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INVESTIGATION OF DOMAIN INSTABILITY IN THE FOUR DOMAIN TWISTED NEMATIC CONFIGURATIONS

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Abstract Considering multi-domain TN displays, a four-domain structure gives the most symmetric viewing angle characteristics and gray scale performance. However, domain instability of the four configurations in the operating state is an obstacle for their practical application. In this paper, the origins of the instability in different four domain configurations are investigated. We evaluate the critical conditions for the domain stability using a simple model. The consequences of the model are tested by experiments, and methods to prevent the domain instability are suggested.

INTRODUCTION

Single domain twisted nematic (TN) cells are most commonly employed in the flat panel liquid crystal display (LCDs). However, the TN mode has an intrinsic viewing angle problem[1]. Technologies have been developed to overcome this shortcoming of conventional TN LCDs. These are the film compensated TN mode[2], multi-domain TN mode (including amorphous multi-domain TN mode)[3-6] and more recently in-plane switching mode[7]. The main idea of the multi-domain TN technique is to divide each pixel into subpixels in which the mid-plane director points in different directions, and the asymmetry in the off-axes viewing characteristics is partially averaged out. The optical simulation showed that for the multi-domain TN displays, the display with four-domain structure gives an symmetric viewing angle characteristic and gray scale performance[8]. However, the domain instability of the four domain TN configurations in the operating state is a big obstacle for its practical application[6].

In this paper, the origins of the instability in different four domain TN configurations are investigated. The critical conditions for the domain stability are evaluated using theoretical models and Gibbs energy calculation. The consequences of the calculations are tested by experiments. The prevention for domain instability is also suggested.

4-DOMAIN TN CONFIGURATIONS

All currently existing 4-domain TN configurations are shown in Fig.1. The one in Fig.1(a), super-multi domain (SMD) proposed by Kobayashi's group, consists of four identical handedness subpixels[8]. The other four were proposed by us in the last two years, with the name of KSU-I, KSU-II, KSU-III and KSU-IV 4-domain TN configurations, respectively[6,9]. In KSU-I configuration, there are two left-handed and two right-handed TN subpixels. The LC twisted states are fully determined by surface pretilt angles and no chiral additive is needed. The common characteristics of KSU-II, III, and IV 4-D TN configurations are that the top and bottom substrates in each subpixel have "hybrid" pretilt angles which are required to create the controlled viewing zone for the different subpixels. The structure shown in Fig.1(c) consists of two perpendicular Domain Divided TN (DDTN) structure proposed by Koike[3]. Subpixels have the splayed TN configurations. This structure is further modified to have one single alignment layer at the top substrate, whose pretilt angle has a value between the high and low pretilt of the other substrate, as shown in Fig.1(d). The structure of KSU-IV 4-D TN, shown in Fig.1(e), has two complementary TN (C-TN) structures in which one is rotated 90^0 with respect to the other[4]. It has two twisted and two splayed twisted subpixels. From the manufacturing point of view, KSU-I configuration has the fewest fabrication processes, while SMD is the most complicated one to realize. The KSU-II,III and IV 4-D TN configurations usually require two different polyimides.

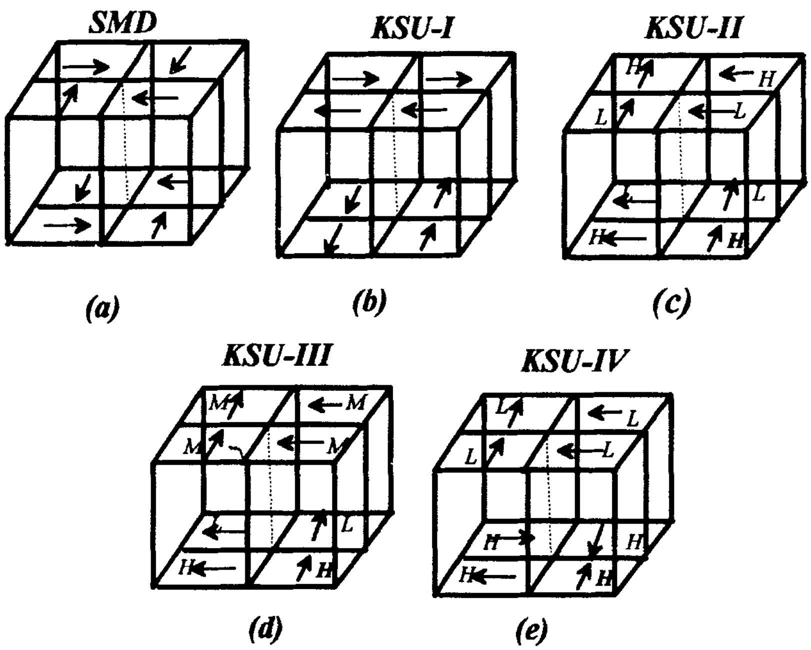

Fig.1 The configurations of the currently existed 4-D TN displays. H, M and L are defined as the high, middle and low pretilt angle regions.

THEORETICAL MODEL

As shown in Fig.1(a), the subpixels in KSU-I configuration are separated by reverse twisted lines. A high pretilt is needed to offset the energy cost of the generating twist disclinations. The photomicrograph of a typical cell fabricated by the reverse rubbing technique is shown in Fig.2. The surfaces were rubbed to generate 7^0 pretilts. The reverse twist disclination lines appear and are stable when the applied voltage is larger than 1V. The pretilt angle required for a stable KSU-I 4-D TN display can be evaluated by comparing the disclination line energy and the splayed energy introduced by the subpixel having the "wrong" handedness. The stability depends on the cell geometry (tilt angle, t, and subpixel dimensions LxLxd). In the absence of disclinations, the entire LC medium has either a right or left handed twist. Thus half of the subpixels having the "wrong" handedness would introduce a splayed distortion given approximately by 2t/d. The corresponding splay energy of two subpixels is

$$F_S \cong K(\frac{2t}{d})^2 L^2 d \tag{1}$$

where K is the splay elastic constant. The 4-D TN configuration is stable only if $F_S<F_d$, where F_d is the twist disclination energy given by

$$F_d = 8E_c L \tag{2}$$

where E_C is the disclination core energy per unit length. Since the tension is larger at the center of the disclination, it is believed that, below a certain critical radius, it should be large enough to transform the material from nematic to the isotropic phase[10]. The core energy is given approximately by

$$E_c \cong \frac{1}{2}\alpha S^2(\pi\xi^2) \tag{3}$$

where $\alpha S^2/2$ is the first term of the nematic Landau free energy; $\alpha=\alpha_0(T-T^*)$ and S is the nematic order parameter; ξ is a nematic correlation length (we assume 2ξ as the core diameter) equals to $\xi\sim(K/\alpha S^2)^{1/2}$[10]. The stability condition for the 4-D TN display is

$$\frac{F_S}{F_d} \sim \frac{Kt^2L}{2dE_C} = \frac{t^2L}{d\pi} \geq 1 \tag{4}$$

We can decompose the KSU-II, III and IV 4-D TN structures into two identical perpendicularly aligned 2-D TN structures. Therefore, we can convert the investigation of instability of these 4-D TN displays into that of 2-D TN displays (DDTN and C-TN). In the DDTN configuration, the cell has "opposite rubbing direction arrangement" (the handedness of the chiral dopant is opposite to the handedness of the rubbing arrangements)[3] and both subpixels are in the splayed TN state. In C-TN configuration, one subpixel is in the twisted state while the other is in the splayed TN state. These splayed TN states are stabilized by the chiral additive in LC at zero field. However, the experiments have shown that this desired splayed twisted TN state is not stable when a voltage is applied and it prefers to convert into reversed twisted state (see Fig.3). We evaluate the stability by calculating the Gibbs free energy of splayed and reversed twisted TN states using a numerical relaxation technique[11].

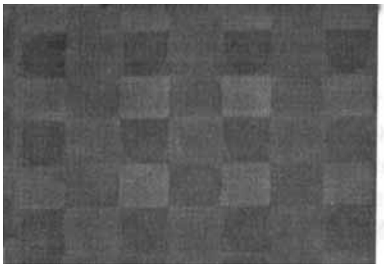

Fig.2 The orthoscopic photomicrograph of KSU-I 4-D display made by reverse rubbing at the at the full off state.

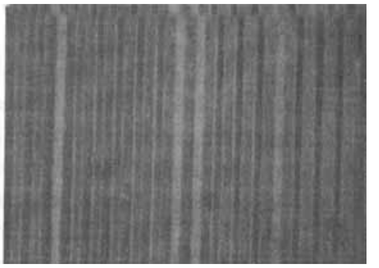

Fig.3 Picture of a complementary 2-domain TN display at full on state(5V). The bright region is the reverse twisted domain due to the polarizers arrangement.

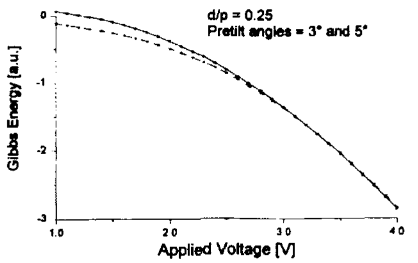

Fig.4(a) The Gibbs free energy of splayed TN(dash) and TN states versus voltage.

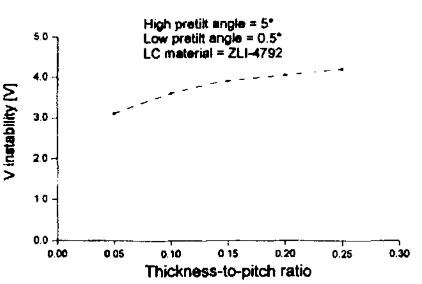

Fig.4(b) The instability voltage versus the concentration of chiral dopant.

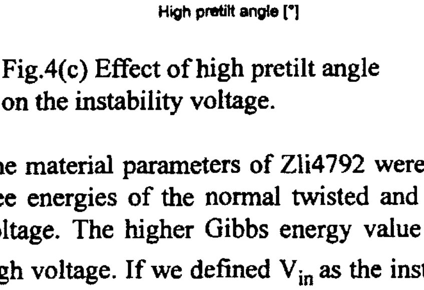

Fig.4(c) Effect of high pretilt angle on the instability voltage.

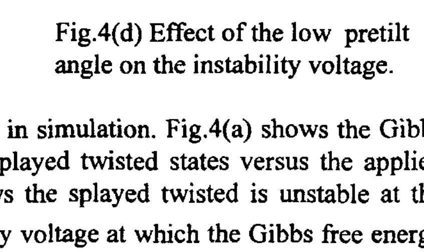

Fig.4(d) Effect of the low pretilt angle on the instability voltage.

The material parameters of Zli4792 were used in simulation. Fig.4(a) shows the Gibbs free energies of the normal twisted and the splayed twisted states versus the applied voltage. The higher Gibbs energy value shows the splayed twisted is unstable at the high voltage. If we defined V_{in} as the instability voltage at which the Gibbs free energy is same for both states, the relationship between V_{in} and the pretilt angle as well as LC pitch, are calculated and shown in Figs.4(b), (c) and (d). These results indicate that the high pretilt angle almost have no effect on V_{in}. The stability of the splayed twisted state is dominated by the low pretilt angle. V_{in} also increases slightly with increasing chiral dopant concentration.

RESULTS AND DISCUSSIONS

From Eqn.[4], it is clear that the stability of KSU-I 4-D TN configuration is truly determined by the pretilt angle of alignment layers. For L/d~20 (d=50μm and L=100μm), it predicts that the required pretilt angle t_{min} to stabilize the structure is about 22°. This simple model seems to be consistent with our experimental results. A stable KSU-I 4-D TN structure at zero field was obtained with t~25° using 85° oblique SiO_X evaporation. A applied voltage of 1.6V is required to hold this 4-D structure when NLC Zli4792 is used (pretilt of 4.5° with polyimide PI7311). This voltage can be reduced to 1V if NLC E7 is used (pretilt of 6.5° with the same polyimide). In order to verify the geometry factor in Eqn[4], we made some wedge cells where the alignment was obtained using two step SiOx evaporation[6]. The cell gap varies from zero to 50μm. After LC was injected into cell, there was a clear boundary that separated the stable and unstable 4-D structure region on the 4-D structure region. It was found that the critical cell thickness is round 12μm for KSU-I 4-D structure having subpixel size 75μm, while the critical cell gap increases up to 25μm if the subpixel size is changed to 200μm. In spite of the ratio of the critical cell gap to pixel size not exactly equal in two cases, the tendency matches with the expectation of Eqn.(4). Although our model does give us the important information on how to get a stable KSU-I 4-D TN display and seems to work pretty well, our model is very crude and the elastic distortions in the vicinity of the disclinations are ignored.

Our simulation results show that the stability of splayed TN configuration is dominated by the low pretilt angle. This agrees with the other people's work[12]. This can be understood by looking at an extreme case of zero low pretilt angle. In this case, the right and left handed twisted states are degenerated without chiral dopant and the instability voltage is infinite. Because of the importance of the low pretilt angle, we conclude that the KSU-III 4-D TN configuration is not suitable for the manufacture. It is obvious that the different subpixels in the KSU-III 4-D TN configuration are out of balance in stability. The increase of the chiral dopant concentration will slightly increase the instability voltage of splayed TN configuration. However, people have found that the trade off is the reduction of display contrast[13].

The experimental results agree with our simulation rather well. The complementary two domain TN cells with the various pretilt angle values for the low pretilt angle substrate were constructed. The high pretilt angle substrate was made by the reverse buffing technique on Nissan PI7311. 4.5° was obtained with LC ZLI-4792. Dupont PI2555 was used for the low pretilt angle plates. The pretilt angles were 4.5°, 1.9°, 1.5° and 0.3°, respectively, after post air baking at 200° C for zero, 20min, 40min and 60min. The instability voltages of these complementary two domain TN cells with d/p=0.25 are 4.2, 5.2, 6.3 and 8 V. The tendency matches with our simulation results.

When we discuss the stability of splayed TN state, the contributions from the reverse tilt wall and reverse disclination lines are neglected due to their complexity.

A polymer network has been successfully used to prevent the instability of the KSU-I at zero field[14]. The NLC mixed with one to two percents monomer was injected into the KSU-I 4-D TN cells and exposed to UV light with 5-10V applied. The formed polymer network effectively locked the 4-D structure at zero field. For the KSU-II and IV 4-D configurations, the instability should not be a problem for the practical application with low pretilt angle of less than 0.5^0.

CONCLUSIONS

The domain stability of the currently existed 4-D TN configurations have been investigated. The KSU-I 4-D TN configuration needs a high pretilt angle to hold its structure at zero field. The splayed twisted state is intrinsically unstable if a high voltage is applied. In order to increase the instability voltage for the splayed TN state, a alignment layer with sufficient small pretilt angle is required for the low pretilt regions in KSU-II and KUS-IV 4-D configurations. The KSU-III 4-D configuration is not suitable for the practical application due to unbalance of stability in different subpixels. The critical conditions for the domain stability have been evaluated using our simple model and calculated Gibbs free energy. The consequences of the model have been tested by experiments. This work is financially supported by Samsung Electronics Co., Ltd. Kyungki-Do, South Korea.

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