P-45: Assembly of an XGA 0.9” LCoS Display using Inorganic Alignment Layers for VAN LC

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Abstract

An assembly process for LCoS microdisplays using inorganic alignment layers has been developed. The specific problems emerging when using this approach were identified and solved. This enables the production of extremely high contrast, fast display devices when using the VAN LC mode.

1. Introduction

Liquid Crystal on Silicon (LCoS) is widely seen as a potential low-cost technology for the production of high-definition light valves. Projection is a very important application for this type of cells and encompasses products such as HDTV-sets, high-end monitors, data projectors and maybe even electronic cinema projectors. Besides an appropriately designed backplane, these applications also require a suitable liquid crystal mode and related technology to achieve the specifications. The advantages of the Vertical Aligned Nematic mode for reflective applications have already been pointed out in several publications [1], [2]. Envisaged benefits include extremely high contrast, fast response and modest voltage requirements. Adoption of this mode in real display devices for the applications outlined above is however still quite low, a few notable exceptions left out. A key factor in this reluctance may be the realization of the alignment.

2. Alignment issues

Unlike most other modes, VAN LC mode requires an initial orientation of the molecules that is (almost) vertical to the substrate plane. The conventional polyimide + rubbing technique is not suited for this purpose. Special polyimides have been developed and are commercially available giving a rub-free vertical alignment. However, since the LC molecules are then oriented perfectly vertical, there is no imposed preferential direction and an unwanted and to a certain extent unpredictable director distribution is obtained when the molecules are switched. In polarizer-less modes, like the vertically aligned dyed cholesteric effect, this is not a problem, but in a normal VAN cell it will cause the white-state to be of very poor quality.

2.1 Polyimide solutions

To achieve vertical alignment with a small pre-tilt angle using these polyimides, several techniques have been proposed. First of all, and the most straightforward, is to add an additional rubbing step after all, hereby introducing a preferential direction. Unfortunately, this also reintroduces the problems related to this technique, like ESD, non-uniformities, reproducibility, dust contamination…

Another method for obtaining a vertical alignment together with a small pre-tilt employs so-called surface relief gratings or protrusions [3]. The homeotropic alignment is still imposed by a polyimide, but protrusions created underneath by various ways offset the molecules a little and deform the electric field such that again a preferential direction is created. Most of the time this technique is used in combination with a multi-domain structure to widen the viewing angle. Disadvantages of this method are the fact that the structures are rather large (a pitch of 20 µm is not uncommon), making their use difficult for small devices such as microdisplays; there is also the possibility of optical artefacts due to the protrusions and the occurrence of disclinations at their edges.

A third method uses the relatively new technique of photo-alignment, whereby a polymer layer is irradiated with linearly polarized UV light [4]. Alignment from planar to vertical is possible, but the technique is not yet mature and stability may be an issue.

2.2 Inorganic alignment layer

Finally, inorganic layers can also serve as aligning agent. An obliquely deposited, thin layer of inorganic material, mostly SiOx, can align LC molecules over the full range of pre-tilt angles, with varying anchoring energy, depending on the deposition parameters. Alignment can be very uniform if the configuration for the deposition is carefully chosen, while defects commonly associated with the spin coating technique are avoided. The very thin layer does not optically interfere in any way and its inorganic nature should ensure a high reliability to the device.

Despite the apparent advantages of this approach, only one commercially available device employs this technique [5]. Our goal was to tackle the technological difficulties related to this form of alignment in order to be able to take full advantage of the benefits outlined above.

3. Technology

We developed a process for the deposition of inorganic alignment layers. The optimisation of parameters of course envisaged the vertically aligned mode and thus homeotropic alignment, but could equally well be carried out for other orientations. Silicon dioxide was chosen as inorganic material because of its stability when compared to the non-stoechiometric silicon monoxide and SiOx, these being the traditional choice. The material is obliquely evaporated under 45º in a slightly adapted standard thin-film evaporator. This is possible because instead of the complete wafer the microdisplays are mounted individually. This approach ensures a very tight control of deposition angles, resulting in very uniform aligning properties. Final thickness of the deposited layer is set to 6 nm. The performance of the resulting layer can be evaluated based on the electro-optical characteristics presented in section 5.

Table 1. Process flow for the assembly of display cells after deposition of the alignment layer.

<table>
<tr><th>DIE</th><th>COUNTER ELECTRODE</th></tr>
<tr><td></td><td>Apply spacers by spin coating</td></tr>
<tr><td></td><td>Dispense UV-curable glue drops</td></tr>
<tr><td colspan="2">Join die & CE, set cell-gap</td></tr>
<tr><td colspan="2">Fixation of assembly by UV illumination</td></tr>
<tr><td colspan="2">Dispense border seal</td></tr>
<tr><td colspan="2">Cure border seal</td></tr>
<tr><td colspan="2">Fill cell with LC using vacuum method</td></tr>
<tr><td colspan="2">Dispense end seal cap</td></tr>
<tr><td colspan="2">Final cure of end seal</td></tr>
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3.1 Assembly process flow

The schematic process flow for the further assembly of the displays is given in Table 1. A brief discussion of each item is presented below.

Round spacer balls of 3.0 µm are randomly distributed over the counter electrode by dispensing them on a spin-coater; afterwards the solvent is removed by a short bake step on a hotplate. The spacer density should be around 100/mm^2. Very small drops of UV curable glue are then dispensed at the border of the glass, which is subsequently registered with the backplane and then pressed together. Once the cell gap is reached, this pre-assembly is fixed by curing the glue drops with UV-light. The actual border seal, which ensures that the cell will be airtight, can then easily be dispensed against the rim of the counter electrode without having to worry about the exact amount of glue needed. Capillary forces will drag the glue inwards into the cell; when the desired seal width is reached, progression is stopped immediately by illuminating the area and thus snap-curing the glue. This two-step method enables the use of very thin seal borders together with small cell gaps as needed for microdisplays yet prevents having to spent great effort on the dispensing technique (Figure 1). A thorough cure finalizes the main seal deposition.

The cell is filled with LC using the standard vacuum method. Afterwards the filling opening is closed with the end seal cap, which most of the time will be the same glue as used for the main seal. Lastly, the device is subjected to a final cure step to inhibit the end seal.

3.2 Technology issues

Apart from the deposition parameter optimisation, the main technological problem turned out to be the realization of a reliable main seal that lasts with time. Although functional displays can be obtained with most of the commonly used seal materials, a sometimes rapid degradation of the initial alignment occurred in the majority of our tests, disqualifying these devices for production altogether.

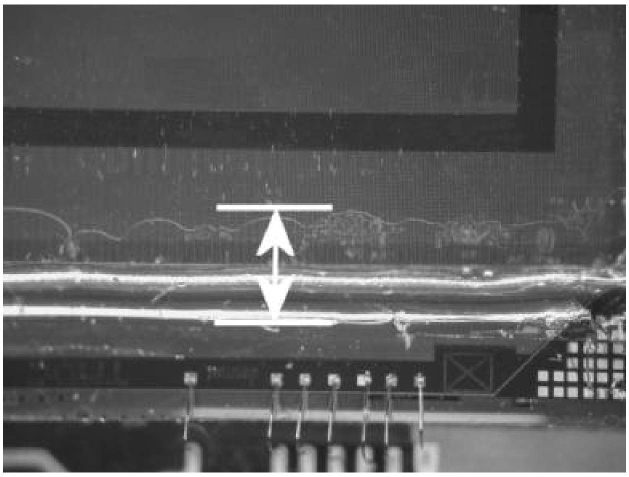

Figure 1. Detail of the seal on an actual microdisplay with 3 µm cell gap. Picture is taken near a corner of a cell with a 0.9” diagonal active matrix. The arrow indicates the total thickness of the seal, around 1 mm. The jaggedness at the inside of the sealant is due to manual dispensing.

4. Experimental

In order to solve the problem outlined above, a systematic survey of seal materials was carried out. Previous extensive experiments already showed that the choice of glue is indeed the crucial and sole parameter to obtain stable displays. Several types of glue were selected for use as sealing material; for certain common types, different brands were included for the tests to avoid brand-specific particularities. The better performing types of glue tested include, amongst others: a UV curable urethane acrylate based aerobic adhesive, a UV curable mercaptoester based adhesive, a single component thermal curing epoxy, and a UV curable bisphenol based epoxy.

Of these, only one, the UV curable epoxy, provided a seal that was fully compatible with the other display components. All displays assembled with the other glue types exhibited a zone of interaction at the seal where the vertical alignment was broken and converted into a planar one, with preservation of the preferential direction. This misalignment zone starts at the seal borders and grows inwards with time until the complete display is affected and rendered useless (Figure 2).

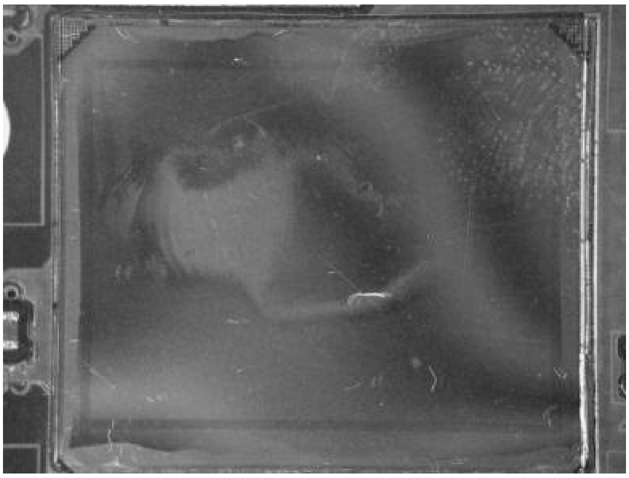

Figure 2. Polarized light picture of a cell assembled with an incompatible seal. The interaction is complete and has turned the original vertical alignment into a planar one. For certain polarizer angles, this results in distinctly colored areas, which have been converted to grayscales.

It is important to be certain that the interaction is not due to incompletely cured seal material. This was assured by using various curing schemes, some of which largely exceeded the manufacturer's specifications; it is widely known that the highest degree of chemical inertness is sometimes only achieved for curing conditions that deviate from the prescribed one. Alternatively, great care was exercised to remove possibly excessive and uncured material by using solvents.

Taking into account these observations and precautions, we believe that misalignment (planar instead of homeotropic) at the seal border can be triggered depending upon the chemical nature of the seal material. Knowing that the anchoring energy of inorganic layers is inherently somewhat lower, this can ultimately lead to an extension of the misalignment over the complete cell, as this could become the lowest energy configuration.

A confirmation for this hypothesis is found in the fact that the phenomenon is strictly confined to the use of inorganic layers. If for reference purposes, a polyimide alignment is used, all combinations of glues and curing schedules previously tested and dismissed now give perfectly good results (Figure 3).

5. Demonstrator

The acquired insights into the assembly process issues were employed to manufacture microdisplays for demonstration purposes. The backplane used was a 0.9” diagonal active matrix XGA silicon chip with 17.6 µm pixels, developed by our research group for Taiwan Microdisplay Company and processed at UMC. The cell gap was set to 3.0 µm and is maintained by means of soft polymer spacers of Sekisui. The seal material, both for main and end seal, was chosen to be OG116-31 optical adhesive from Epotek, a representative of the bisphenol based epoxy family. This UV curable glue allows for an additional thermal curing step once it has been exposed to UV light, a useful feature to ensure thorough crosslinking. Liquid crystal was Merck's MLC-6610 mixture with negative dielectric anisotropy (Figure 4).

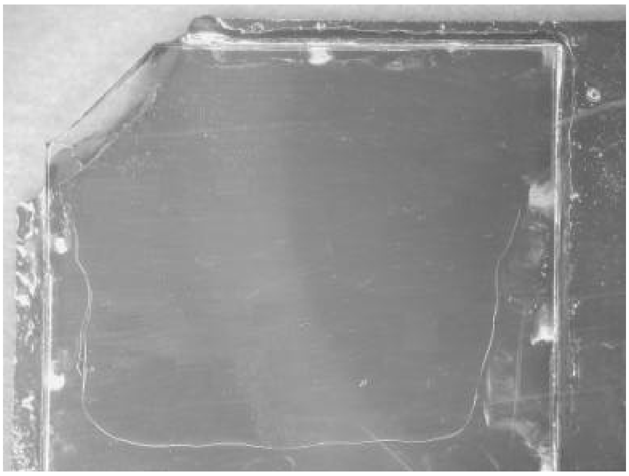

Figure 3. Polarized light view of a simple test cell with polyimide alignment layers (homeotropic) and assembled with a thermally cured one-component epoxy. No interaction can be detected.

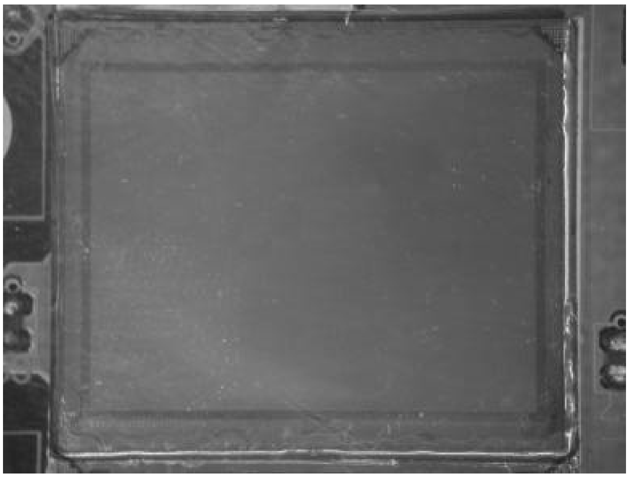

Figure 4. Polarized light picture of a fully assembled 0.9” XGA VAN cell.

We evaluated the attainable contrast of this cell in a dedicated optical setup and ended up with the exceptional value of 17000:1 (at 543 nm, on axis, laser spot illumination). A response speed of less than 15 ms (Figure 5), and an electro-optical response curve as shown in figure 6 with a voltage requirement of 5.5 Vp-p complete the outstanding specifications.

Finally, a projector demonstrator has been made using three of the above cells. Figure 7 and 8 show the set-up with a projected image and the ColorCorner based optical engine with three cells, respectively.

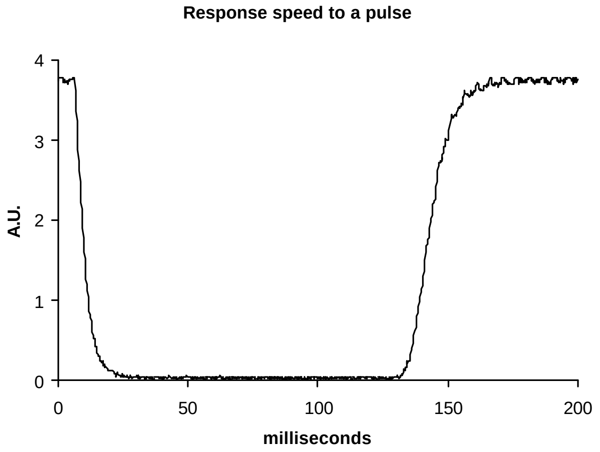

Figure 5. Measured response to a pulse (full white to full black) of a typical 3.0 µm MLC-6610 cell.

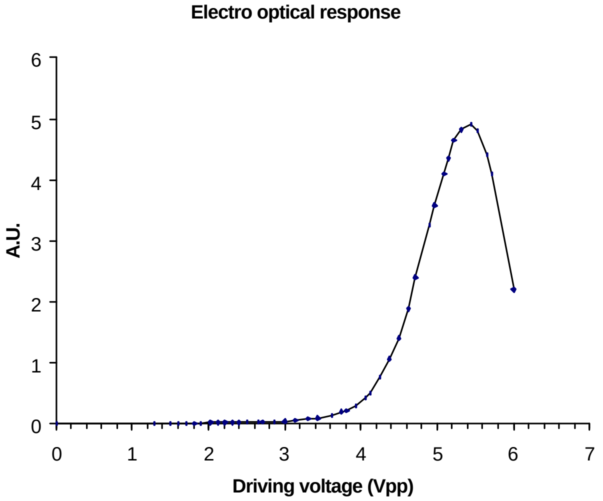

Figure 6. Measured electro optical response of a 3.0 µm MLC-6610 cell.

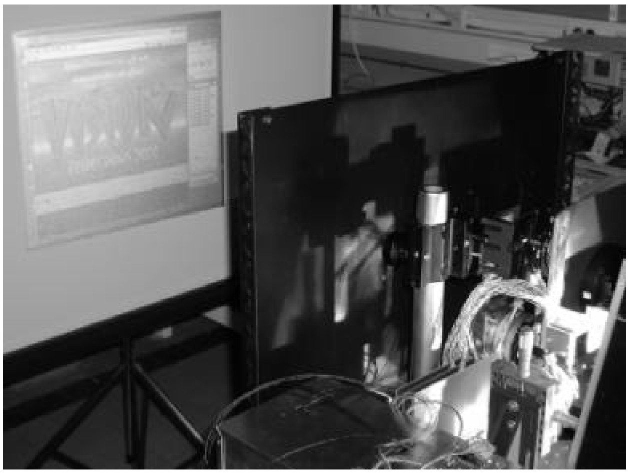

Figure 7. Prototype projector setup on an optical bench (right) together with a projected image.

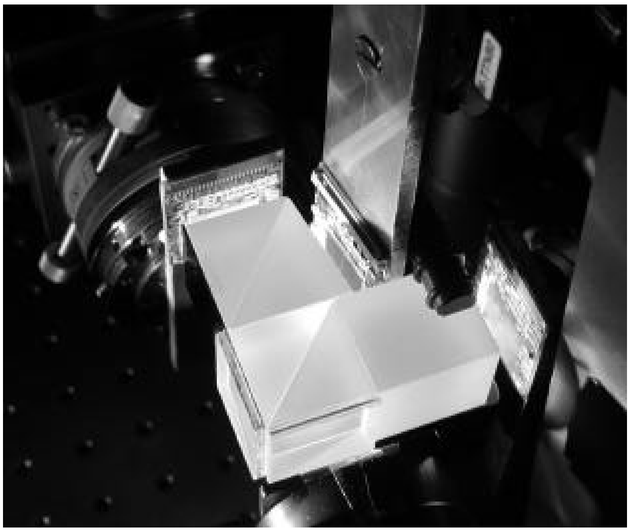

Figure 8. Heart of the projector's optical engine: Unaxis' Colorcorner with three cells.

7. Conclusion

Reflective microdisplays using vertically aligned nematic LC can offer outstanding characteristics. The appropriate aligning method for these devices is an inorganic layer. The technological problems with this method have been addressed and solved. Commercial microdisplays have been assembled and show excellent characteristics, including a 17000:1 contrast ratio.

8. Acknowledgements

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9. References

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