On the Fabrication Improvements of Liquid Crystal Beam Steering Device for Light Field VR System

Yu-Min Chen[1,*] Chung-Jen Ou[2,**] Ming-Wei Tsai[2] Chien-Chih Chen[2]
Chih-Hung Lu[2] Pei-Ting Chen[2] Yen-Ting Wang[3] Huang-Ming Philip Chen[1,***]

*jabby0317.eo08g@nctu.edu.tw
**owen.ou@coretronic.com, crou@hust.edu.tw
***pchen@nctu.edu.tw
[1]National Yang-Ming Chiao-Tung University, Taiwan
[2]Coretronic Corporation, Taiwan
[3]Showa Denko International (Taiwan) Co., Ltd
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ABSTRACT

The liquid crystal beam steering device proved to be a promising device for the light field VR eye box extension. The manufacturing process of liquid crystal beam steering components requires special adjustments of electrodes and electrical fields, and numerous difficulties are encountered during development. This paper will present these challenges and improvement approaches.

1 Introduction

Liquid crystal (LC) already been widely used in display for our daily life, and one of the novel advance applications, known as liquid crystal beam steering (LCBS) [1-3], can be applied for the eye box extension of AR/VR. During the first stage of the exploration of the function of the LCBS sample, questions of manufacturing tolerance for a laborious process with well-defined equipment might not the first priority. However, for advanced research with general fab equipment, it becomes important to study the root cause of the issue. Once solving the fundamental questions, similar problems for LC based device (e.g. liquid crystal antennas of satellite communication, micro pixelized LCoS for new generation display, LC based optical communication) could be overcome with the same analysis strategies.

The principle of LCBS is to control the liquid crystal orientation into a specific deflection pattern through delicate electrode design and driving condition, such that the incident image from the display panel can be deflect into the desired *EYEBOX* position. The deflection angle is affected not just by the electric field, but also by the uncertainty factor in the manufacturing process. This will degrade the image quality of the appliance. Consequently, this work has focused on process quality in laboratory and fab tools. With optimization and a unified approach, possible improvement strategies for the LCBS are reported.

2 Design Methods

Figure 1 shows the initial structure of the first version of the LCBS. Electrode width is 1 um, the first electrode gap is 1 um and the second electrode gap is 1.5 um. There is a High-K (HK) wall between each periodical structure, and the maximum height of the HK wall is 330 nm. The thickness of the PI layer is about 30nm.

By using liquid crystal simulation software, one can estimate the position of the center of the deflection angle caused by the liquid crystal director field, which is around 7.6 degrees (figure 2). The estimate method is based on the equivalent geometric ray trace method [4]. Note that the position of the 2nd order diffraction caused by the electrode and HK is 8.1 degree.

The difference among the two is about 6%. It should be noted that in the course of the manufacturing process it is not easy to establish a complete correspondence between the simulation prediction and the manufactured sample. A number of adjustments based on this initial design have been made to meet the requirements of the processing machine.

Figure 3 shows the upgraded version of the LCBS following several manufacturing trials. From the update simulation results, the position of deflection angle caused by the liquid crystal is now about 5.8 degrees, and the position of the second-order diffraction light generated by the electrode and HK structure is now 6.1 degrees. The difference between the two is 5%, which is inferior to the original design. However, the sample produced is more attainable. In summary, comparing geometric estimation with diffraction theory provides LCBS design strategies.

3 Results and Discussions

In the initial design, the electrodes were exposed by a direct Mask Laser Writer (MLA 150 Heidelberg Instruments), while the development and etching processes were following the standard Laboratory protocol during the EVT. After the electrode process is the HK process, wherein SiN is chosen as HK material for LCBS design. The final procedure is the liquid crystal cell conditioning procedure. The following list identifies three major problems encountered during the electrode process.

1. The layout area is too large, resulting in a lack of power uniformity during direct exposure to laser writing.
2. The 1 um line width of the electrode is too small, which has caused the difficulties of the etching process and the conductivity of the electrodes.
3. Particle issue

Since the total area of the component is 40 mm by 40 mm, and the exposure method of the laser direct writing machine is a localized treatments process, it is expected to encounter different exposure parameters between the adjacent blocks. However, other processes like development and etching will result in non-uniform electrode widths.

Note that the requirement for long and thin electrodes in the LCBS design might cause difficulties in the process. In addition to the exposure problems mentioned above, excessive etching leads to a significant decrease in the yield rate due to the electrode length. Moreover, such a long and thin electrode indicates that the resistance will increase dramatically, degrading the precise control function of the electric field (Figure 5).

To overcome this scenario with minimal resources, the DOE method can be introduced to improve the entire processes (Figure 6) and explore the parameter space. In addition to ensuring the consistency of the concentration of the developing and etching solution, delicate controlling of the marking time on soft baking, developing, etching, as well as the consistent cleaning protocol, can surly improve the defect rate. With respect to the design layout, allocation on the appropriate geometric shape factors of the electrodes and introducing a particular design on the exposed area will also be useful. All this can improve the efficiency of the electrode, in which the reliability of the exposure process can also be improved. In doing so, the problem of failure due to exposure problems may be improved.

The packaging process for LC cells consists of PI coating, rubbing, spacer spraying, packing and filling of liquid crystals. The thickness of the LC layer and the uniformity directly affect the quality and brightness of the image, whereas the main factor that affects the thickness of the LC layer is the packing of the spacer. However, if the spacer is not evenly distributed in the UV adhesive, it can lead to non-uniform distribution of the spacer and non-uniform thickness. Three approaches can overcome this challenge.

1. Optimize the spacer spreading position.
   - away from the packing region between the two substrates.
   - The spacer could agglomerate because of bleeding UV glue after pressing.
2. Standardization the package process
   - use a test sample for quality control.
   - Adjustment of the distribution parameters using the sample results.
3. Standardization of the pressing method.
   - using the same loading object to make the pressing after packaging
   - exposure time determination.

It would be difficult to improve the manual processes within a certain range. However, following the three approaches, the LC layer thickness was improved (Figure 7). Meanwhile, the driving result of the 2nd sample is shown in figure 8.

4 Conclusions

This report outlines the strategies to obtain the qualities of the LCBS system. By minimizing the risk of individual processes, high quality LCBS samples could be obtained from optimized resources. The measured deflection angle (eye box extension) of the manufactured LCBS sample is about 6.1 degrees in both directions, which is consistent with the expected 2nd diffraction positions. This suggests the current improvement strategies are achievable.

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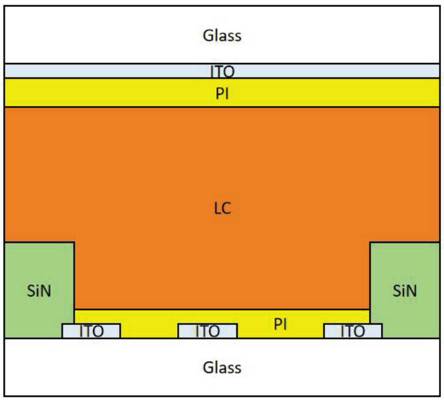

Fig. 1 initial design of LCBS.

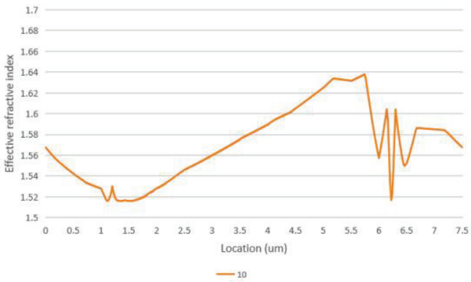

Fig. 2 The predictive refractive index distribution of first version design.

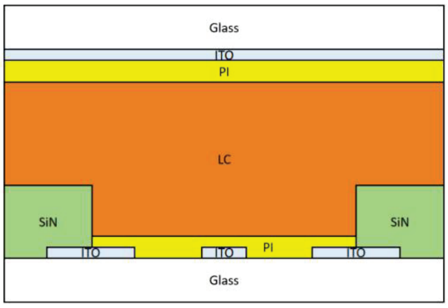

Fig. 3 2nd version design of LCBS

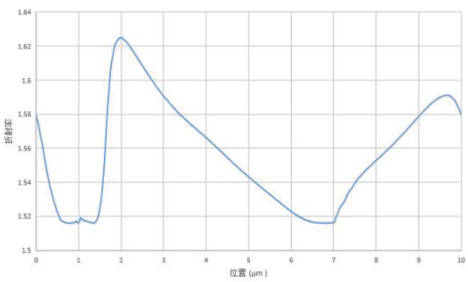

Fig. 4 The predictive refractive index distribution of second version design.

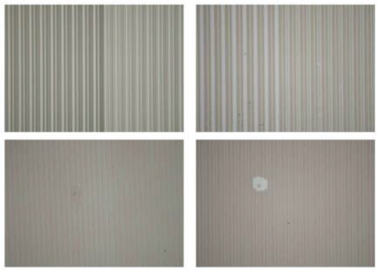

Fig. 5 The images after the laser exposure process. These images show the nonuniform exposure and particles making the bad performance.

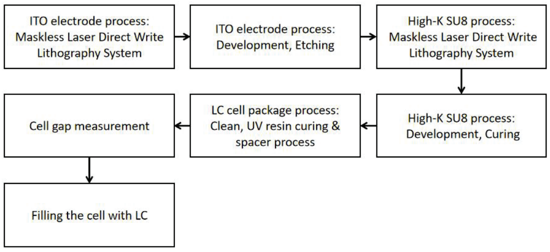

Fig. 6 The process flow

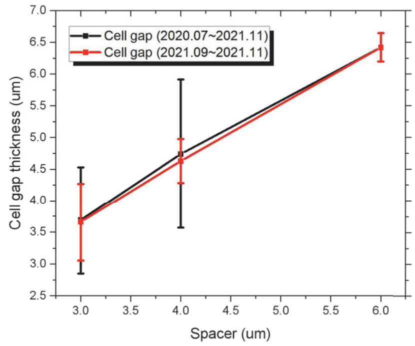

Fig. 7 The distribution of cell gap (LC layer thickness) changing after process improvement.

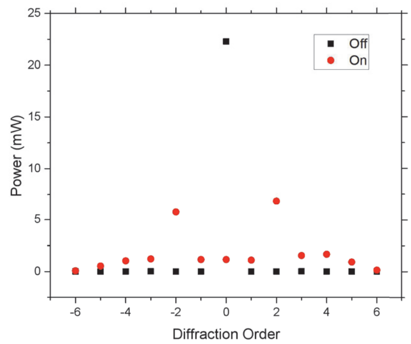

Fig. 8 The driving result of second version sample.