A NOVEL SPACER TECHNOLOGY FOR MAKING LIQUID-CRYSTAL-ON-SILICON DISPLAYS WITH ALIGNMENT POSTS

BACKGROUND OF THE INVENTION

(1) Field of the Invention

This invention relates to new method of photolithographic fabrication of alignment posts directly on liquid-crystal-on-silicon displays.

(2) Description of the Prior Art

The picture quality of liquid crystal displays from the simple seven segments to millions of pixels is determined by the structure used to control the variation of thickness and position leads after wafer processing. There are known processes for creating insulated alignment posts based on preformed glass microspheres or cylinders or rods; relatively low series resistance posts can be obtained by means of selective deposition of polysilicon and metallic

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silicide. (The making of metallic vias and contacts is a comparatively well known processing art.)

US Patent 5,498,925 to Bell et al describes the formation of posts in flat panel displays using processes based on a heat-treated slurry or paste upon a glass plate. US Patent 5,597,736 teaches the function of a light-blocking layer deposited upon a semiconductor substrate material that can emit light. US Patent 5,744,824 and US 5,748,828 show various LCD structures and external optics.

Until now, it has been difficult to construct alignment posts using photolithography onto a semiconductor substrate material used to control the gray-level of each pixel. The thickness of the liquid crystal is limited to the available preformed spacer sizes supplied by the manufacturers of such preforms.

BRIEF SUMMARY OF THE INVENTION

A principal object of the present invention is to describe two novel methods for building a flat-panel liquid-crystal display upon an integrated circuit (IC) die. There is a controlled inter-relationship between the height of the alignment posts supporting the overlaying glass cover plate

and the image quality viewed from the liquid-crystal-on-silicon display devices.

Another object of this invention is to describe effective and very manufacturable methods of photolithographic formation of insulating spacers or alignment posts (also called studs or pillars). These methods can be used in processing many different device types, and are described in this application for liquid crystal display devices as a way of illustrating their embodiment at a pixel density beyond that achievable with preformed micro-glass spheres and rods.

A further object of the present invention is to describe two methods of deposition for the alignment posts that retain their desired structure during deposition of subsequent features. The process methods are classified into two method categories: 1) patterned insulating material; 2) alignment posts formed in the peripheral sealant of the top glass cover over liquid-crystal-on-silicon display devices.

1. NO DISCONTINUITIES NEAR THE SPACERS DUE TO THERMAL FLUCTUATIONS, HENCE CONTINUOUS LIQUID FILMS.
2. PREVENTION OF SEAL RING BREAKAGE AND SUBSEQUENT LEAKAGE OF THE LIQUID CRYSTAL.

Two new methods for the formation of an improved liquid-crystal-on-silicon display are described, in which the device structure is enhanced by the photolithographic building of alignment posts in the presence of the mirror pixels of the microdisplay. These two methods are:

1. Photolithographic Alignment Posts Formed in Active Area - wherein a photolithographic method forms patterned oxide spacers or alignment posts in the active area of the device structures.

2. Photolithographic Alignment Posts Formed in Peripheral Sealant - wherein said alignment posts are deposited by the photolithographic process in the area of the ring sealant/glue for the glass top cover.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings becoming a material part of this description, there is shown:

Figs. 1 through 3 schematically illustrate in cross-sectional representation a preferred embodiment of the device structure of the present invention. The base silicon substrate with the formed metallic pixels on the display device is shown in Fig. 4.

The process flow for making the alignment posts by the two process methods is shown in Figs. 5 to 9.

Fig. 5 shows the structure of the liquid-crystal-on-silicon display device with sprayed SiO2 particles used as spacers or alignment posts, which illustrates the prior art used before the invention of the two novel methods described herein.

Fig. 6 shows the metallic pixels passivated with layers of silicon nitride and USG and the insulation material, such as SiO2 and Si3N4, located there over.

Fig. 7 shows the structure of the liquid-crystal-on-silicon display device with photolithographic alignments posts used as spacers.

Fig. 8 shows the top view of the structure of the liquid-crystal-on-silicon display device with the spacers or alignment posts located in the ring sealant.

Fig. 9 shows a cross-sectional view of the same structure illustrated in Fig. 8.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now more particularly to Fig. 1, here is shown a portion of a partially completed integrated circuit liquid-crystal display. The glass cover plate 10 provides the transparent enclosure for the external incident light to be reflected back to an observer. The strength of reflected light is dependent on the light polarization, absorption and light scattering properties of each liquid-crystal display pixel, which is controlled by the electrical field established within the liquid crystal material 11. The IC die 12, separated from the glass plate 10 by the alignment posts 14 generates these E-fields. The resultant space or thickness gap between the glass plate 10 and the silicon wafer 12 is filled with the chosen liquid crystal material 11. Incident light, either provided or ambient, enters the open face of the liquid-crystal-on silicon and is reflected from the underlying pixels to form a viewable pattern of polarized light, i.e. the image is viewed directly or projected through an optical polarized system.

Fig.2 illustrates the bonding pads 20 on the IC die to which the external wires 22 are attached. The silicon wafer contains the embedded control circuits that activate the pixel patterns in the viewable area 24. The refractive index anisotropy of the liquid crystal is influenced by the electric fields above the IC surface. A small change in voltage makes a large change in the optical transmission.

Because this invention teaches the photolithographic making of patterns of alignment posts, the ratio of pixels 30 to posts 14 is often fabricated in the range 0.25 to 0.125. As shown in Fig. 3, the photolithographic method permits these alignment posts to be constructed in the space between adjacent pixels.

The base silicon substrate with the formed metallic pixels on the display device is shown in Fig. 4. A typical LCD microdisplay contains metallic pixels (measured 19 by 19 microns) with 0.7 microns thickness gap to the glass top cover, and a total pixel array count of 1024 by 768. The distance between the pixels when measured in the top view of the LCD display can be about one micron.

The process steps for making the alignment posts by means of the various photolithographic categories is shown in Figures 5 to 9.

Starting with Fig. 5, the conductive metallic (or polysilicon) layer 30 is formed over the silicon oxide 40, which is formed on top of the first metal layer 41 on the IC. Prior to formation of the silicon oxide 40, the metal 20 as bond pad is deposited and connected to metal layer 41 with a barrier/glue layer 26 composed of Ti/TiN. On top of the metal 20 is a tungsten plug 21, placed there by the method of CVD. Another barrier/glue layer 23 made of Ti/TiN

is formed on top of metal 20 and another barrier/glue layer 28 made of Ti/TiN on top of the silicon oxide 40. For all three layers (23, 26 and 28), the process of PVD is used to deposit these barrier/glue layers of thickness about one micron. A silicon semiconductor substrate 15 has active devices therein and an insulating layer 16 upon which metal layer 41 is formed.

Then a photoresist layer is deposited over the metal 30 to construct the pixels. The photoresist is exposed and a portion of the metallic layer 30 is removed so that each pixel retains a metallic surface, which shall act as a mirror reflector for the light incident upon the pixel. (The unprotected barrier/glue layer 28 is also removed in this process step.) In both these novel methods, the metallic pixels 30 are not coated with either an anti-reflective coating ARC or an optical interference filter OIL.

After the photoresist is stripped, as shown in Fig. 5, the device is prepared for subsequent deposition of the insulation material from which the spacers, also called alignment posts, will be patterned. (The purpose of this passivation preparation is the protection of the existing metallic pixels 30 from any corrosion or damage from the liquid crystal material.) At this point in the novel method, two protective layers of passivation are formed.

1) An optically transparent coating of undoped silicon glass USG 65 of the thickness between about 1000 and 2000 Angstroms is formed over the metallic pixels 30 and the silicon oxide 40 by the process of CVD.
2) An optically transparent coating of silicon nitride 66 of thickness between about 2500 and 10000 Angstroms is formed over the layer USG 65 by the process of CVD. (Careful attention is required in constructing these optical transparent layers so as not to disturb any underlying device structures.)

In one form of prior art, the spacers between these optical transparent protective layers and the glass top cover have been fabricated by spraying SiO2 glass particles 55. A process step of particle spray cannot be well controlled in terms of the size of the resultant particles, i.e. clusters of particles 56 can form and cause a defective deviation in the film thickness of the liquid crystal, as illustrated in Fig. 5.

Fig. 6 shows the insulation material 60 deposited onto the silicon nitride protective layer 66 of thickness between about two and three microns by the process of high-density plasma oxide (HDP) undoped or HDP FSG-doped oxide, which is then followed by a 1.2 micron plasma-enhanced tetraethyl orthosilicate (PETEOS) glass film.

This film of insulating material is then smoothed using chemical-mechanical polish CMP for two purposes: 1) to attain the desired height of the gap between the metallic pixels and the lower surface of the glass top cover; 2) to planarize the surface by making the whole surface flat. The thickness gap now becomes a design parameter for the liquid-crystal-on-silicon display device, and any topographic non-uniformity in gap thickness has been eliminated by CMP. The resultant structure is now ready for the photolithographic fabrication of the alignment posts.

The alignment posts are constructed from the insulation material layer by the following methods described herein:

Method 1 - Photolithographic Alignment Posts Formed in Active Area

A photomask, not shown, is formed on top of the layer of insulating material 60. The photomask protects the insulation material when the insulating material 60 is removed by a dry or wet etch process. The photomask, about 4 microns across at the location of each alignment post, is resistant to the removal process, resulting in the formation of the spacers or alignment posts. After the formation of these spacers or alignment posts, the remaining photoresist

is removed by the conventional developer method. The resultant alignment posts 71 are shown in Fig. 7.

For the final step, a film of liquid crystal placed on the silicon nitride protective layer and the top glass cover placed down. The spacers (alignment posts) hold the glass plate to a uniform thickness of the liquid crystal film above the metallic pixels, as shown in Fig. 7.

Method 2 - Photolithographic Alignment Posts Formed in Peripheral Sealant

In this method the spacers (alignment posts) 72 are located in the peripheral area of the liquid-crystal-on-silicon display device. In particular this novel method locates the spacers in the adhesive sealant 81 of the glass top cover. Adhesive sealants glue the top cover to the silicon substrate 12. There are many types of seal ring adhesive/glue, including thermosetting epoxy resin, which can be chosen for this novel method. The liquid crystal film material is inserted through the orifice in the right hand side of Fig. 8 after this seal ring adhesive is mate pressed and cured. A cross-sectional view, taken at position 79, of one display-device-design example is illustrated in Fig. 9.

The device design layout for the photolithography described in this method may include spacers within the active area (in addition to the spacers formed in the location planned for the ring sealant). The actual design choice depends upon the dimensions of the active area 76 inside the ring 81, and the stiffness plus weight of the glass top cover 10,

For the two methods of photolithographic formation of alignment posts on LCD-on-silicon display devices, the existence of numerous alignment posts permits the usage of an ultra-thin glass plate or cover over the liquid crystal material. This implementation results in lightweight displays for portable applications. Glass covers supported by alignment posts are typically 0.5 millimeters in thickness, and can range between about 0.1 millimeters to 2 millimeters.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

CLAIMS

1. A method of forming insulating material alignment posts associated with active device structures comprising:

providing a silicon semiconductor wafer having patterned said active device therein and thereon; and

forming said insulating material alignment posts in a photolithographic pattern over said pattern of active device structures.

2. A method according to Claim 1 wherein said photolithographic spacers or alignment posts improve the thickness uniformity of the liquid crystal film.

3. The method of claim 1 wherein said spacers or alignment posts are formed by the process of photolithography.

4. The method of claim 1 wherein said spacers or alignment posts are composed of the materials: HDP oxide, PETEOS, FSG Doped PETEOS, and Sillyoxide.

5. The method according to Claim 1 wherein said spacers or alignment posts are of height between about 1 micron and 10 microns.

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6. The method according to Claim 1 wherein said alignment posts are placed on a passivation layer deposited over the metallic pixels on said silicon wafer.

7. The method according to Claim 1 for building the said alignment posts on the periphery of the active display area in the vicinity of the ring sealant.

8. A method of forming a device structure that combines insulating materials for alignment posts associated with an active device structure in a silicon body comprising:

providing a silicon semiconductor wafer having a pattern of active device structures therein and thereon;

forming a first metallic layer there over;

forming a silicon-oxide insulating layer over the said first metallic layer;

forming a second metallic layer over the said silicon-oxide layer;

forming a photoresist mask over the said second metallic layer having a covering over the planned pixel locations of the said liquid-crystal-on-silicon display device;

removing the said second metallic layer not covered by the said photoresist mask;

removing the said photoresist mask to provide that each said pixel retains said metallic layer, which shall act

as a mirror reflector for the light incident upon said liquid-crystal-on-silicon display device;

9. The method of claim 8 wherein said alignment posts are deposited by chemical vapor deposition.

10. The method of claim 9 for forming a silicon dioxide layer of thickness about one micron to achieve the desired height of the alignment posts.

11. The method of claim 9 for forming a photoresist mask over the said silicon oxide layer to cover the location of each planned alignment post.

12. The method of claim 9 for removing the said insulation material layer by means of etching to form the said alignment posts, and removing the said photoresist mask.

13. The method of claim 8 wherein said alignment posts are deposited by the photolithographic process in the area of the ring sealant/glue for the glass top cover.

14. The method of Claim 13 for forming by chemical mechanical polish CMP the insulation material layer to a controlled thickness between about one and ten microns in the area of the ring sealant.

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15. The method of Claim 13 for a uniform thickness gap from the metallic pixels to the lower surface of the glass top cover.

16. The method of Claim 13 for removal of the insulation material such that the spacer-controlled gap can be a design parameter for the liquid-crystal-on-silicon microdisplay.

17. The method of claim 13 for forming a photoresist mask over the said insulation material in the vicinity of the ring sealant of the glass top cover for the location of each planned alignment post.

18. The method of claim 13 for removing the said insulation material by etching to form the said alignment posts, and subsequent removal of the said photoresist mask.

19. A device structure that combines insulating materials for alignment posts associated with an active device structure in a silicon body comprised of:

a silicon semiconductor wafer having a pattern of said active device structures therein and thereon;

metallic pixels on said semiconductor wafer.

bonding pads on the said silicon body having wire attached and said wire connected to external contacts for the control logic and power;

liquid crystal material located in the valleys below the peaks of the alignment posts;

glass top cover placed upon and supported by the alignment posts to encapsulate the said liquid crystal material, but not over the area outside the liquid-crystal material where the bonding pads are located.

20. A device structure according to Claim 19 that combines the insulating material for the alignment posts with a passivation layer above the active device structure in a silicon body.

21. A device structure according to Claim 19 that combines the insulating material for the alignment posts with a sealant ring for the glass top cover.

22. A device structure according to Claim 19 wherein the alignment posts are made by means of photolithography rather than pre-formed glass beads or rods.

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