Modeling an e-Beam Addressed Liquid Crystal Projection Display

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Abstract

We have carried a theoretical study on e-beam addressed liquid crystal projection display in which the liquid crystal is switched by the electric field of the charge, produced by an electron beam, on the surface of the display. We calculated the electric field produced by the surface charge, the liquid crystal director configuration and the profile of the transmitted light. We studied the factors affecting the resolution of the display. We also studied the effect of pretilt angle on the performance of the display. The e-beam addressed liquid crystal projection display potentially has the advantages of high resolution and high brightness.

Background and objective

In recent years, there have been intensive research and develop activities on liquid crystal projection displays because of their superior performance. The popular liquid crystal displays (LCD) used for projection are high-temperature-poly-silicon LCD and liquid-crystal-on-silicon (Lcos). The consumer television market is, however, still dominated by cathode-ray tube (CRT) because its low cost. About a decade ago Tektronix developed e-beam addressed LCD projection display which was a combination of LCD and CRT. Since then there were few activities on this display because of the emergence of the new LCD projection technologies. However, a few companies recently become interested in this technology because of its potential application in high brightness and high resolution projection displays. We have carried a theoretical study on the e-beam addressed LCD in order to investigate its limitations. We studied the electric field of the surface charge produced by e-beam, liquid crystal working mode and various factors affecting the resolution of the display.

Results

The schematic diagram of the e-beam addressed liquid crystal projection display is shown in Fig. 1. Crossed polarizers, which are placed far away from liquid crystal, are used but not shown in the figure. The e-beam places electrons on the surface of the mica film. The surface charge produces an electric field inside the mica and liquid crystal films, which controls the liquid crystal director configuration.

In the calculation of the electric field,

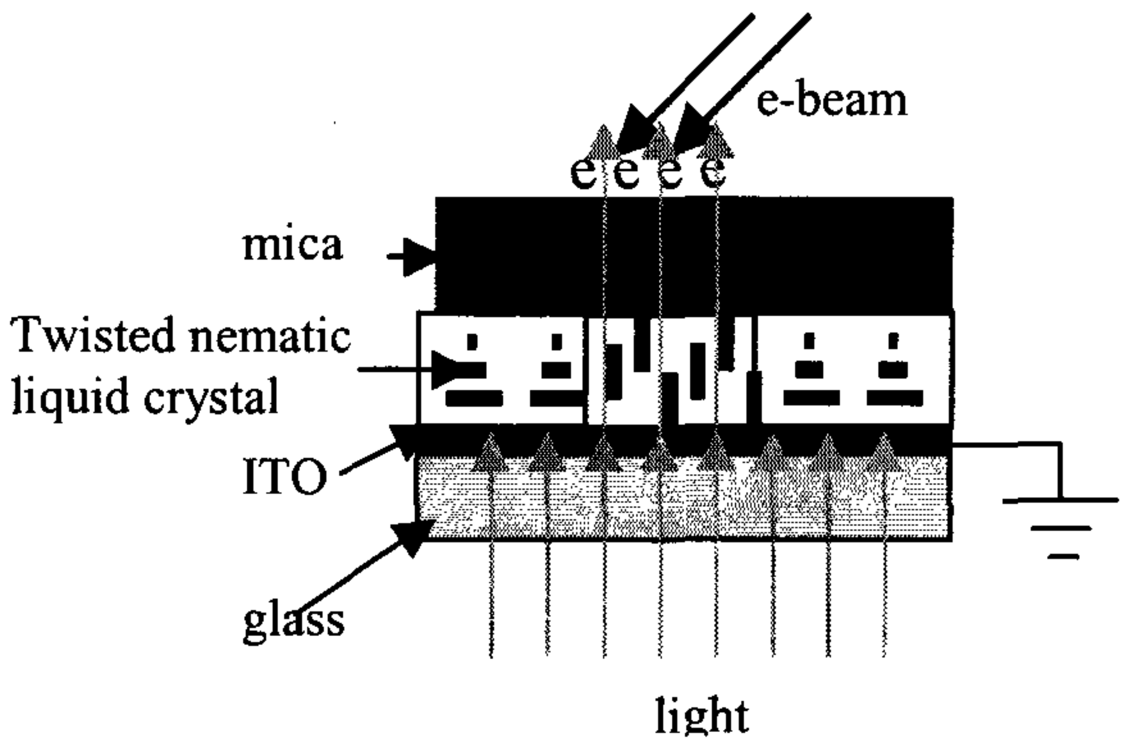

Fig. 1 Schematic diagram of the e-beam addressed liquid crystal projection display

we use Green function method. We first calculate the electric field produced by a point charge. In the real display, the charge on the surface of the mica film is not a point charge but approximately uniformly distributed over a disk of diameter D. The field produced by the disk of charge is numerically calculated by adding the fields produced by the point charges located all over the disk. Figure 2 shows the electric field produced by a disk of charge with $D = 10\,\mu m$. It should be noticed that the electric field has components perpendicular and parallel to the liquid crystal film. It should also be noticed that the field has significant strength outside the charge disk region because of the finite thickness of the mica and liquid crystal films.

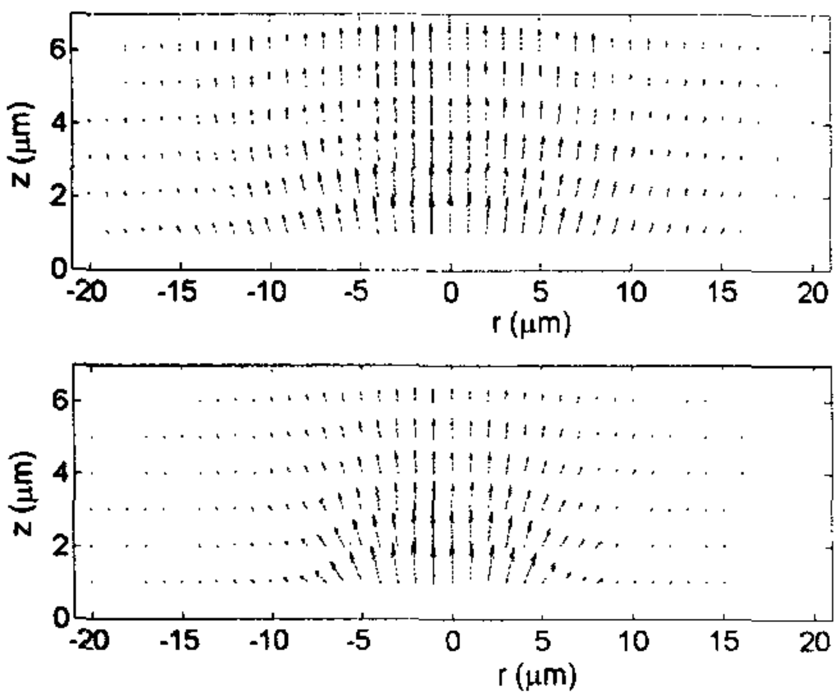

Fig. 2 The electric field inside (a) liquid crystal film and (b) mica film. The thickness of the films 6 μm. The unit of the field in (b) is 3 times larger than that in (a).

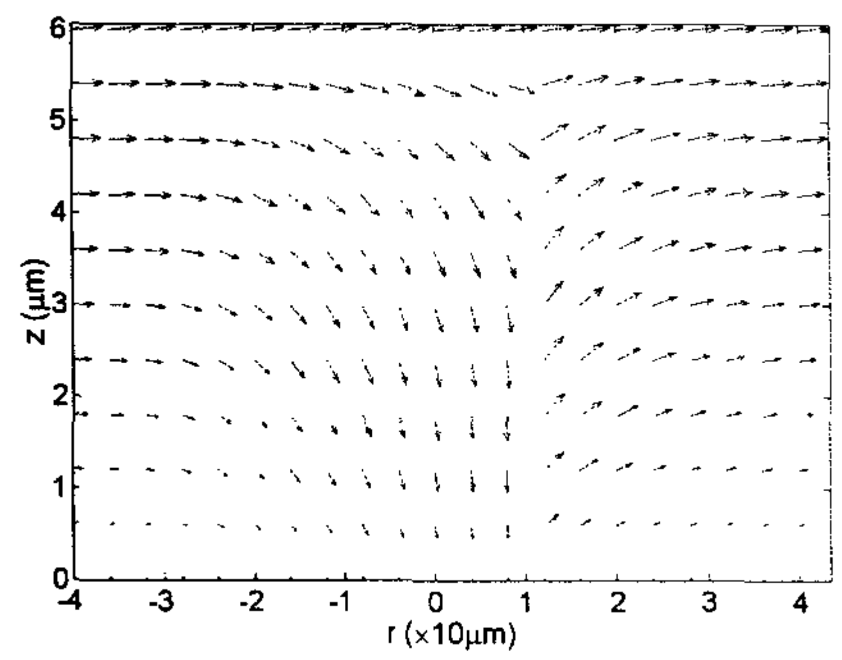

Fig. 3 The liquid crystal director configuration when the surface charge density is higher than the threshold.

In the calculation of the liquid crystal director configuration, we use tensor relaxation method. At zero field, the liquid crystal director is parallel to the cell surface and has a 90^o twisted structure. When sufficient amount of charge is placed on the surface of the mica film, the liquid crystal director is tilted away from the cell surface. Because the electric field has components perpendicular and parallel the cell surface, the liquid crystal director $\vec{n}$ is a function of x, y and z. The calculated liquid crystal director configuration when the surface charge density is higher than the threshold is shown in Fig. 3 where the pretilt angle of the alignment layer is 1^o. Because the component of the electric field parallel to the cell surface on the two sides from the center is in opposite directions, the liquid crystal director is tilted in different directions on the two sides, and therefore there is a defect in the middle. We study the effects of pretilt angle, and find that the defect in the middle can be eliminated by using alignment layers with high pretilt angles.

We use Jose matrix method to study the optical properties of the display. The simulated transmittance as function of position is shown in Fig. 4 where the surface charge density is sufficiently higher than the threshold. The width of the transmission peak is about 20 μm which is much wider than the diameter (10 μm) of the charge disk because of the finite thickness of the mica and liquid crystal films.

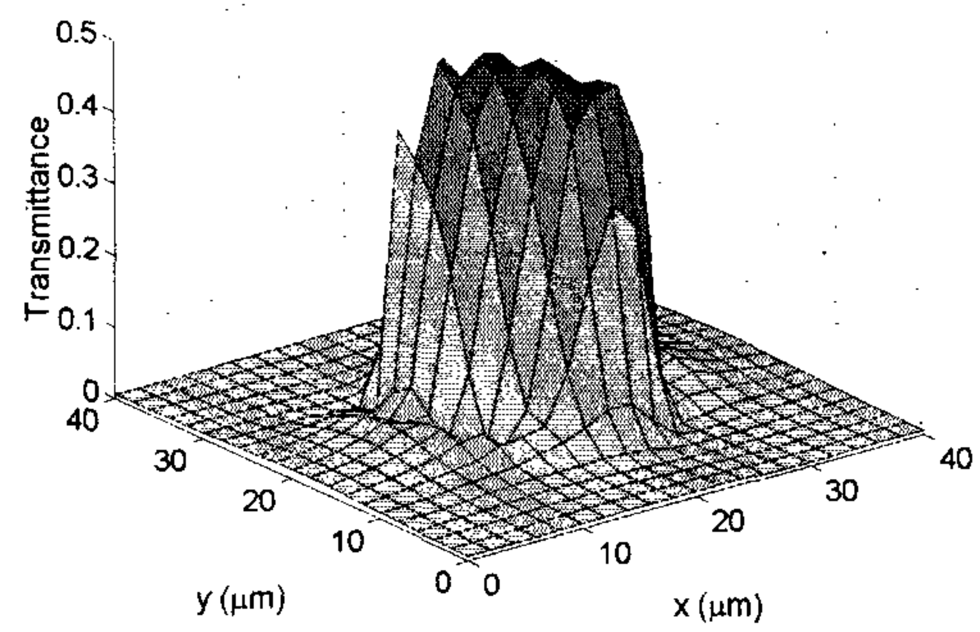

Fig. 4 The transmittance as a function of position of the e-beam addressed LCD.

We study the factors affecting the resolution of the display, and find that the thickness of the mica and liquid crystal films is the main factor. The calculated width of the transmission peak vs. the diameter of the disk of the charge is shown in Fig. 5. In the calculation, the thickness of the mica film and the liquid crystal film are assumed to be the same and is denoted by d in the figure. With the current technology, the size of the e-beam, which is essentially the diameter of the disk of the charge, can be as small as 2 μm. In order to achieve high resolution, the thickness of the mica and liquid crystal films must be small.

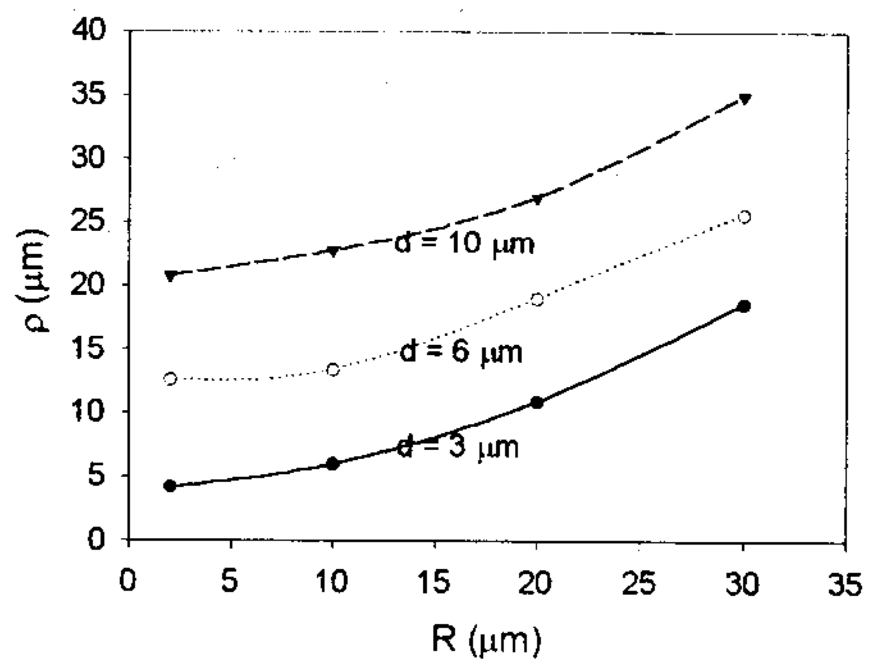

Fig. 5 The width of the transmission peak vs. the diameter of the charge disk with various thicknesses of the mica and liquid crystal films.

Impact

We have carried a simulation study of the e-beam addressed liquid crystal projection display. Our results showed that the technology could be used to make high resolution displays because the pixel size on the LCD panel can be smaller than 10 μm. Our results also showed that the defect in the liquid crystal director field could be eliminated by using alignment layers with high pretilt angles.