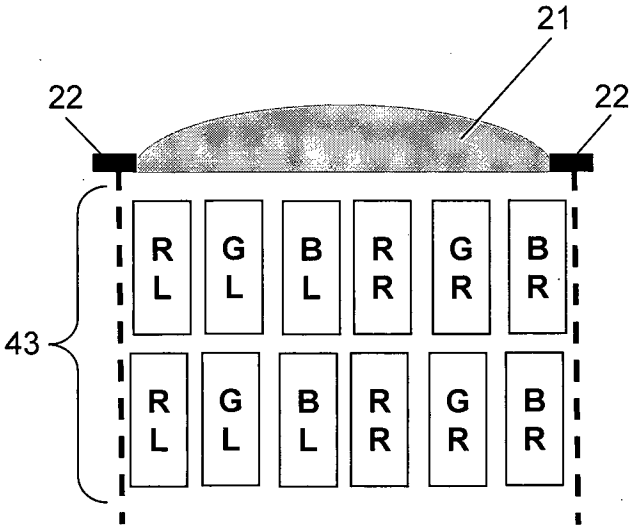
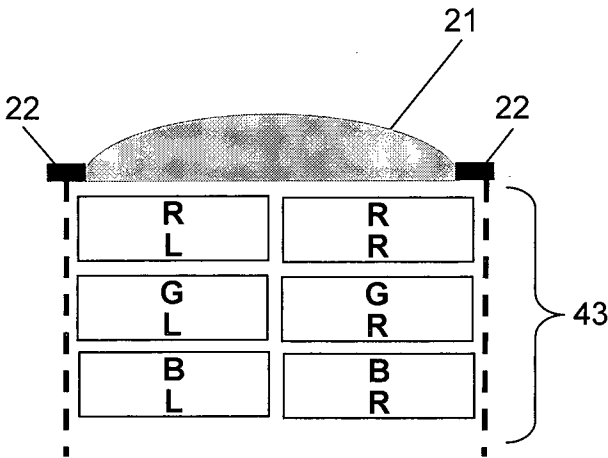
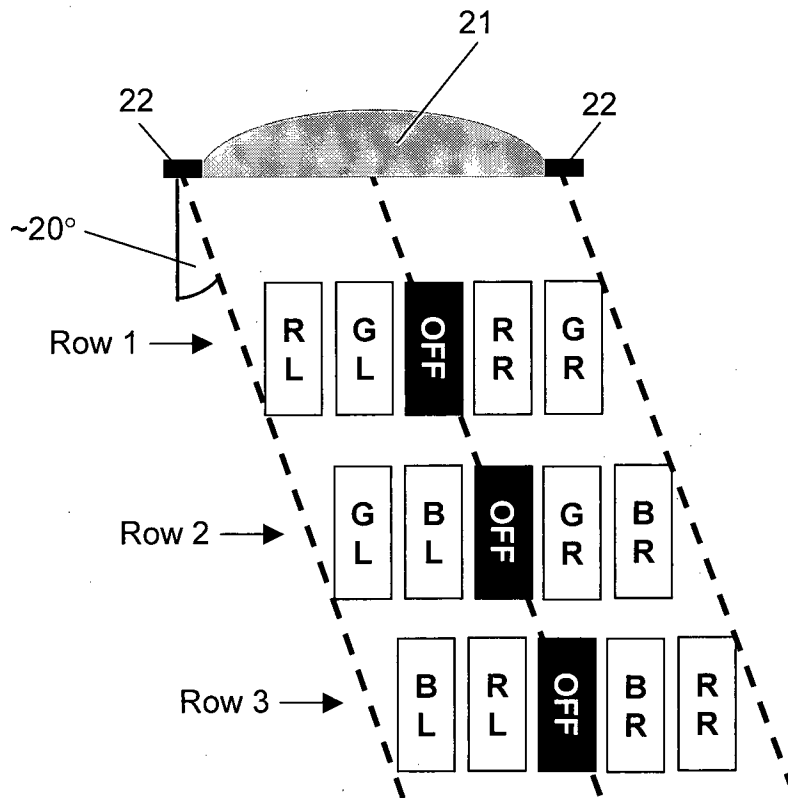


FIG. 31b



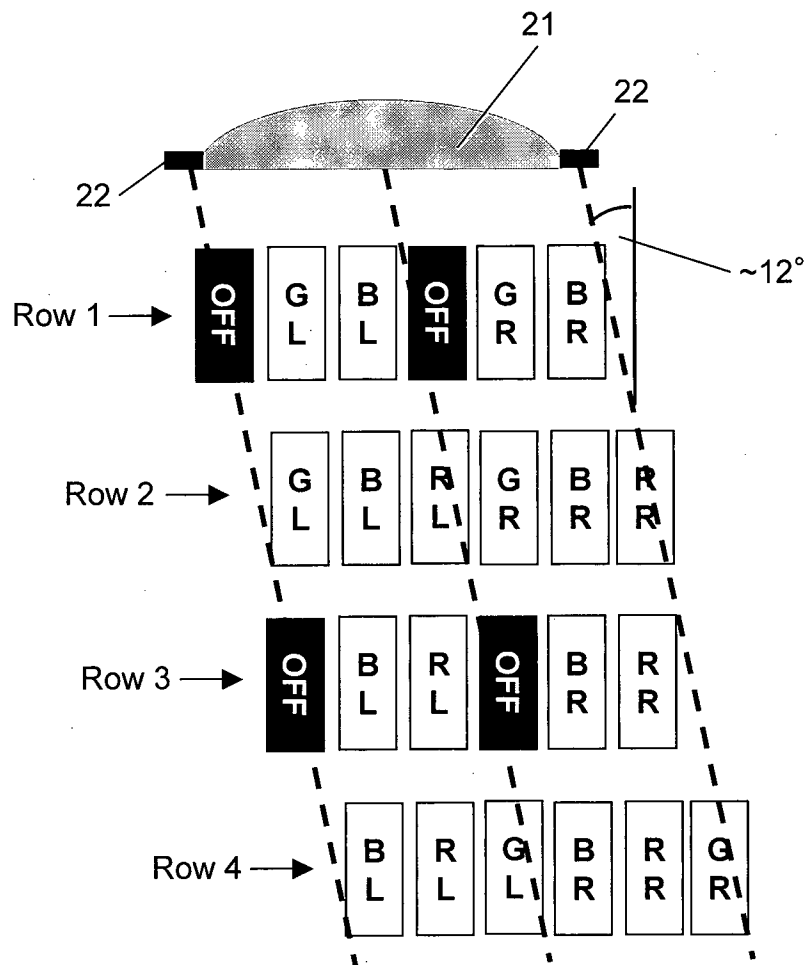
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FIG. 31c



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FIG. 31d



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FIG. 32a

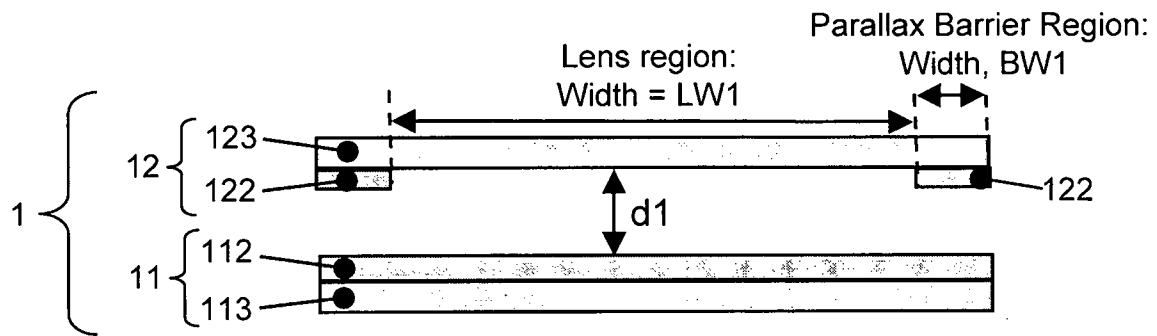
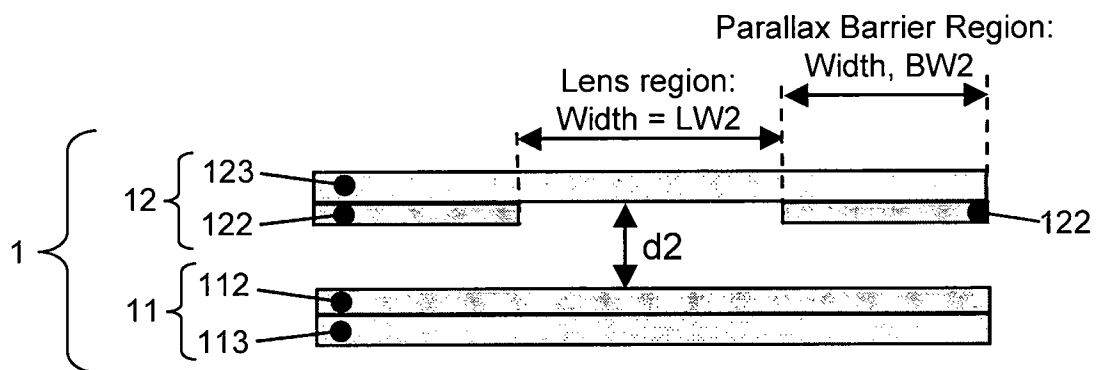


FIG. 32b



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FIG. 33a

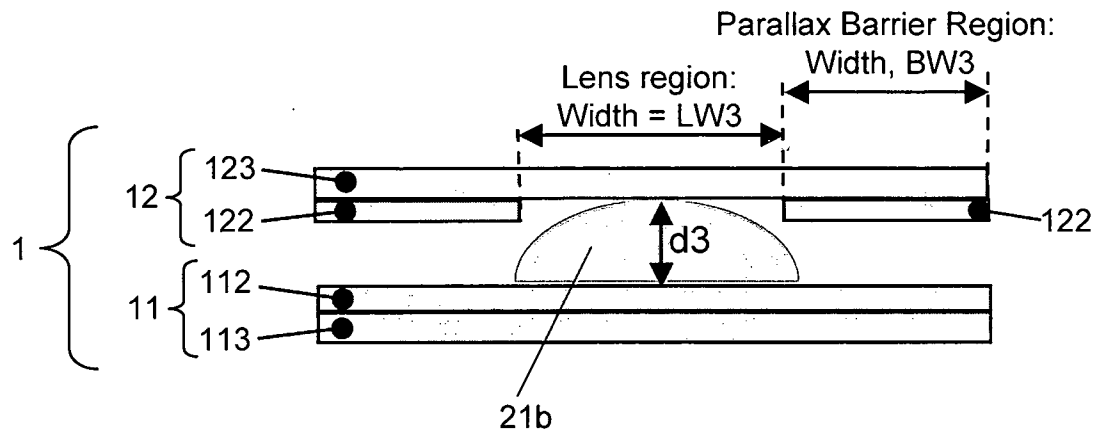
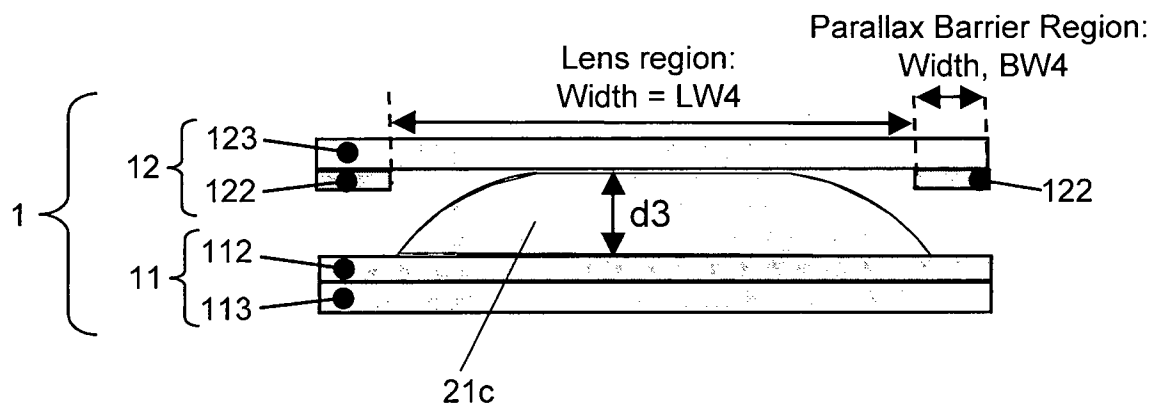


FIG. 33b



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/056220

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. G02B27/22 (2006.01) i, G02F1/00 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. G02B26/02-26/04, 27/22,
G02F1/00-1/065, 1/13-1/225

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2012
Registered utility model specifications of Japan 1996-2012
Published registered utility model applications of Japan 1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

JSTPlus (JDreamII)
JST7580 (JDreamII)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 07-234414 A (Toshiba Corp.) 05 September, 1995 (05.09.95), Par. Nos. [0020] to [0118], Figs. 10 to 35 & US 5434690 A & EP 0636921 A2 & EP 0636921 A3 & KR 10-0148502 B1	18-24 1-17
A	JP 2003-279924 A (Ricoh Company, Ltd.) 02 October, 2003 (02.10.03), Par. Nos. [0027], [0033] to [0049] (No Family)	1-24

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☐ See patent family annex.

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Date of the actual completion of the international search

04.04.2012

Date of mailing of the international search report

17.04.2012

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/056220

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-080286 A (Citizen Holdings Co., Ltd.) 16 April, 2009 (16.04.09), Par. Nos. [0030] (No Family)	1-24
A	JP 2006-516753 A (AU Optronics Corp.) 06 July, 2006 (06.07.06), Par. Nos. [0105] to [0182], Figs. 11 to 14 & WO 2004/070467 A2	1-24
A	JP 10-026765 A (Toshiba Corp.) 27 January, 1998 (27.01.98), Par. Nos. [0158] to [0261], (No Family)	1-24