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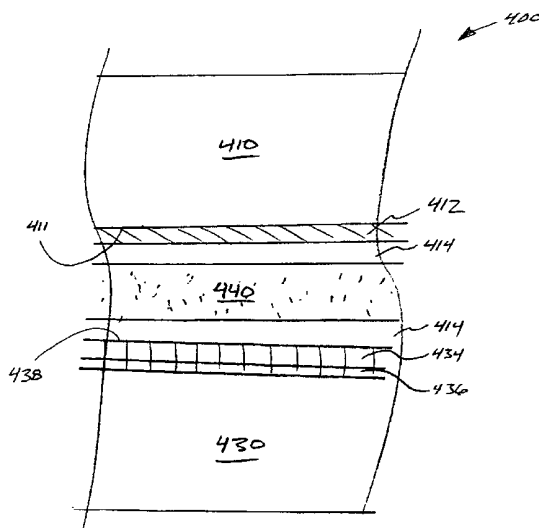
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(54) Title: METHODS AND APPARATUS FOR A DISPLAY COMPATIBLE WITH A WIDE RANGE OF LIQUID CRYSTAL MATERIALS



(57) Abstract: A liquid crystal display (400) is described which is suitable for use with a wide range of liquid crystal materials. A liquid crystal (440) on silicon display includes a semiconductor device (430) which is configured such that the charge associated with individual pixels (436) is maintained, and hence liquid crystal materials (and other components of the display) with low charge-hold ratios (CHR) may be used. The semiconductor device comprises, for example, a static random access memory device (SRAM), for example, a six-transistor (6-T) SRAM.



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METHODS AND APPARATUS FOR A DISPLAY COMPATIBLE WITH A WIDE RANGE OF LIQUID CRYSTAL MATERIALS

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

The present invention relates, generally, to display systems and, more particularly, to liquid crystal-on-silicon displays.

2. Background

10 In an effort to develop smaller, thinner, and more efficient displays, recent efforts have centered on the development of advanced liquid crystal displays such as flat-panel displays and, more recently, liquid crystal-on-silicon displays or microdisplays. In general, a microdisplay includes a liquid crystal layer sandwiched between a transparent plate and a silicon backplane device comprising a high-
15 resolution array of picture elements (pixels). Such microdisplays, which can be found in projection and near-to-eye (NTE) applications, are typically less than 1.0 inch diagonal, but can offer resolutions from 1/4 VGA (78 thousand pixels) to UXGA+ (over 2 million pixels.)

Modern high-resolution liquid crystal displays typically utilize an active
20 matrix system. That is, referring now to FIG. 1, a matrix of thin-film transistors (TFTs) 110 are arranged in a regular pattern and are addressable in the conventional fashion via row select lines 104 and column select lines 102. The liquid crystal material is selectively activated over pixels corresponding to the individual TFTs 110.

For the purposes of characterizing the dynamic characteristics of this scheme,
25 the individual liquid crystal pixels 202 can be modeled as shown in FIG. 2, i.e., as a capacitor 204 in parallel with a resistor 206. When a voltage pulse is applied across this system (nodes 208 and 210), the potential across the nodes rises, then decays depending upon the characteristics of capacitor 204 and resistor 206. This effect is shown graphically in FIG. 3, wherein a set of pulses 306 charge the capacitor 204, and
30 the resistor 206 results in a substantially first-order decay 308 from an ideal constant

voltage 304. In the context of liquid crystal displays, this decay has a deleterious effect on the display characteristics of the individual pixels.

In order to address the foregoing, known LCD systems attempt to increase the charge-hold-ratio (CHR) of the liquid crystal used. CHR is a figure-of-merit used to characterize a material's optical response between pulses (i.e., during scanning). The CHR corresponds generally to the ratio of area under curve 308 shown in FIG. 3 to the area under the ideal level 304. CHR levels of greater than or equal to 98% are desirable in order to achieve high contrast displays; however, such materials are quite expensive and have a variety of other non-optimum characteristics and properties when compared to many of the available liquid crystal materials with much lower CHRs.

SUMMARY OF THE INVENTION

A method and apparatus in accordance with various aspects of the present invention provides a liquid crystal display suitable for use with a wide range of liquid crystal materials. In accordance with one aspect of the present invention, a liquid crystal on silicon display includes a semiconductor device which is configured such that the charge associated with individual pixels is substantially maintained, allowing the use of liquid crystal materials (and other components of the display) with low charge-hold ratios (CHR). In accordance with another aspect of the present invention, the semiconductor device comprises a static random access memory device (SRAM), for example, a six-transistor (6-T) SRAM.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

The subject invention is described in conjunction with the appended drawing figures, wherein like numerals denote like elements, and:

FIG. 1 depicts a typical active matrix display system, showing an array of thin-film transistors;

FIG. 2 depicts a simplified equivalent circuit of a typical pixel;

FIG. 3 depicts the leakage characteristics of the model shown in FIG. 2;

FIG. 4 shows a liquid crystal structure in accordance with various aspects of the present invention; and

5 FIG. 5 shows a flowchart in accordance with various aspects of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Methods and apparatus in accordance with various aspects of the present invention provide for a liquid crystal display system compatible with a wide range of liquid crystal materials. In accordance with one aspect of the present invention, a liquid crystal on silicon display includes a semiconductor device which is configured such that the charge associated with individual pixels is substantially maintained, allowing the use of liquid crystal materials (and other components of the display) with low charge-hold ratios (CHR).

15 In this regard, the subject matter of the present invention is particularly suited for use in connection with liquid crystal displays (LCDs) such as microdisplays or other systems using liquid crystal on silicon. As a result, the preferred exemplary embodiment of the present invention is described in that context. It should be recognized, however, that such description is not intended as a limitation on the use or applicability of the present invention, but is instead provided merely to enable a full and complete description of a preferred embodiment.

25 An exemplary LCD structure comprises a reflective-mode microdisplay device 400 as shown in FIG. 4. A suitable microdisplay 400 comprises a liquid crystal layer 440 disposed between a transparent layer 410 and a semiconductor device 430. Transparent plate 410 is suitably bonded to an active surface 438 of semiconductor device 430 via an adhesive seal (not shown), which also acts to constrain liquid crystal layer 440. Semiconductor device 430 suitably comprises an array of pixels 436, one or more contacts (not shown), and a reflective layer 434 disposed upon and

associated with pixels 436. The bottom surface of transparent plate 410 is preferably coated with a conductive, substantially transparent film 412. An alignment layer 414 is provided on conductive film 412 and reflective surface 434 to facilitate operation of liquid crystal layer 440 as described further below.

5 Liquid crystal layer 440 works in conjunction with pixels 436 and reflective layer 434 to form a high-resolution two-dimensional image. Specifically, in the reflective mode illustrated, incident light entering the top of transparent plate 410 passes through liquid crystal layer 440, is reflected from reflective layer 434, and passes again through transparent plate 410 for projection or direct viewing, depending
10 on the specific external configuration. Suitable addressing circuitry is used to control pixels 436 and thereby effect the configuration of the liquid crystal layer 440. Depending upon the configuration of the liquid crystal, the polarization state of light passing through the layer is modified in a suitable manner.

 Liquid crystal 440 may be selected in accordance with various design
15 parameters. While prior art systems depend upon specific liquid crystal materials (e.g., temperature range, optical birefringence, dielectric anisotropy, charge holding ratio, etc.), a display system according to various aspects of the present invention uses liquid crystal material which is less dependent on optimizing one or more of these parameters. More particularly, as described below, the use of a semiconductor device
20 430 which does not require refresh allows the use of liquid crystal materials which have traditionally been considered unusable for high resolution, active matrix displays. Furthermore, the liquid crystal display is more manufacturable in that the CHR value will not degrade to an unsatisfactory value during processing as is typical with high-CHR liquid crystal materials. The system is therefore robust to variations in
25 the manufacturing process.

 Liquid crystal materials with low CHR values, e.g., below about 95%, may be used. In one embodiment, the CHR is between 30 and 85 %, e.g., about 50%. A variety of liquid crystal materials are suitable for this purpose; for example, the model ZLI 2293 liquid crystal material manufactured by E. Merck KGaA.

While an illustrated embodiment employs twisted nematic liquid crystal, other classes are suitable, for example, non-twisted nematic, supertwisted nematic, homeotropic nematic, ferro-electric liquid crystals, polymer dispersed liquid crystals, and the like. The thickness of liquid crystal layer 440 can be selected according to any appropriate criteria, for example using spacers, such as dimension-controlled rods or spheres, disposed in the gap between alignment layers 414. In an exemplary embodiment, spheres with a diameter of about 1-5 microns are used. Other spacers may also be used depending upon the desired liquid crystal 440 thickness. Spacers of suitable size or any other mechanism for maintaining the desired thickness may be used.

Transparent plate 410 provides for transmission of light to and from liquid crystal layer 440. In this regard, a variety of materials are suitable for use as the transparent plate 410, including, for example, silicate glasses and other substantially transparent materials, e.g., Schott AF-37 or Corning 1737F glass. Transparent plate 410 is preferably chosen such that its coefficient of thermal expansion (CTE) is reasonably close to that of the opposing semiconductor device 430. This tends to reduce thermally-induced stresses arising during processing and temperature cycling. Corning 1737 glass, for example, is suitable in this regard for a silicon substrate. In accordance with another aspect of the present invention, a low-purity glass such as a soda-lime glass may also be employed.

The thickness of transparent plate 410 may be chosen in accordance with various design considerations (e.g., stress conditions, etc.). In an exemplary embodiment, transparent plate 410 suitably has a thickness of about 0.9-1.3 mm, preferably about 1.1 mm. Alternatively, transparent plate 110 may consist of two or more layers of the same or different material.

Semiconductor device 430 includes a silicon substrate 431 and an active surface 438 having an array of pixels 436, reflective layer 434, and appropriate addressing circuitry (not shown) necessary to electrically activate pixels 436 and thereby generate an image via the overlying liquid crystal layer 440, which is responsive to the activated pixels. Pixels 436 may be fabricated in accordance with

conventional semiconductor techniques, and may consist of any number of standard device technologies, for example, CMOS cells configured and addressable in a row/column format. Reflective layer 434 suitably comprises a metallized array deposited on pixels 436. Each pixel 436 preferably has an associated reflective layer 434 consisting of, for example, aluminum metallization. Reflective layer 434 may comprise, however, any suitable material for reflecting incident light. That is, whereas an SRAM device is typically configured to supply an output for each individual bit, the present invention employs an SRAM wherein the output is routed to individual electrodes (pixels 436) which make up reflective layer 434.

10 Semiconductor device 430 comprises a semiconductor device suitable for activating pixels 436 in a manner which does not require traditional refresh. In accordance with one embodiment of the present invention, semiconductor device 430 is a static random access memory (SRAM). A variety of conventional SRAMs are suitable for this purpose, ranging from two-transistor SRAMs (2-T) to six-transistor
15 SRAMs (6-T). In accordance with a preferred embodiment, a model OS2 SRAM manufactured by inViso is used.

Because the SRAM maintains its charge, it does not need to be refreshed periodically as is the case with conventional active matrix displays. As a result, liquid crystal parameters such as charge-hold ratio are no longer critical, and a wider range
20 of less-expensive liquid crystal materials may be used.

Substrate 430 suitably comprises conventional semiconductor material, for example silicon. Other suitable materials for semiconductor device 430 include, for example, group IV semiconductors (i.e., Si, Ge, and SiGe), group III-V semiconductors (i.e., GaAs, InAs, and AlGaAs), and other unconventional materials
25 such as SiC, diamond, and sapphire. Substrate 431 may comprise single crystal material, or may comprise one or more polycrystalline or amorphous epitaxial layer formed on a suitable base material. In the illustrated exemplary embodiment, single-crystal silicon is used.

In order to facilitate operation of microdisplay 400, a substantially transparent
30 and electrically conductive film 412 is suitably deposited on the bottom surface of

transparent plate 410. Suitable materials for film 412 include, for example, indium tin oxide (ITO) deposited to a thickness of approximately 250 nm and having a sheet resistance of about 100 Ohms/square. The conductive film 412 is suitably connected to a reference potential (not shown) to facilitate the formation of electromagnetic fields in conjunction with the pixels 436 across the liquid crystal layer 440.

An alignment layer 414 is also suitably provided on conductive film 412 and reflective surface 434. The alignment layers 414 suitably comprise conventional alignment layers for aligning the liquid crystal material 440. In this regard, layer 414 preferably exhibits a high transparency. Materials suitable for this purpose include, for example, polyimide having undergone any suitable conventional rubbing or alternate aligning process. In such an embodiment, the thickness of the polyimide preferably ranges from 200 to 400 Angstroms, although other thickness dimensions are also appropriate. In accordance with another aspect of the present invention, an alignment layer 414 comprises a material with a low CHR, e.g., any of the various polyimides used in connection with passive matrix displays.

Having thus given a description of a display in accordance with various aspects of the present invention, and exemplary method of fabricating such a display will now be described. In this regard, it should be understood that the exemplary process illustrated may include more or less steps or may be performed in the context of a larger processing scheme. Furthermore, the illustrated process should not be construed as limiting the order in which the individual process steps may be performed.

Referring now to the exemplary flowchart shown in FIG. 5 and the illustrated cross-sectional diagram shown in FIG. 4, a semiconductor device 430 and transparent plate 410 are provided (Steps 502 and 504). As mentioned above, a wide variety of semiconductor devices and transparent plates are suitable for this purpose. Transparent plate 410 suitably includes a bottom surface 411 upon which a conductive film 412 has been deposited, and semiconductor device 430 includes an active surface 438 which is used to form the two-dimensional image as described above.

Next, in Step 506, alignment layers 414 are suitably formed on conductive film 412 of transparent plate 410 and active surface 438 of semiconductor device 430. Alignment layers 414 are formed in any convenient manner. In the illustrated embodiment, for example, a suitable polyamide material is dispensed onto surface 438 and conductive film 412 then rubbed in accordance with conventional techniques to produce the desired aligning properties.

In Step 508 a suitable adhesive is provided on the active surface of semiconductor device 430 and/or transparent plate 410. In one embodiment, the adhesive is dispensed on transparent plate 410 in an array of rectangles slightly larger than the size of the semiconductor device's pixel array. Various conventional adhesive materials (e.g., epoxies and the like) are suitable for the purposes of this invention. Spacers, such as spheres or rods, may be incorporated into the adhesive in order to help maintain the uniformity of liquid crystal layer 440.

Next, in Step 510, transparent plate 410 and semiconductor device 430 are suitably bonded. In one embodiment, the adhesive dispensed on active surface 438 of semiconductor device 430 is brought into contact with transparent plate 410. The resulting assembly is then processed as appropriate; e.g., the adhesive may require a cure step and/or a particular compressive force may be required to affect bonding. A gap between transparent plate 410 and semiconductor device 430 is suitably formed to receive the liquid crystal material.

In step 512, liquid crystal material 440 is injected or otherwise inserted into the gap formed between transparent plate 410 and semiconductor device 430. In one embodiment, the display and the desired liquid crystal are placed into a filling machine. The filling machine is then suitably evacuated (i.e., the pressure is reduced) and the displays are lowered into the liquid crystal material. The liquid crystal material flows, via capillary action, through a gap that has been left in the adhesive seal. The pressure is then returned to atmospheric pressure by allowing nitrogen to enter the filling machine, thereby accelerating the injecting step 512. After removing the display from the filling machine, the gap is closed via a suitable adhesive in accordance with any convenient technique.

Although the invention has been described herein in conjunction with the appended drawings, those skilled in the art will appreciate that the scope of the invention is not so limited. For example, while the present embodiment includes a reflective mode, monochrome display, the present invention is not so limited. Other
5 classes of displays, such as sequential color displays, transmissive-mode displays, and the like, may benefit from the techniques of this invention. Modifications in the selection, design, and arrangement of the various components and steps discussed herein may be made without departing from the scope of the invention.

Claims:

1. A liquid crystal display comprising:
 - a semiconductor device having an active surface comprising an array of pixels configured to be selectively activated by application of a charge, wherein said charge of said selectively activated pixels is substantially maintained;
 - a transparent plate bonded to said semiconductor device; and
 - a liquid crystal layer provided between said semiconductor device and said transparent plate, wherein said liquid crystal is responsive to said selectively activated pixels, and wherein said liquid crystal layer exhibits a low charge hold ratio (CHR).
2. The liquid crystal display of claim 1, wherein said semiconductor device comprises a static random access memory device (SRAM).
3. The liquid-crystal display of claim 2, wherein said semiconductor device comprises a 6-T SRAM.
4. The liquid crystal display of claim 1, wherein said liquid crystal layer exhibits a charge hold ratio less than about 95%.
5. The liquid crystal display of claim 1, wherein said liquid crystal layer exhibits a charge hold ratio between about 30% and about 85%.
6. The liquid crystal display of claim 1, wherein said liquid crystal layer exhibits a charge hold ratio of about 50%.
7. The liquid crystal display of claim 1, wherein said liquid crystal display comprises a microdisplay.

8. The liquid crystal display of claim 1, further including an alignment layer formed on said transparent panel, wherein said alignment layer comprises a material with a low charge hold ratio.

9. The liquid crystal display of claim 8, wherein said alignment layer comprises polyimide with a low charge hold ratio.

10. A method of fabricating a liquid crystal display comprising the steps of:

providing a semiconductor device having an active surface comprising an array of pixels configured to be selectively activated by application of a charge, wherein said charge of said selectively activated pixels is substantially maintained;

providing a transparent plate;

bonding said transparent plate to said active surface of said semiconductor device via an adhesive, wherein a gap is provided between said active surface and said transparent plate;

injecting a liquid crystal material within said gap, wherein said liquid crystal material exhibits a low charge hold ratio (CHR).

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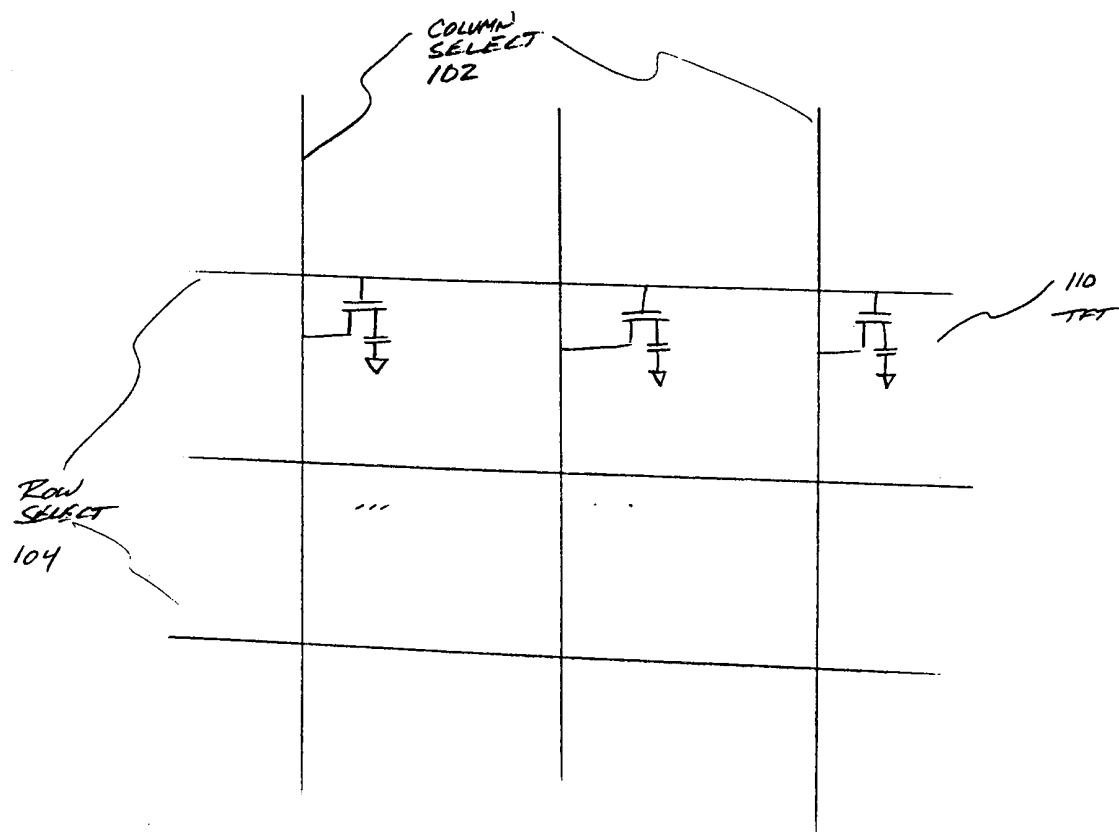


Fig. 1
(PRIOR ART)

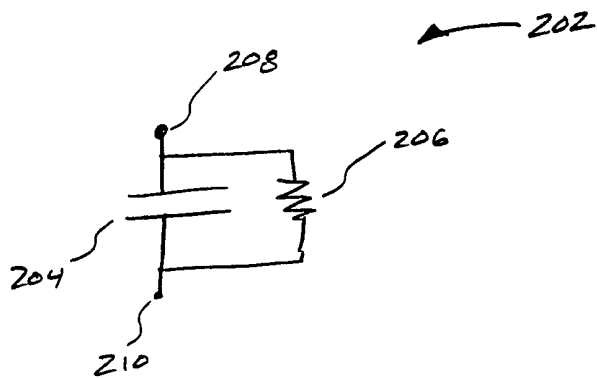


Fig. 2

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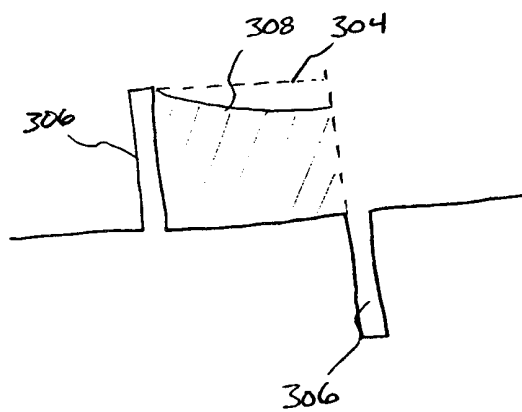


Fig. 3

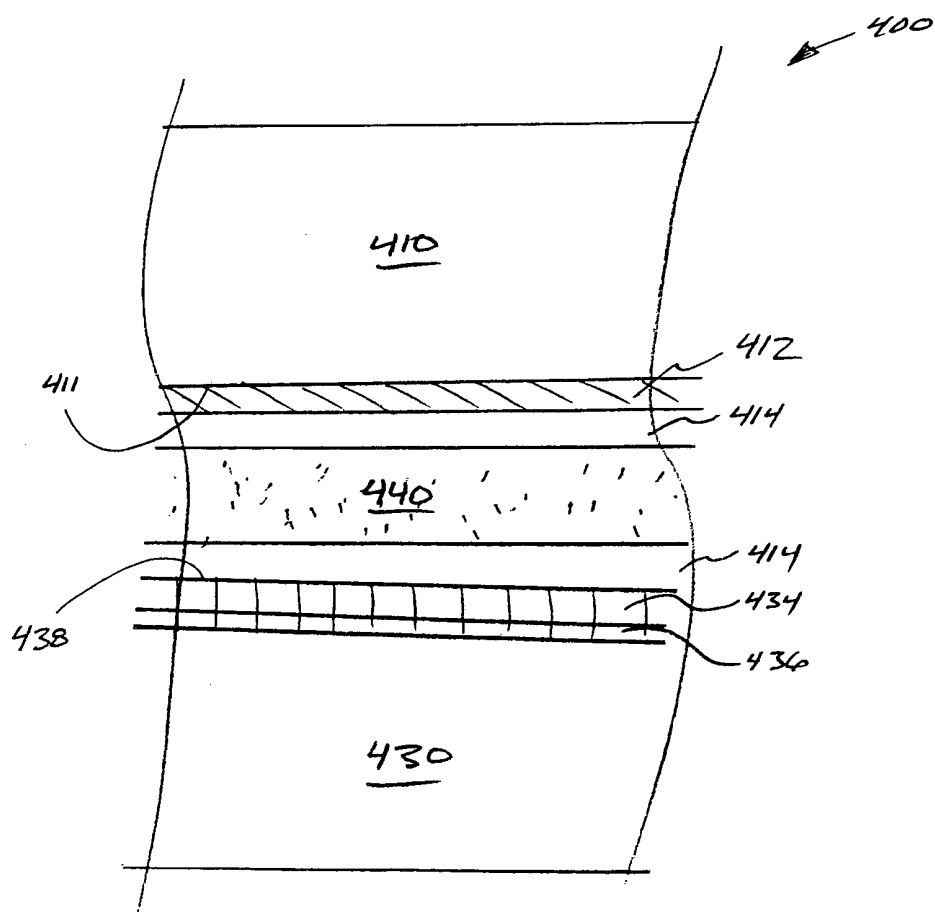


Fig. 4

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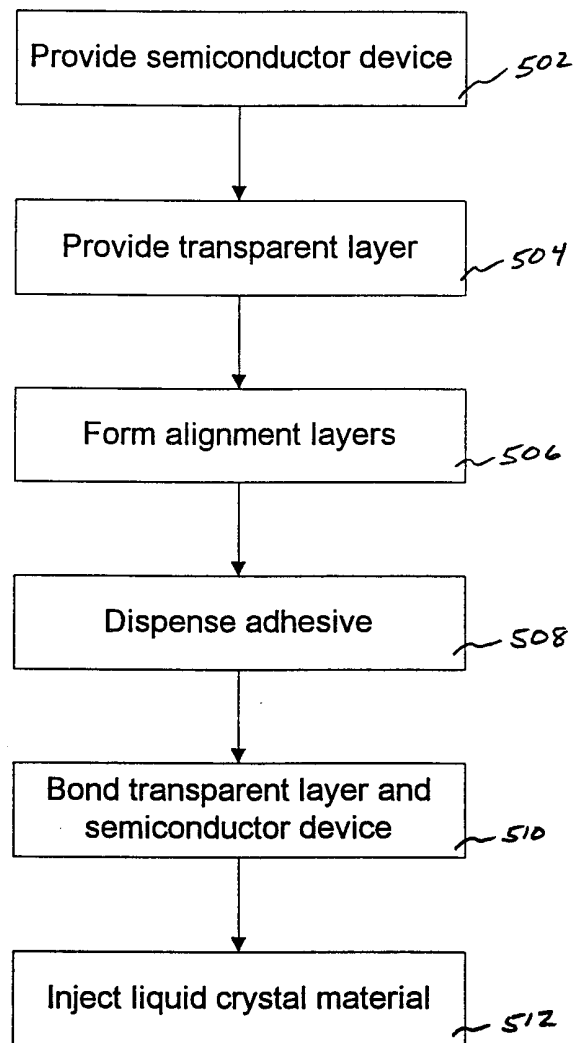


Fig. 5

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER IPC(7) : Please See Extra Sheet. US CL : Please See Extra Sheet. 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) U.S. : 349/42, 43, 86, 88, 187; 252/299.01, 299.64, 299.65, 299.66, 299.67; 257/59, 72; 428/1 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched NONE Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) USPTO APS EAST, WEST, NPL search terms: semiconductor, liquid crystal, charge holding ratio, charge holding characteristics, SRAM		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 6-95152 A (OTA) 08 April 1994 (08.04.1994), abstract.	1-10
Y	US 5,523,127 A (OHNISHI et al) 04 June 1996 (04.06.1996), see entire document.	1-4, 7-10
Y	US 5,627,665 A (YAMADA et al) 06 May 1997 (06.05.1997), see entire document.	1-10
Y	US 5,808,321 A (MITANAGA et al) 15 September 1998 (15.09.1998), see entire document.	1-10
A	US 5,731,861 A (HATANO et al) 24 March 1998 (24.03.1998), see entire document.	1-10
A	US 5,847,798 A (YANG et al) 08 December 1998 (08.12.1998), see entire document.	1-10
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/18075

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,674,576 A (GOTOH et al) 07 October 1997 (07.10.1997), see entire document.	1-10