10-2-1995

Simple 4-Domain Twisted Nematic Liquid-Crystal Display

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Recommended Citation
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(Received 11 May 1995; accepted for publication 1 August 1995)

A particularly simple four-domain (4-D) twisted nematic (TN) liquid crystal display (LCD) device is proposed, which is composed of two left-handed TN and two right-handed TN subpixels. One of each pair of same handedness subpixels is rotated 180° with respect to the other, resulting in four domains that spatially average one another optically to provide a wide angle of viewing with no gray scale inversion. The detailed fabrication process is presented for a two step SiO₂ oblique evaporation technique used to realize this 4-D TN LCD. A reverse rubbed polyamide fabrication process has also been successfully used and will be presented in the full length article. Here we present the complete viewing angle and contrast ratio data for a simple and successful 4-D TN LCD cell. © 1995 American Institute of Physics.

It is well known that single domain twisted nematic (TN) cells, which are now most commonly employed in flat panel liquid crystal display (LCDs) have a narrow and non-uniform viewing angle characteristic.¹ Furthermore, the electro-optic (EO) characteristics of conventional TN-LCDs are strongly dependent on viewing angle, a serious inconvenience for good gray-scale operation, which is a prerequisite to developing a full color display. These drawbacks originate from the fact that the optic axis in the midplane of the cell is uniformly tilted in one direction. Because the nematic liquid crystal is highly birefringent, different viewing directions give substantially different degrees of birefringence, resulting in optical transmission behavior depending strongly on the viewing direction.

To overcome this shortcoming of conventional TN-LCDs, two major approaches have been proposed, namely, negative retardation film compensated and multidomain LCDs.⁴⁻¹⁰ The latter includes amorphous TN-LCDs.¹¹⁻¹³ The negative retardation film compensation technique can only improve the gray scale characteristic in one viewing plane; namely, one of the planes containing the cell normal that is 45° from the polarizer directions. The gray scale inversion problem still exists and sometimes becomes even worse in other viewing planes. On the other hand, although the amorphous multidomain TN-LCD has its own merits, i.e., a wide viewing angle and no rubbing, the disclinations at reverse tilt domain boundaries due to nearly zero pretilt angle seriously degrade its performance.¹³ The multidomain technique was proposed in the late 1980’s. The main idea is to divide each pixel into subpixels in which the molecular configurations and optical responses are different. In this way, properly designed domains will spatially average in the contrast angular dependence to give a wide angle of viewing and improved gray scale characteristics.

Recent analytical simulation of the EO performance of MDTN cells shows that optimum viewing characteristics are obtained in a four domain TN-LCD structure.¹⁴ However, people mainly concentrated their research on two-domain TN-LCDs.⁴⁻¹⁰ Only one technique suggested by Kobayashi’s¹³ group is to pattern photopolymer alignment layers with linearly polarized UV light to fabricate 4-D TN-LCDs. This has the same problem as the amorphous TN cell. The reverse tilt domain defects cannot be controlled. There are currently no complete viewing angle experimental data available for 4-D TN-LCDs fabricated by any method.

In this letter, we report a particularly simple 4-D TN structure. This structure was realized by both two step SiO₂ oblique evaporation and doubly rubbed polyamide. We confine our attention here to the former. The LC director configuration in each of four subpixels was electro-optically analyzed. The viewing angle and gray scale data for our 4-D TN LCD cells are also provided.

The structure of our four-domain TN cell is shown in Fig. 1(a). The arrows and dashed arrows in each subpixel indicates the pretilt directions for the top and bottom plates, respectively. In this configuration, we have two left-handed and two right-handed TN subpixels. There is a twofold symmetry axes normal to and in the center of the pixel. From the pretilt direction of each subpixel, one can easily infer the LC molecular orientation (and, therefore, optic axis orientation), in the midplane of the cell. This is indicated in Fig. 1(b). Note that the nematic director (optic axis) in the midplane of the four subpixels points to each of the four corners of the pixel. This causes the subpixels to spatially average optically, providing good viewing angle characteristics.

For comparison, another four-domain TN structure¹³ is shown in Fig. 1(c) and the director orientations at the midplane of the cell are illustrated in Fig. 1(d). From the symmetry point of view, our four-domain structure is different. The four-domain TN cell of Ref. 13 has four same handedness pixels and belongs to the \( \{ C_4 \} \) symmetry group, whereas our four-domain TN structure has two left-handed and two right-handed subpixels and belongs to the \( \{ D_{2h} \} \) symmetry group. However, the director orientation at the
midplane of the subpixels shows the same configuration in both structures. It is not surprising that both structures give similar optical compensation effects.

Our four-domain TN structure can be realized by a two step SiO$_x$ oblique evaporation process whose flow chart is shown in Fig. 2. A clean indium tin oxide (ITO) coated glass substrate was first coated with an evaporated SiO$_x$ alignment layer. Then, a photolithography process was used to form an equal width striped mask. The photoresist we used was Shipley S1400-31. After the photolithography process, the substrate was rotated by 180° and the second SiO$_x$ evaporation was carried out. Finally, the photoresist used as a mask was removed by acetone. The evaporation angle was 85° from the plate normal. The thickness of the SiO$_x$ layer was ~150 Å. Our 4-D TN cell can be fabricated by assembling the two substrates in the same way as a conventional TN cell using two identical plates fabricated by the method described above. For the EO performance and viewing angle measure-

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The subpixel size is 100 μm and the disclinations at the boundary of each subpixel can be easily seen. If a certain voltage is added to the cell, the brightness of each subpixel will alternate as the viewing direction is varied azimuthally. We notice the fact that one of the subpixels is always darker than the rest (see Fig. 3). It is possible that the cell was not perfectly flat when we took the picture or the LC pretilt angles in adjacent stripes (see Fig. 2) are not the same.

Figure 5 shows isocontrast measurements of the 4-D TN cell. The cell was in the normally white e mode and the on state at 6 V. The polar angle dependence of the transmission, in eight gray levels, of our test cell along vertical viewing direction is indicated in Fig. 6. These experimental results match with that of a computer simulation quite well, although our 4-D TN cell structure is different from that of Ref. 13. The viewing angle characteristics of a TN cell is mainly determined by the director configuration at the cell midplane. Therefore, the identical director configuration at the midplane of the two 4-D TN cells makes these results quite naturally understood.

Our 4-D TN display can also be realized by a reverse rubbing technique, which will be suitable for mass production in the display industry. This part of the work, including the optical simulation of our 4-D TN cell as well as the stability of this 4-D structure and the effect of disclinations on contrast, will be published in a full length article.

A new four-domain TN cell structure was proposed, which has $D_2$ symmetry. This structure is composed of two left-handed TN and two right-handed TN subpixels. A two-fold axis lies normal to and at the center of a pixel, giving it $D_2$ symmetry rather than the $C_4$ symmetry of the cell of Ref. 13. The molecular direction at the midplane of each subpixel points to each of the four pixel corners. This causes the four subpixels to spatially average each other giving a symmetric viewing angle and wide gray scale inversion free zone. Our four-domain structure is very simple and can be realized by many techniques including the double SiO$_2$ oblique evaporation technique. We provided complete experimental data on the viewing angle characteristics of four-domain TN LCDs.

This work is supported by the Advanced Liquid Crystal Optical Materials (ALCOM) Program under Grant No. DMR-8920147 and by Office of Naval Research Grant No. N00014-94-1-0270.