

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 November 2007 (15.11.2007)

PCT

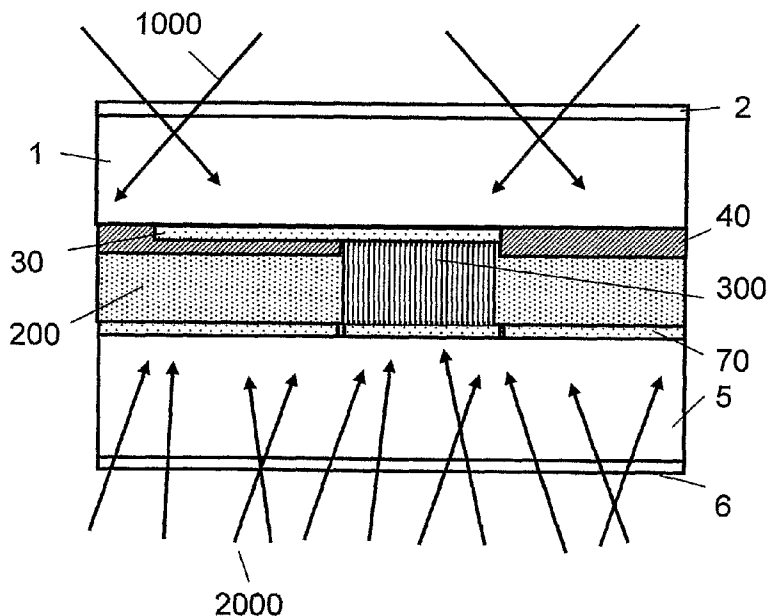
(10) International Publication Number
WO 2007/130130 A2

- (51) International Patent Classification:
H01L 21/54 (2006.01)
- (21) International Application Number:
PCT/US2006/043938
- (22) International Filing Date:
13 November 2006 (13.11.2006)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
60/789,595 6 April 2006 (06.04.2006) US
- (71) Applicant (for all designated States except US): **SBG LABS INC.** [US/US]; 1288 HAMMERWOOD AVENUE, Sunnyvale, CA 94089 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **WALDERN, Jonathan, David** [US/US]; 11491 OLD RANCH ROAD, Los Altos Hills, CA 94024 (US). **GUNTHER, John, Edward** [US/US]; 701 AMY LANE, Redondo Beach, CA

- 90278 (US). **POPOVICH, Milan, Momcilo** [GB/GB]; 53 WESTFIELD ROAD, Leicester XX LE3 6HU (GB).
- (74) Agent: **POPOVICH, Milan, Momcilo**; 53 WESTFIELD ROAD, Leicester, LE3 6HU (GB).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY



(57) Abstract: There is provided a method of fabricating an improved HPDLC transparent symbolic data display for projecting symbology into the field of view of a viewing device in which the HPDLC is localized to the display regions covered by the symbols. In a first step, a substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided. In a second step, portions of said transparent electrode layer are removed to provide a patterned electrode layer including a symbol pad. In a third step, a layer of UV absorbing dielectric material is deposited over said patterned electrode layer. In a fourth step, the portion of said UV absorbing dielectric material overlapping said symbol pad is removed. In a fifth step, a second substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided. In a sixth step, the transparent electrode layer of said

second substrate layer is etched to provide a patterned electrode layer including an electrode element substantially identical to and spatially corresponding with the symbol pad. In a seventh step, the substrates are combined to form a display cell with the coated surfaces of the two cells aligned in opposing directions and having a small separation. In an eighth step, said display cell is filled with a PDLC mixture. In the final step, the cell face formed by the first substrate is illuminated by crossed UV laser beams, and simultaneously illuminating the cell face formed by the second substrate by an incoherent UV source.

WO 2007/130130 A2



Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAYRELATED APPLICATIONS

This applications claims priority to US Provisional 60/789,595 6 April 2006 entitled
5 METHOD AND APPARATUS FOR SWITCHING A PDLC DEVICE.

This application incorporates by reference in their entirety the U.S. Patent Applications:
Ser. No. 10/555,661 filed 4 November 2005, entitled SWITCHABLE VIEWFINDER DISPLAY
Ser. No. 60/814,536 filed 9 June 2006, entitled HOLGRAPHIC WEARABLE DISPLAY.

10 BACKGROUND OF THE INVENTION

This invention relates to a display device, and more particularly to an improved Polymer
Dispersed Liquid Crystal (PDLC) symbolic data display and a method for fabricating said PDLC
display.

15 Optical viewing systems such as cameras, night vision equipment and optical sights often
have a requirement to selectively present symbolic information of various types superimposed
over the view of the outside scene. Static information may be displayed in a viewfinder by the
simple method of placing an etched reticule at an image plane within the optical system, such as
the reticules commonly found in the eyepieces of microscopes. A number of schemes are used
20 to present dynamic information, including selective illumination of symbology engraved on a
reticule, or the use of a beam-splitter to combine the information presented on a small display
device with the outside scene. In some optical systems, however, a suitable image plane may
not be available for the insertion of display information. In the case of a single lens reflex

camera, a diffusing screen may be placed at the image plane within the viewfinder. In other optical systems, the image plane may exist within an optical element such as a prism.

It is well known that diffractive optical elements are ideally suited to projection of
5 symbology. Bragg gratings (also commonly termed volume phase grating or holograms), which offer the highest diffraction efficiencies, have been widely used in devices such as Head Up Displays. An important class of diffractive optical element known as an Electrically Switchable Bragg Gratings (ESBG) is based on recording Bragg gratings into a polymer dispersed liquid crystal (PDLC) mixture. Typically, ESBG devices are fabricated by first placing a thin film of a
10 mixture of photopolymerisable monomers and liquid crystal material between parallel glass plates. One or both glass plates support electrodes, typically transparent indium tin oxide films, for applying an electric field across the PDLC layer. A Bragg grating is then recorded by illuminating the liquid material with two mutually coherent laser beams, which interfere to form the desired grating structure. During the recording process, the monomers polymerize and the
15 PDLC mixture undergoes a phase separation, creating regions densely populated by liquid crystal micro-droplets, interspersed with regions of clear polymer. The alternating liquid crystal-rich and liquid crystal-depleted regions form the fringe planes of the grating. The resulting Bragg grating can exhibit very high diffraction efficiency, which may be controlled by the magnitude of the electric field applied across the PDLC layer. In the absence of an applied
20 electric field the ESBG remains in its diffracting state. When an electric field is applied to the hologram via the electrodes, the natural orientation of the LC droplets is changed thus reducing the refractive index modulation of the fringes and causing the hologram diffraction efficiency to

drop to very low levels. The diffraction efficiency of the device can be adjusted, by means of the applied voltage, over a continuous range from essentially zero to near 100%.

U. S. Patent 5,942,157 by Sutherland et al. and U. S Patent 5,751,452 by Tanaka et al.
5 describe monomer and liquid crystal material combinations suitable for fabricating ESBG
devices. A recent publication by Butler et al. ("Diffractive properties of highly birefringent
volume gratings: investigation", Journal of the Optical Society of America B, Volume 19 No. 2,
February 2002) describes analytical methods useful to design ESBG devices and provides
numerous references to prior publications describing the fabrication and application of ESBG
10 devices.

One approach to fabricating an HPDLC symbology display is to record the HPDLC over
the entire display surface and to incorporate the individual symbol shapes into the electrode
pattern. However, this approach suffers from the problem that, while the background grating is
15 substantially removed by the application of a field, the residual grating may still be sufficiently
pronounced to reduce the quality of the viewed image.

In order to provide crisply defined symbols it is desirable to confine the H-PDLC grating
within the display region defined by the symbol. Such a display can be provided by using a
20 focused mask in the exposure set-up. Ideally, the mask size should be slightly larger than the
actual symbol to improve background clarity. However, such methods suffer from the need for
tight tolerances in mass production and hence high costs.

Hence there exists a need for an improved HPDLC transparent symbolic data display for projecting symbology into the field of view of a viewing device in which the HPDLC is localized to the display regions covered by the symbols. There is a further requirement for a method of fabricating an HPDLC symbols display that will result in a more efficient and cost effective mass production process.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved HPDLC transparent symbolic data display for projecting symbology into the field of view of a viewing device in which the HPDLC is localized to the display regions covered by the symbols. It is a further object of the present invention to provide a method of fabricating an HPDLC symbols display that will result in a more efficient and cost effective mass production process.

The objects of the invention are achieved in a first embodiment comprising a first transparent substrate, an antireflection coating, a first transparent electrode layer covering a portion of the surface of the substrate, a UV absorbing dielectric layer covering a portion of the first transparent electrode layer and said substrate, a PDLC layer into which an HPDLC region has been recorded and a second substrate to which a transparent patterned electrode and an anti reflection coating have been applied.

The objects of the invention are also achieved in a method of fabricating a PDLC symbolic data display comprising the following steps:

a first step in which a substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided;

5 a second step in which portions of said transparent electrode layer are removed to provide a patterned electrode layer including a first symbol pad;

a third step in which a layer of UV absorbing dielectric material 4 is deposited over said patterned electrode layer;

a fourth step in which the portion of said UV absorbing dielectric material overlapping said symbol pad is removed;

10 a fifth step in which a second substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided;

a sixth step in which the transparent electrode layer of the second substrate layer is etched to provide a patterned electrode layer including a second symbol pad substantially identical to and spatially corresponding with the first symbol pad;

15 a seventh step in which the two substrates processed according to the above steps are combined to form a display cell with the coated surfaces of the two cells aligned in opposing directions and having a small separation;

an eight step in which the display cell is filled with a PDLC mixture;

20 a ninth step in which the cell face formed by the first substrate is illuminated by crossed UV laser beams, and simultaneously the cell face formed by the second is illuminated by an incoherent UV source forming an HPDLC region confined to the region between the first and second symbol pads and surrounded by a PDLC region

In preferred embodiments of the invention the HPDLC regions functions as an ESBG.

In preferred embodiments of the invention the transparent electrode layer of the second substrate layer further provides a background electrode area surrounding said second symbol pad and perimeter regions from which electrode material has been removed disposed between the
5 second symbol pad and said background electrode area.

In a further embodiment of the invention a compact high quality and lightweight display for projecting symbolic information into the field of view of a viewing device in which the
10 HPDLC is localized to the display regions covered by the symbols is provided comprising at least one ESBG device sandwiched between a pair of transparent plates which together function as a total internal reflection lightguide, switching electrodes and means for coupling illumination into the lightguide. Each ESBG device contains information encoded in a multiplicity of separately switchable grating regions. Each ESBG region is surround by a PDLC region. A
15 plurality of independently switchable transparent electrodes elements substantially overlay the separately switchable grating regions. When no electric field is applied, the ESBG device is in its diffracting state and projects images of said information towards the viewer. The projected images are superimposed onto an image of the external scene. When an electric field is applied the ESBG no longer diffracts and hence no information is displayed.

20

A more complete understanding of the invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings wherein like

index numerals indicate like parts. For purposes of clarity details relating to technical material that is known in the technical fields related to the invention have not been described in detail.

BRIEF DESCRIPTION OF THE DRAWINGS

- 5 FIG.1 is a series of schematic front elevation views of the display at successive stages in its fabrication according to the basic principles of invention.
- FIG.2 shows a series of schematic side elevation views of the display at successive stages in its fabrication according to the basic principles of the invention.
- FIG.3 is a side elevation view of the assembled display
- 10 FIG.4 is a side elevation view of the assembled display showing the recording process
- FIG.5 shows a series of schematic side elevation views of the display at successive stages in its fabrication according to the basic principles of the invention.
- FIG.6 is a flow diagram of a method of fabricating the display according to the principles of the invention.
- 15 FIG.7 is a schematic unfolded side view of a symbol generator according to the basic principles of the invention integrated within a Single Lens Reflex (SLR) camera.
- FIG. 8 is a schematic side view of the symbol generator.
- FIG. 9 is a chart illustrating the diffraction efficiency versus incident angle of an ESBG in the state in which no electric field is applied to the ESBG.
- 20 FIG. 10 is a schematic side view of the exposure system to create the ESBG.

DETAILED DESCRIPTION OF THE INVENTION

The process of fabricating a display according to the basic principles of the invention is shown in FIGS.1 to 4. The first six steps are shown in FIGS.1-2. For the purposes of explaining the invention a display comprising a single rectangular shaped symbol is considered.

5

Step 1 is illustrated by the plan view of FIG.1A and the side elevation view of FIG.2A. In Step 1 a substrate coated on one side with an anti reflection coating 2 and coated on the opposing side with a layer of Indium Tin Oxide (ITO) 3 is provided. The element shown in FIG.1A and FIG.2A is referred to as the electrode plate. Only the ITO coated surface is shown in FIG.1A.

10

Step 2 is illustrated by the plan view of FIG.1B and the side elevation view of FIG.2B. In Step 2 portions of the ITO on the electrode plate are removed to provide a patterned ITO region generally indicated by 30 and comprising the symbol pad 31, an electrical connection path 32 and a power supply connector pad 33. At this stage in the process the alignment markers 11,12
15 may be deposited onto the substrate.

Step 3 is illustrated by the plan view of FIG.1C and the side elevation view of FIG.2C. In Step 3 a layer of UV absorbing dielectric material 4 is deposited over the electrode layer 30.

20

Step 4 is illustrated by the plan view of FIG.1D and the side elevation view of FIG.2D. In Step 4 a portion of said UV absorbing dielectric material overlaying symbol pad 31 is removed. FIG.1E shows a plan view of the superimposed dielectric layer and ITO layer.

At Step 5, which is not illustrated, a second substrate again coated on one side with an anti reflection coating and coated on the opposing side with a layer of ITO is provided.

Step 6 is illustrated by the plan view of FIG.1F and the side elevation view of FIG.2E. In
5 Step 6 the ITO layer of said second substrate is etched to provide the electrode structure general indicated by 70 comprising a central portion 71 substantially identical to and spatially corresponding with the symbol pad 31, the background area 72 and the perimeter regions 73a, 73b from which ITO material has been removed. The width of the perimeter regions 73a, 73b are required to be large enough to avoid the risk of short circuits occurring. Desirably the width
10 of the perimeter regions should be less than 50 microns.

In a further step, Step 7, which is not illustrated, the two substrates processed according to the above steps are combined to form a display cell with the coated surfaces of the two cells aligned in opposing directions and having a small separation.

15

In a further step, Step 8, which is not illustrated, the display cell is filled with a PDLC mixture.

In the final step, Step 9, of the fabrication process the HPDLC symbol is recorded.

20

A schematic side view of an assembled display according to the basic principles of the invention is shown in FIG.3. The display comprises a first transparent substrate 1, an antireflection coating 2, a first ITO layer 30 covering a portion of the surface of the substrate, a

UV absorbing dielectric layer 40 covering a portion of the ITO and of the substrate, a PDLC layer 100, a second substrate 5 having one surface coated with an ITO pattern indicated by 70 and the opposing face coated with an anti reflection coating 6.

5 FIG.4 shows the HPDLC recording process used. The display cell is illuminated from one side by a pair of intersecting beams generally indicated by 1000 from a UV laser. The incidence angles of the beams will be determined by the viewing configuration of the display. Typically the recording geometry will be configured for image reconstruction by edge lit illumination and viewing in a direction substantially normal to the surface of the display. The
10 intersecting laser beams interfere only in the region of PDLC under the apertures etched out of the dielectric layer. As described earlier the interference causes a grating 300 comprising alternating LC-rich/polymer-depleted and LC-depleted/polymer-rich regions to be formed. At the same time, the PDLC material is UV cured by illuminating the display from the opposite side using incoherent UV light generally indicated by 2000. The incoherent UV light gives rise to the
15 PDLC region 300. The PDLC is characterized by large LC droplets having random orientations. However, the HPDLC grating is characterized by tiny droplets having a preferred alignment. The relative intensities of the UV laser and the incoherent UV source are balanced to optimize the switching characteristics of the PDLC and HPDLC regions. When an electric field source is coupled across the ITO electrodes 30 and 70 the grating remains active when no field is applied
20 but is deactivated when a field is applied. During normal operation the display is edge illuminated. The PDLC provides a highly transparent and uniform background when illumination is applied to the display. Since the HPDLC is confined to the region under the symbol the effects of image degradation due to residual gratings are eliminated.

For the purposes of explaining the invention the thicknesses of the coatings in FIGS 1-4 have been greatly exaggerated. The details of the wiring around the symbol pads and the means of connecting the pad to the power supply have not been shown in FIGS 1-4. Although FIGS.1-4 show only one symbol pad, the process steps may be applied to an array of symbol pads arrayed on large area substrates, such as commercially available 7-inch substrates. Although the symbol pad shown in FIGS.1-4 is of rectangular shape, the process may generally be applied to symbology of any required shape and size.

The fabrication of a complete symbol display according to the basic principles of the invention is shown in FIG.5. The symbol display of FIG.5 comprises a 3x3 symbol array.

Step 1 is illustrated by the plan view of FIG.5A and the side elevation view of FIG.5B. In Step 1 a substrate coated on one side with an anti reflection coating 2a and coated on the opposing side with a layer of Indium Tin Oxide (ITO) 3a is provided. Only the ITO coated surface is shown in FIG.5A.

Step 2 is illustrated by the plan view of FIG.5C In Step 2 portions of the ITO on the electrode plate are removed to provide a patterned ITO region generally indicated by 30 and comprising an array of symbol pads such 31, electrical connection paths such as 32 and power supply connector pads such as 33. At this stage in the process alignment markers which are not illustrated may be deposited onto the substrate.

Step 3 is illustrated by the plan view of FIG.5D. In Step 3 a layer of UV absorbing dielectric material 4 is deposited over the electrode layer 30.

Step 4 is illustrated by the plan view of FIG.5E. In Step 4 a portion of said UV absorbing dielectric material overlaying the symbol pad array is removed. FIG.5E shows a plan view of the superimposed dielectric layer and ITO layer.

Step 5 is illustrated by the plan view of FIG.5F and the side elevation view of FIG.5G. In Step 5 a second substrate coated on one side with an anti reflection coating 2b and coated on the opposing side with a layer of Indium Tin Oxide (ITO) 3b is provided. Only the ITO coated surface is shown in FIG.5F.

Step 6 is illustrated by the plan view of FIG.5H. In Step 6 the ITO layer of said second substrate is etched to provide the electrode structure generally indicated by 70 comprising a central portion 71 substantially identical to and spatially corresponding with the symbol pad 31, the background area 72 and the perimeter regions 73a, 73b from which ITO material has been removed. The width of the perimeter regions 73a, 73b are required to be large enough to avoid the risk of short circuits occurring. Desirably the width of the perimeter regions should be less than 50 microns.

Step 7 is illustrated by the plan view of FIG.5I and the side elevation view of FIG.5J. In Step 7 the two substrates processed according to the above steps are combined to form a display cell with the coated surfaces of the two cells aligned in opposing directions and having a small separation. As shown in the side elevation view of FIG.5J the cell comprises from left to right an antireflection coating layer 2a, a substrate 1, an ITO layer 3a, an air space 290, an ITO layer 3b, a substrate 5, and an antireflection coating layer 2b.

Step 8 is illustrated by the side elevation view of FIG.5K. In Step 8, the display cell is filled with a PDLC mixture 300.

In Step 9 which is not illustrated the cell face formed by the first substrate is illuminated by crossed UV laser beams, and simultaneously illuminating the cell face formed by the second substrate by an incoherent UV source.

5 A method of fabricating a display in accordance with the invention will now be described with reference to FIG.6.

At step 500,a substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided.

At step 501,portions of said transparent electrode layer are removed to provide a
10 patterned electrode layer including a symbol pad.

At step 502,a layer of UV absorbing dielectric material is deposited over said patterned electrode layer.

At step 503,the portion of said UV absorbing dielectric material overlapping said symbol
pad is removed.

15 At step 504,a second substrate to which an anti reflection coating and a transparent electrode layer have been applied is provided.

At step 505,the transparent electrode layer of said second substrate layer is etched to provide a patterned electrode layer including an electrode element substantially identical to and spatially corresponding with the symbol pad.

20 At step 506,the substrates are combined to form a display cell with the coated surfaces of the two cells aligned in opposing directions and having a small separation.

At step 507,said display cell is filled with a PDLC mixture.

At step 508, the cell face formed by the first substrate is illuminated by crossed UV laser beams, and simultaneously illuminating the cell face formed by the second substrate by an incoherent UV source.

5 In production, the masks will need to be mirror imaged and colored appropriately for the particular process and photo-resist used. The top level ITO mask would typically include a set of alignment features such as the ones shown in FIG.1 to facilitate the assembly of the display. Further alignment features may be incorporated if required by the process.

10 The ITO layer 30 in FIGS1-4 typically has a coating resistance of typically 300-500 Ohm/sq. A typically example of an ITO film used by the inventors is the N00X0325 film manufactured by Applied Films Corporation (Colorado). Typically, the ITO film has a thickness of 100 Angstrom. Typically, the ITO film is applied to 0.7 mm thickness 1737F glass. The ITO layer 70 in FIG.3 should have the same properties as the ITO of Level 1.

15 The dielectric layer 40 in FIG.3 should have a thickness sufficient to withstand a peak voltage of 100V between the ITO layers. Desirably, the dielectric should be free from pinholes. The transmission of the dielectric layer at a wavelength of 365nm and incidence angle in the range 30 to 60 degrees should, ideally, be less than 0.1%. However, in many applications
20 transmissions of up to 5% may be acceptable.

Typically the layer-to-layer registration should be ± 25 micron (± 0.001 inch).

A first benefit of the process discussed above is that it eliminates the need for a focused mask in the exposure set-up. In mask-based exposure processes the grating area would need to be slightly larger than the actual symbol in order to improve background clarity. The use of an etched UV absorbing dielectric layer as disclosed in the present application allows more readily achievable production tolerances, simplifying mass production and lowering cost.

A second benefit of the disclosed fabrication process is that it provides an extremely clear background, which is highly desirable in camera, applications.

The invention does not rely on any particular process. The fabrication steps may be carried out using standard etching and masking processes. The number of steps may be further increased depending on the requirements of the fabrication plant used. For example, further steps may be required for surface preparation, cleaning, monitoring, mask alignment and other process operations that are well known to those skilled in the art but which do not form part of the present invention.

The HPDLC regions may comprise a grid of bars. The invention may be used to provide an active matrix HPDLC display in which each pixel is a HPDLC.

In a preferred embodiment of the invention the above display device forms part of a compact high quality and lightweight ESBG symbol display for projecting symbolic information into the field of view of a viewing device in which the HPDLC is localized to the display regions covered by the symbols. In a preferred embodiment of the invention illustrated in FIGS.7-10

7said symbol display is based on the transparent edge lit ESBG display described in United States Patent Application Ser. No. 10/555,661 filed 4 November 2005, entitled SWITCHABLE VIEWFINDER DISPLAY. The embodiment of the invention illustrated in FIGS.7-10 uses an ESBG fabricated according to the principles illustrated in FIGS.1-6.

5

FIG. 7 shows a schematic unfolded side view of a Single Lens Reflex camera comprising an objective lens 81 which forms a focused image of an external scene on a diffusing screen 84, a symbol generator 83 which projects images of symbols onto said screen, a Light Emitting Diode (LED) 82 optically coupled to the symbol generator and an eyepiece lens 85 through
10 which an image of the scene can be viewed. The symbol generator is transparent to external light rays generally indicated by 3000. In FIG.7 the path of the light from the symbol generator is generally indicated by the ray 4000. By placing the screen at the focal point of the eyepiece an image of the external scene with superimposed symbolic data is formed at some nominal comfortable viewing distance. The objective lens 81 and the diffusing screen 84 do not form
15 part of the invention.

Turning now to FIG.8 in which the symbol generator 83 is again illustrated in a schematic side view, it will be seen that the symbol generator comprises, a lightguide 87, a beam stop 86, a pair of transparent substrates 1 and 5 and an ESBG region sandwiched between the
20 substrates comprising at least one grating region 300 and a flood cured regions 200a,200b on either side of the ESBG grating region. The grating region has a first surface facing the viewer and a second face. A set of transparent electrodes, which are not shown, is applied to both of the inner surfaces of the substrates. The electrodes are configured such that the applied electric field

will be perpendicular to the substrates. The substrates are prepared according to the procedures illustrated in FIGS.1-6. Typically, the planar electrode configuration requires low voltages, in the range of 2 to 4 volts per μm . The electrodes would typically be fabricated from Indium Tin Oxide (ITO). The two substrates 1 and 5 together form a light guide.

5

The input lightguide 87 is optically coupled to the substrates 1 and 5 such the light from the LED undergoes total internal reflection inside the lightguide formed by 1 and 5. Light from the external scene, generally indicated as 7100 propagates through the symbol generator onto the screen where it forms a focused image of the external scene. The function of the symbol generator may be understood by considering the propagation of rays through the symbol generator in the state when the ESBG is diffracting, that is with no electric field applied. The rays 5000 and 6000 emanating from the light source 82 are guided initially by the input lightguide 87. The ray 6000 which impinges on the second face of the grating region 300 is diffracted out of the symbol generator in the direction 7200 towards the screen where an image of the symbol holographically encoded in the ESBG is formed. On the other hand, the rays 5000 which do not impinge on the grating region 300 will hit the substrate-air interface at the critical angle and are totally internally reflected in the direction 7000 and eventually collected at the beam stop 86 and out of the path of the incoming light 7100.

20

The grating region 300 of the ESBG contains slanted fringes resulting from alternating liquid crystal rich regions and polymer rich (ie liquid crystal depleted) regions. In the OFF state with no electric field applied, the extraordinary axis of the liquid crystals generally aligns normal

to the fringes. The grating thus exhibits high refractive index modulation and high diffraction efficiency for P-polarized light.

FIG. 9 is a chart illustrating the diffraction efficiency versus angle of an ESBG grating in the OFF state. This particular grating has been optimized to diffract red light incident at around 5 72 degrees (the Bragg angle) with respect to the normal of the substrate. The Bragg angle is a function of the slant of the grating fringes and is chosen such that the diffracted light exits close to normal (0 degrees) to the substrate 5 in order to be captured by the eyepiece 85. To maximize the light throughput from the light source 82 to the eyepiece 85, the light source and input 10 lightguide should be configured such that light is launched into the lightguide at the Bragg angle. This can be accomplished by various means well known to those skilled in the art, including the use of lenses. Light launched into the lightguide must be at an angle greater than the angle for Total Internal Reflection (TIR) in order to be guided by the lightguide. Hence, the Bragg angle must be chosen to be larger than the angle for TIR.

15

When an electric field is applied to the ESBG, the grating switches to the ON state wherein the extraordinary axes of the liquid crystal molecules align parallel to the applied field and hence perpendicular to the substrate. Note that the electric field due to the planar electrodes is perpendicular to the substrate. Hence in the ON state the grating exhibits lower refractive 20 index modulation and lower diffraction efficiency for both S- and P-polarized light. Thus the grating region 300 no longer diffracts light into the eyepiece and hence no symbol is displayed.

In order to ensure high transparency to external light, high contrast of symbology (ie high diffraction efficiency) and very low haze due to scatter the following material characteristics are desirable.

- 5 a) A low index modulation residual grating with a modulation not greater than 0.007. This will require a good match between the refractive index of the polymer region and the ordinary index of the liquid crystal.
- b) High index modulation capability with a refractive index modulation not less than 0.06
- 10 c) Very low haze for cell thicknesses in the range 2-6 micron
- d) A good index match (to within +0.015) for glass or plastic at 630 nm. One option is 1.515 (for example, 1737F or BK7 glasses). An alternative option would be 1.472 (for
- 15 example Borofloat or 7740 Pyrex glasses)

FIG. 10 is a schematic side elevation view of a laser exposure system used to record the ESBG grating. The exposure system comprises a prism 90 mounted on top of and in optical contact with the substrate 1, a mask for defining the shapes of the symbols to be projected

20 containing opaque regions such as 91a and 91b, and two mutually coherent intersecting laser beams generally indicated by 8000 and 9000. The prism has a top surface substantially parallel to the substrate and angle side faces. The beam 8000 is introduced via the top surface of the prism. The beam 9000 is introduced via a side face of the prism. The mask defines an aperture

through which portions of the beams can impinge on the mixture of photopolymerisable monomers and liquid crystal material confined between the parallel substrates 1 and 5. The interference of the beam within the region defined by the aperture creates a grating region 300 comprising alternating liquid crystal rich and polymer rich regions. The shape of the aperture defines the shape of the symbol. It will be clear from consideration of FIG.10 that a plurality of symbols may be created in this way.

Each symbol may be independently controlled by an independent pair of planar electrodes. Typically, the electrode on one substrate surface is uniform and continuous, while electrodes on the opposing substrate surface are patterned to match the shapes of the said ESBG symbol regions. Desirably, the planar electrodes should be exactly aligned with the ESBG symbol regions for optimal switching of the symbols and the elimination of any image artefacts that may result from unswitched grating regions.

Referring again to FIG.10 we see that the flood-cured regions 200a, 200b are created by the beam 9000. Since there is no intensity variation in this region, no phase separation occurs and the region is homogeneous, haze-free and generally does not respond to applied electric fields.

In one practical embodiment of the invention directed at SLR cameras the symbol generator would have a square aperture of side dimension equal to 30 mm. The beam inside the light guide would have an incidence angle of 72 degrees corresponding to the Bragg angle of the ESBG grating.

In a further embodiment of the invention, the symbol generator could be configured to provide symbols of different colors by arranging for different symbols to contain ESBGs optimized for the required wavelengths and LEDs of appropriate spectral output.

5 In a yet further embodiment of the basic invention several ESBG panels could be stacked such that by selectively switching different layers it is possible to present a range of different symbols at any specified point in the field of view.

Although in FIGS.7-10 the light source is coupled to the symbol generator by means of a
10 light guide, other methods involving prisms, lenses or diffractive optical elements may be used.

The basic edge lit display device described above may be used in camera viewfinders, head up displays and optical sights. It may be used in wearable displays such as the one described in United States Patent Application No. 60/814,536 filed 9 June 2006, entitled HOLGRAPHIC
15 WEARABLE DISPLAY.

Although the invention has been described in relation to what are presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not limited to the disclosed arrangements but rather is intended to cover various modifications and
20 equivalent constructions included within the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A method of fabricating a display comprising the following steps:

providing a first transparent substrate having a first surface to which an anti reflection

5 coating has been applied and a second surface to which a transparent electrode layer has been applied;

removing portions of said transparent electrode layer to provide a patterned electrode layer including an first symbol pad;

depositing a layer of UV absorbing dielectric material over said patterned electrode layer;

10 removing the portion of said UV absorbing dielectric material overlapping said first symbol pad;

providing a second transparent substrate having a first surface to which an anti reflection coating has been applied and a second surface to which a transparent electrode layer has been applied;

15 removing portions of the transparent electrode layer of said second substrate layer to provide a second patterned electrode layer including a second symbol pad substantially identical to and spatially corresponding with said first symbol pad;

combining the substrates to form a display cell with the transparent electrode coated surfaces of the two substrates aligned in opposing directions and having a small

20 separation, wherein the antireflection coated surface of said first substrate forms a first cell face, wherein the antireflection coated surface of said second substrate forms a second cell face;

filling said display cell with a PDLC mixture;

illuminating said first cell face by crossed UV laser beams, and simultaneously
illuminating said second cell face formed by an incoherent UV source.

2. The method of claim 1 wherein said step of illuminating said first cell face by crossed
5 UV laser beams, and simultaneously illuminating said second cell face formed by an
incoherent UV source forms an HPDLC confined to the region between said first symbol
pad and said second symbol pad.
3. The method of claim 1 wherein said step of illuminating said first cell face by crossed
10 UV laser beams, and simultaneously illuminating said second cell face formed by an
incoherent UV source forms an HPDLC confined to the region between said first symbol
pad and said second symbol pad, wherein said HPDLC is surrounded by a PDLC region.
4. The method of claim 1 wherein said step of illuminating said first cell face by crossed
15 UV laser beams, and simultaneously illuminating said second cell face formed by an
incoherent UV source forms an ESBG confined to the region between said first symbol
pad and said second symbol pad.
5. The method of claim 1 wherein said step of illuminating said first cell face by crossed
20 UV laser beams, and simultaneously illuminating said second cell face formed by an
incoherent UV source forms an ESBG confined to the region between said first symbol
pad and said second symbol pad, wherein said HPDLC is surrounded by a PDLC region.

6. The method of claim 1 wherein said first symbol pad is replaced with a multiplicity of symbol pads and said second symbol pad is replaced by a second multiplicity of symbol pads substantially identical to and spatially corresponding with said first symbol pads.
- 5 7. The method of claim 1, wherein said transparent substrates together function as a light guide.
8. The method of claim 1, wherein the transparent electrode layer of said second substrate layer further provides a background electrode area surrounding said second symbol pad
10 and perimeter regions from which electrode material has been removed disposed between said second symbol pad and said background area.
9. The method of claim 1, wherein the width of said perimeter regions is less than 50
15 microns.
10. The method of claim 1, wherein the width of said perimeter regions is less than 100
microns.
11. A display device comprising:
20 a first transparent substrate having a first surface to which an anti reflection coating has been applied and a second surface to which a transparent electrode layer has been applied;
a layer of UV absorbing dielectric material over said transparent electrode layer,

a second transparent substrate having a first surface to which an anti reflection coating has been applied and a second surface to which a transparent electrode layer has been applied;

wherein said first and second substrates form a display cell with the transparent electrode coated surfaces of the two substrates aligned in opposing directions and having a small separation, wherein the antireflection coated surface of said first substrate forms a first cell face, wherein the antireflection coated surface of said second substrate forms a second cell face.

wherein portions of the transparent electrode layer of first substrate layer have been removed to provide a patterned electrode layer including a first symbol pad, wherein the portion of said UV absorbing dielectric material overlapping said first symbol pad has been removed,

wherein portions of the transparent electrode layer of said second substrate layer have been removed to provide a second patterned electrode layer including a second symbol pad substantially identical to and spatially corresponding with said first symbol pad.

12. The display device of claim 11, wherein said transparent substrates together function as a light guide.

13. The display device of claim 11, wherein said substrates sandwich an electro optic layer comprising PDLC and HPDLC, wherein said HPDLC is confined to the region between said first symbol pad and said second symbol pad.

14. The display device of claim 11, wherein said display cell is initially filled with a PDLC mixture, wherein an HPDLC is formed in said PDLC mixture by illuminating said first cell face by crossed UV laser beams, and simultaneously illuminating said second cell face formed by an incoherent UV source.

5

15. The display device of claim 11, wherein the transparent electrode layer of said second substrate layer further provides a background electrode area surrounding said second symbol pad and perimeter regions from which electrode material has been removed disposed between said second symbol pad and said background area.

10

16. The display device of claim 15, wherein the width of said perimeter regions is less than 50 microns.

15

17. The display device of claim 15, wherein the width of said perimeter regions is less than 100 microns.

18. The display device of claim 13, wherein said HPDLC functions as an ESBG.

20

19. The display device of claim 18, wherein said second cell face faces a viewer; wherein said ESBG diffracts light of a first wavelength; wherein said ESBG is operative to project an image of said information towards said viewer when said first face is illuminated using light of said first wavelength and no electric field is applied to said ESBG.

20. The display device of claim 18, wherein said ESBG encodes information.

21. The display device of claim 18 further comprising means for coupling illumination into said display cell.

5

22. The display device of claim 18, wherein said illumination means provides linearly polarized light.

10

23. The display device of claim 18, wherein said illumination means is a Light Emitting Diode.

24. The display device of claim 18, wherein said illumination means provides light having a limited bandwidth centered about a wavelength, and the maximum diffraction efficiency of said ESBG occurs at approximately the same wavelength.

15

25. The display device of claim 18, wherein said first symbol pad is replaced with a multiplicity of symbol pads and said second symbol pad is replaced by a second multiplicity of symbol pads substantially identical to and spatially corresponding with said first symbol pads, wherein said first and second; corresponding first and second symbol pads provide separately switchable ESBGs.

20

26. The display device of claim 25, wherein said separately switchable ESBGs provide images of symbols.

27. The display device of claim 25, wherein said separately switchable ESBGs are configured to diffract light at different wavelengths provided by a multiplicity of light sources of appropriate spectral output.

5 28. The display device of claim 18, further comprising a third transparent substrate and a second ESBG sandwiched between said second and third transparent substrates; wherein said first, second and third transparent substrates together function as a light guide; wherein each said second ESBG contains information encoded in a multiplicity of
10 separately switchable grating regions; wherein said switchable grating regions of said first and second ESBGs substantially overlap; said second ESBG being operative to project the images of said information towards said viewer when said ESBG rear side is illuminated using light of a second wavelength and
15 no electric field is applied to said second ESBG.

29. A display device comprising:

At least one ESBG having a front side facing towards the viewer and a rear side; wherein said ESBG is sandwiched between first and second transparent substrates,
20 wherein said transparent substrates together function as a light guide, wherein each said ESBG contains information encoded in a multiplicity of separately switchable HPDLC regions, wherein said separately switchable HPDLC regions are surrounded by PDLC regions;

a plurality of independently switchable transparent electrodes elements, said electrodes substantially overlaying said separately switchable grating regions; and means for coupling illumination into said transparent substrates, said ESBG being operative to project the images of said information towards said viewer when said ESBG rear side is illuminated using light of a first wavelength and no electric field is applied to said ESBG.

5

30. The display device of claim 29, wherein said ESBG provides a grating within each of said separately switchable regions and is clear elsewhere.

10

31. The display device of claim 29, wherein said illumination means provides linearly polarized light.

15

32. The display device of claim 29, wherein said illumination means is a Light Emitting Diode.

20

33. The display device of claim 29, wherein said illumination means provides light having a limited bandwidth centered about a wavelength, and the maximum diffraction efficiency of said ESBG occurs at approximately the same wavelength.

34. The display device of claim 29, wherein said separately switchable grating regions provide images of symbols.

35. The display device of claim 29, wherein said separately switchable grating regions are configured to diffract light at different wavelength provided by a multiplicity of light sources of appropriate spectral output.

5 36. The display device of claim 29, further comprising a third transparent substrate and a second ESBG sandwiched between said second and third transparent substrates; wherein said first, second and third transparent substrates together function as a light guide; wherein each said second ESBG contains information encoded in a multiplicity of
10 separately switchable grating regions; wherein said switchable grating regions of said first and second ESBGs substantially overlap; said second ESBG being operative to project the images of said information towards said
15 viewer when said ESBG rear side is illuminated using light of a second wavelength and no electric field is applied to said second ESBG.

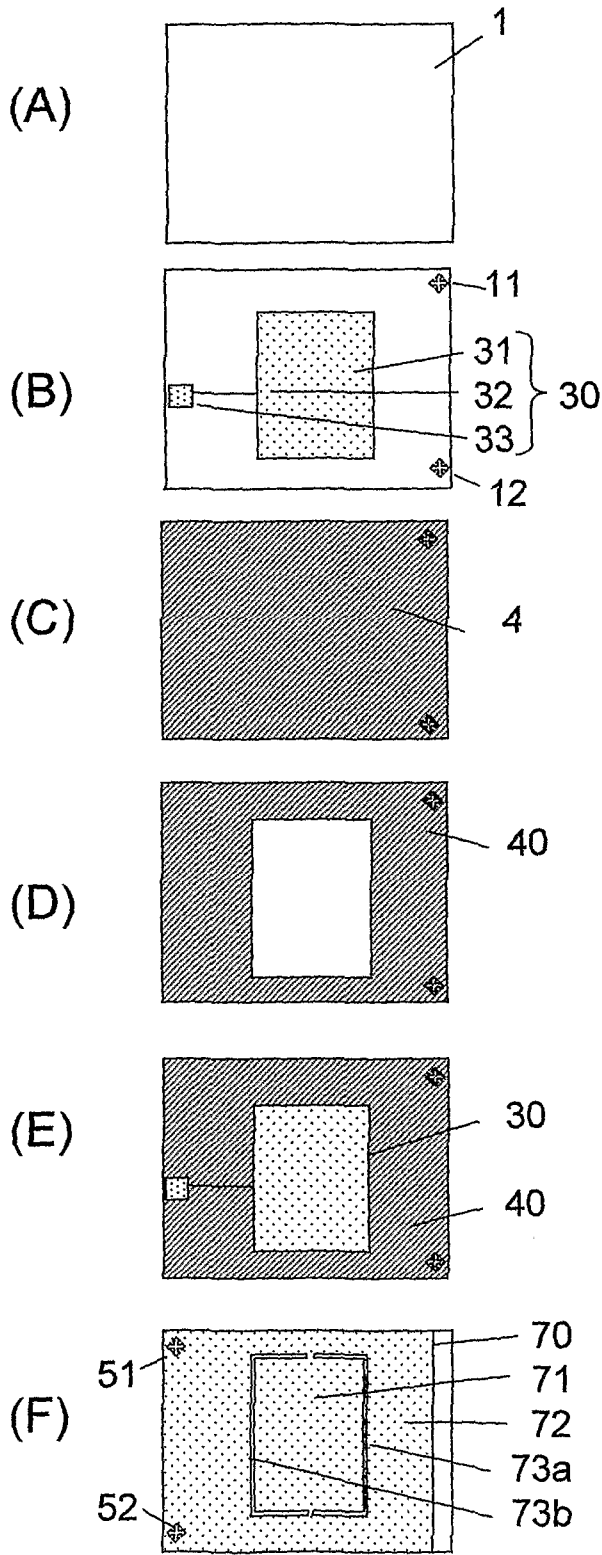


FIG. 1

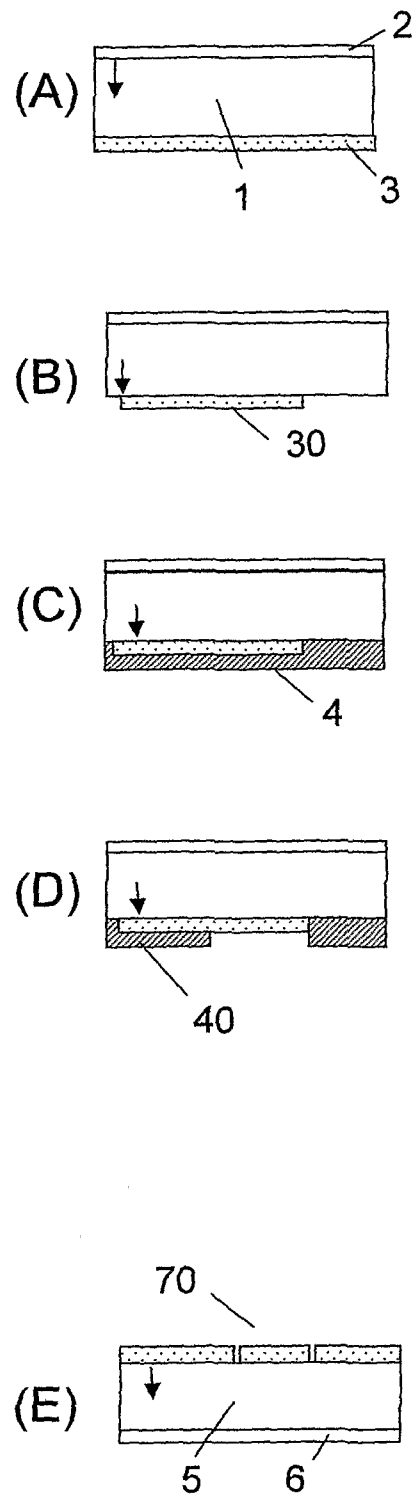


FIG. 2

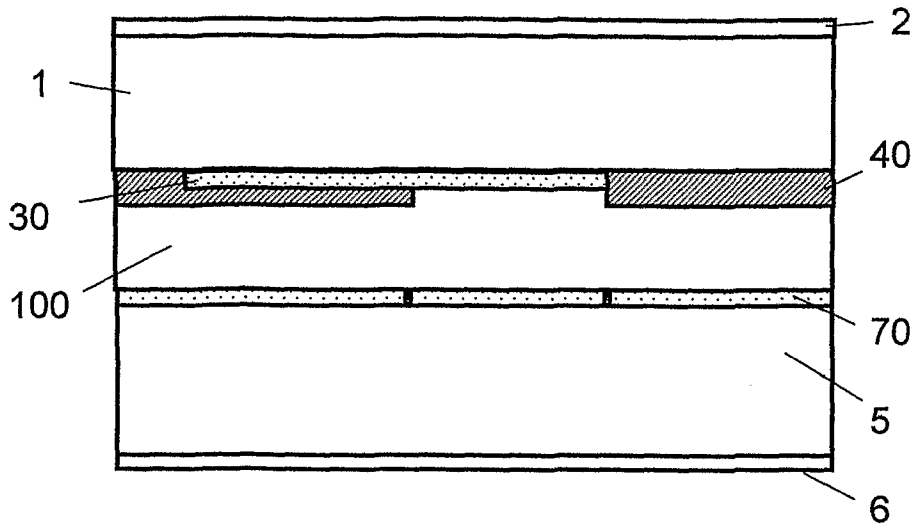


FIG. 3

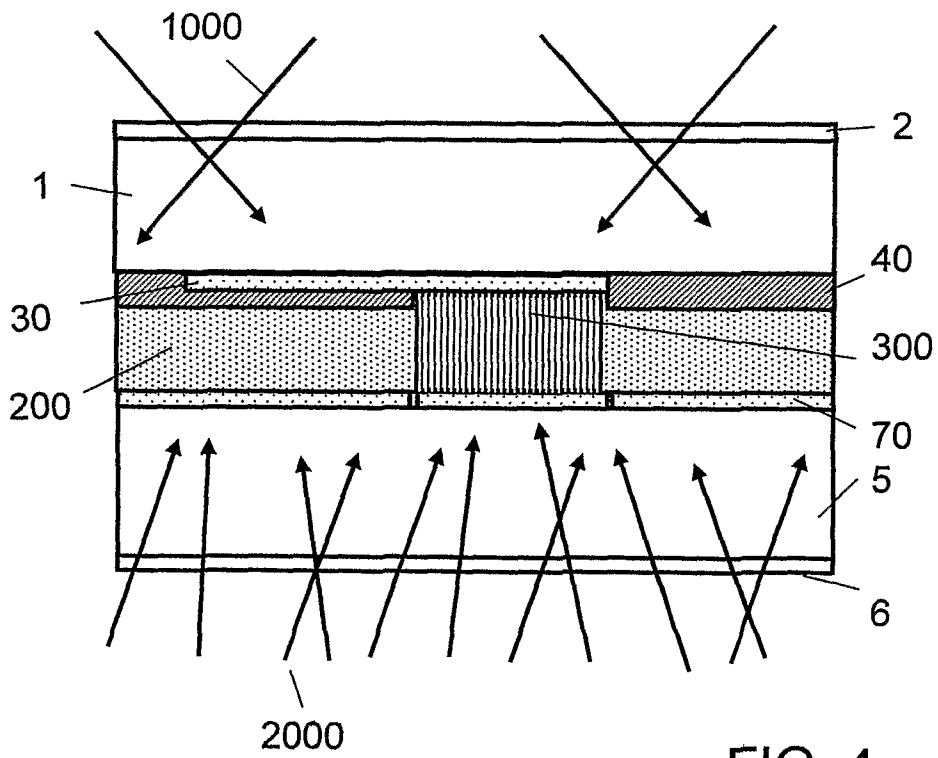


FIG. 4

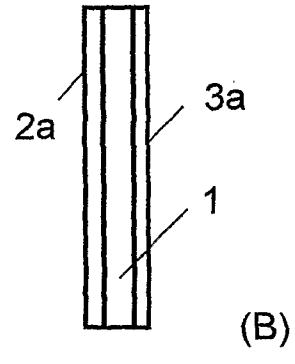
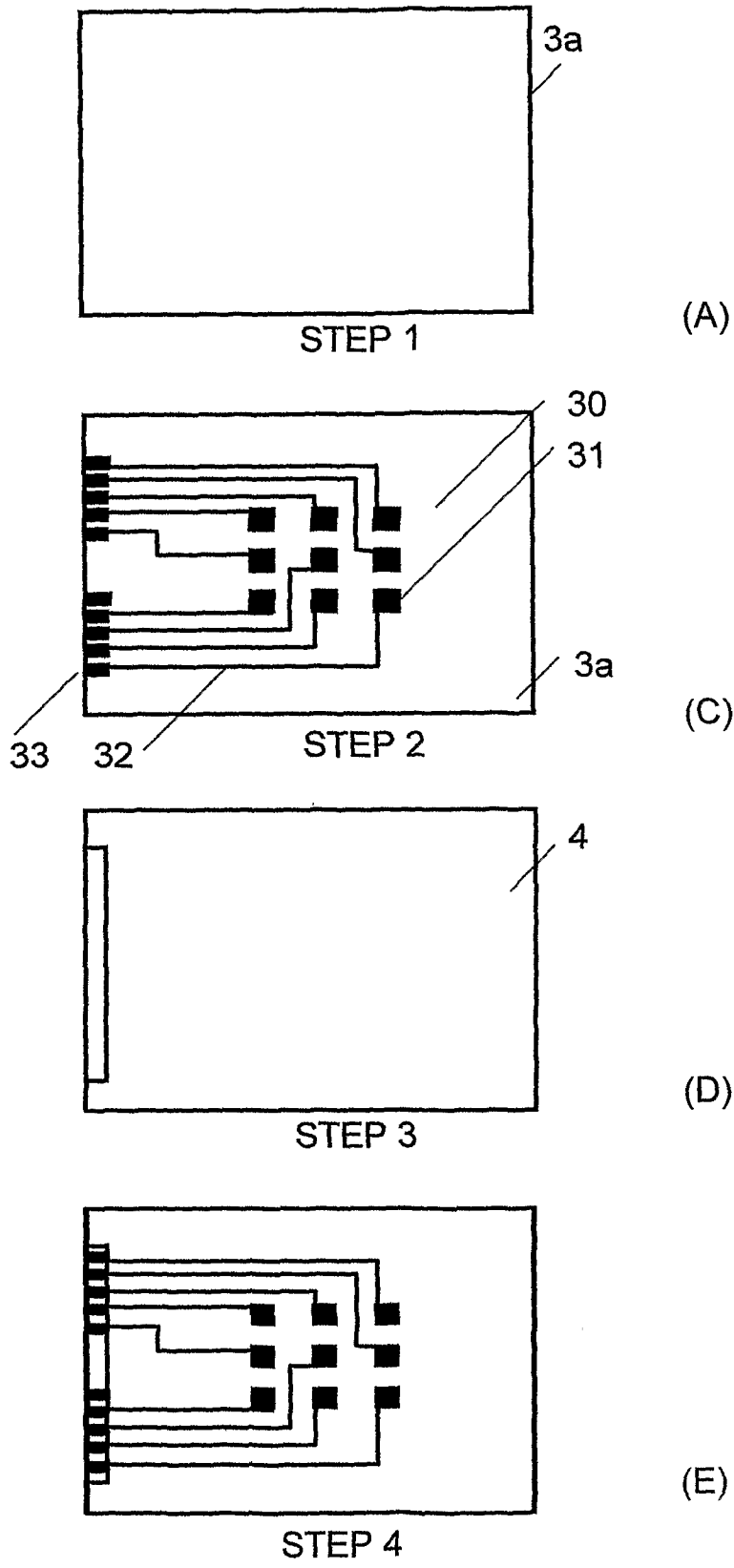


FIG. 5

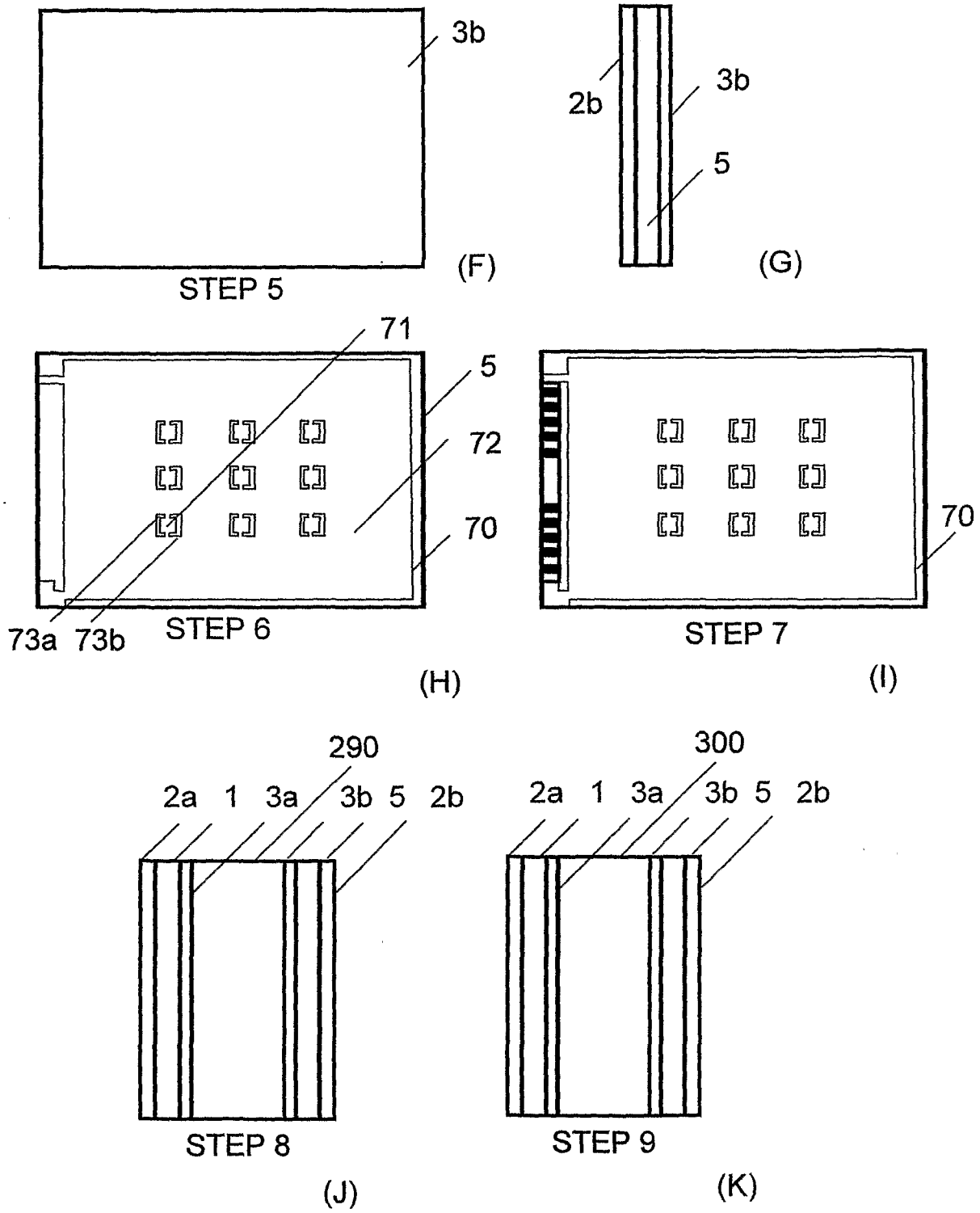


FIG. 5

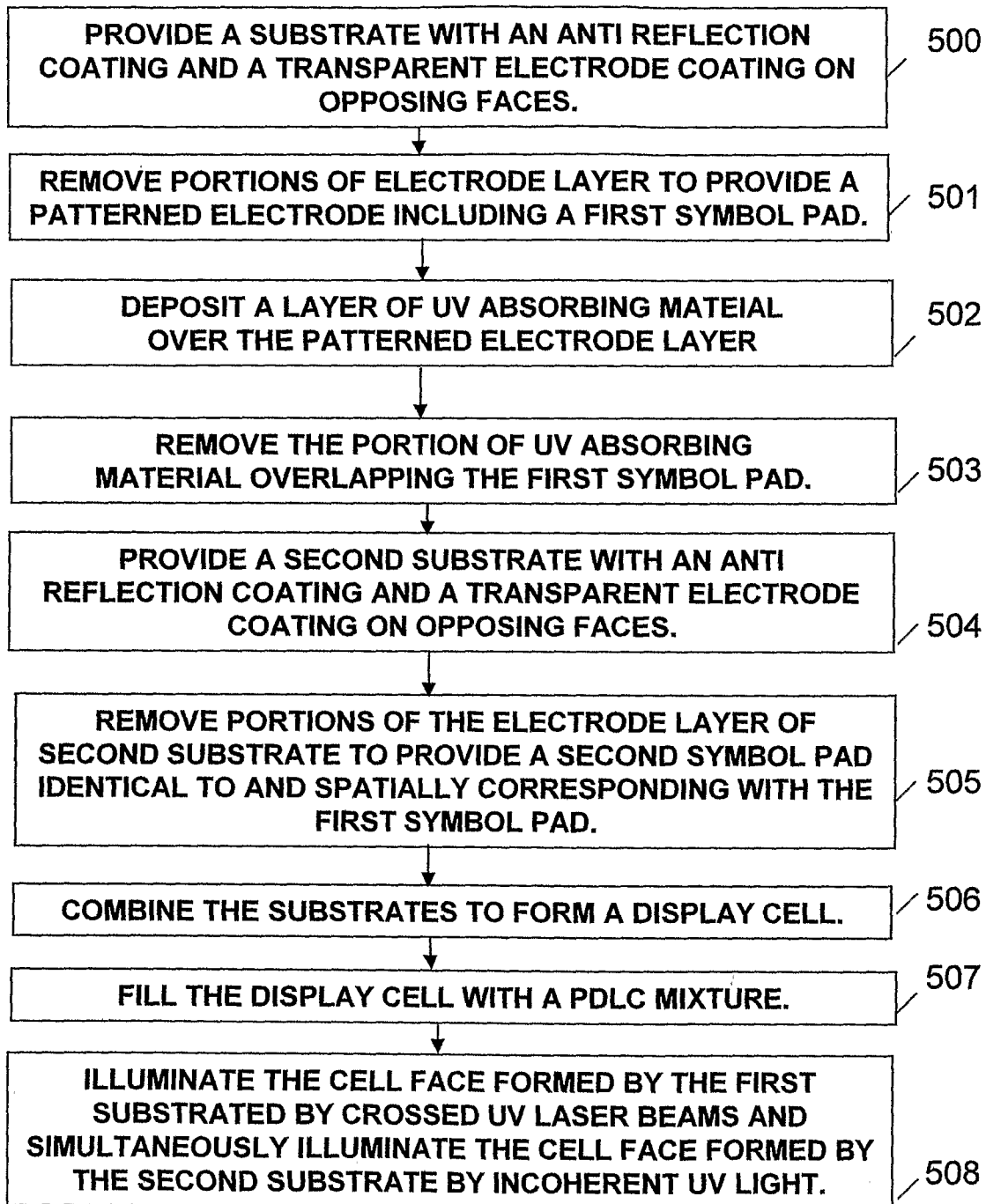
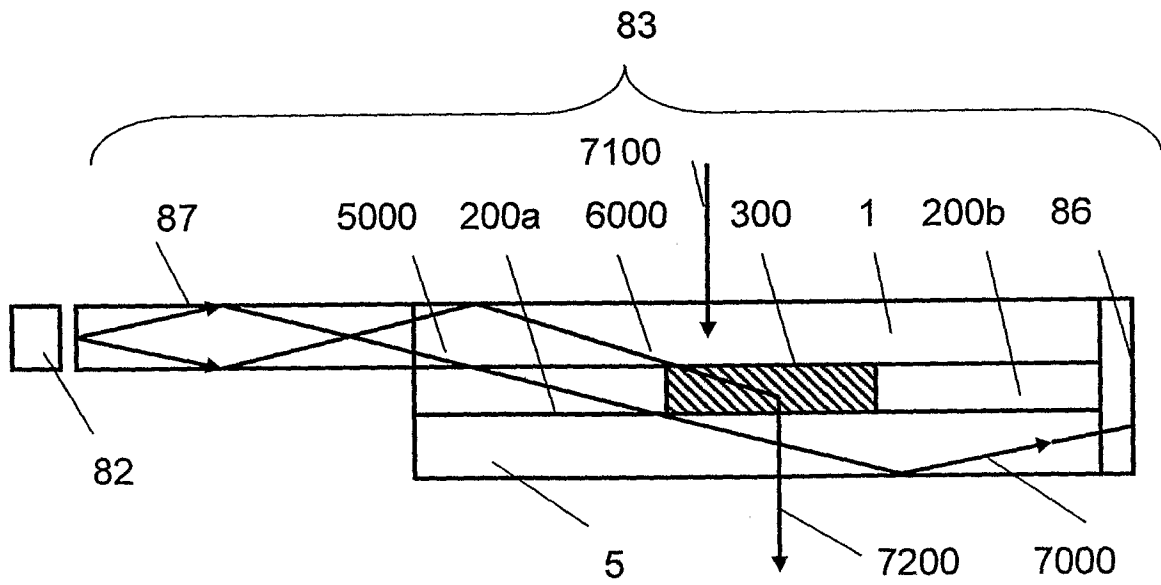
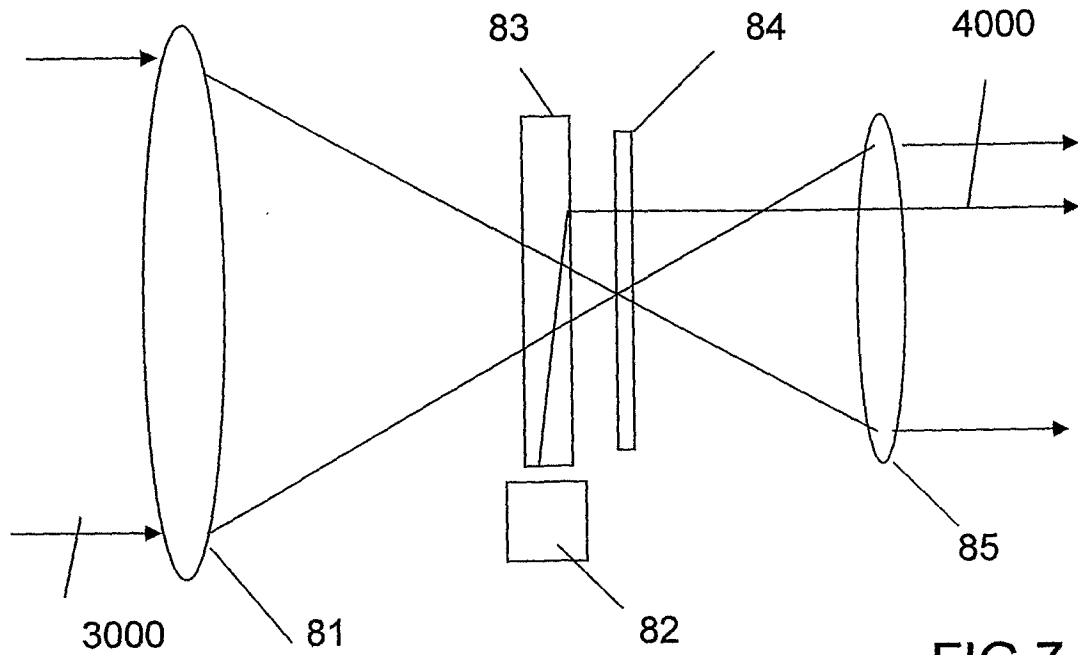


FIG. 6



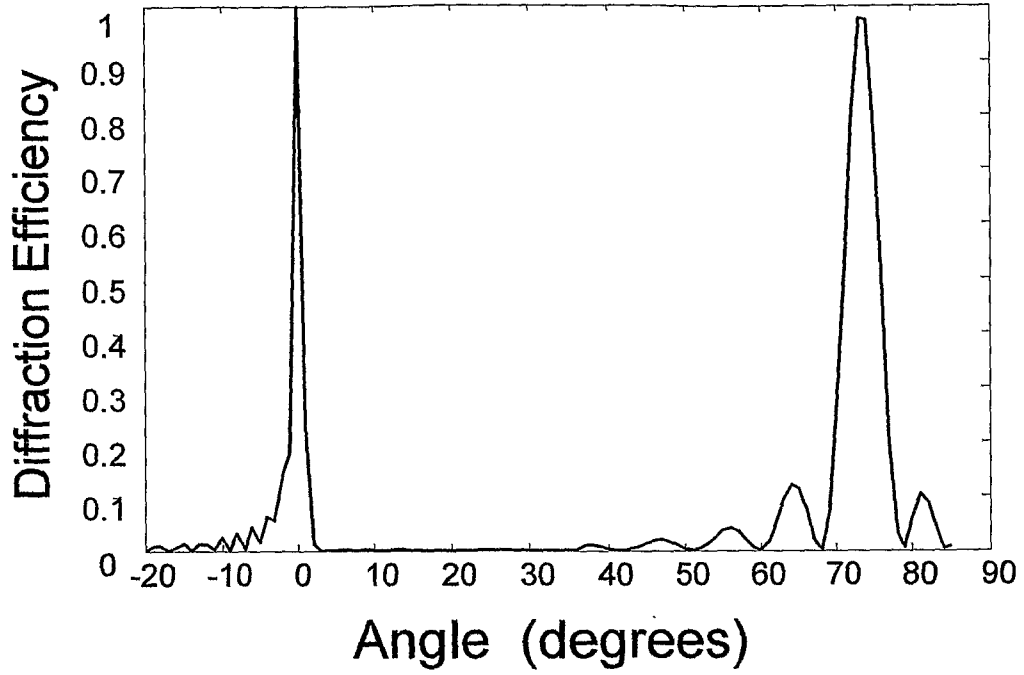


FIG. 9

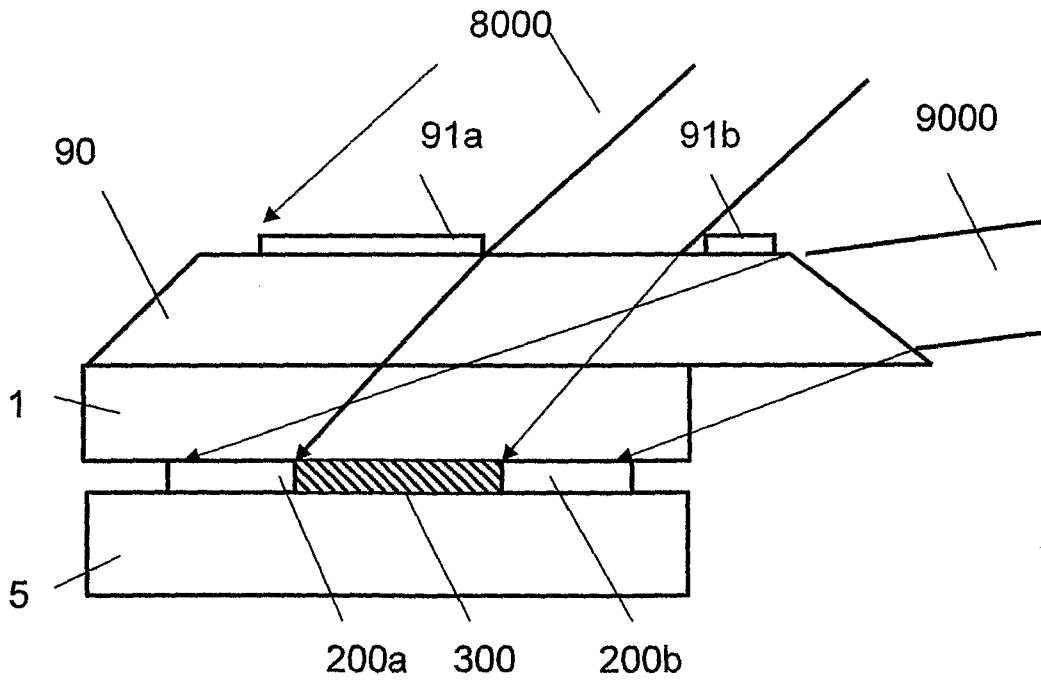


FIG. 10