Liquid Crystal Alignment Layer With Controllable Anchoring Energies

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Abstract—We demonstrate a liquid crystal alignment layer with controllable polar and azimuthal anchoring energies. This alignment layer is based on a nanostructured surface formed by mixing a conventional polyimide and a nonaligning polymer. By using this variable anchoring alignment layer, large cell gap bistable twisted nematic LCD requiring asymmetric anchoring can be fabricated.

Index Terms—Alignment layer, anchoring energy.

I. INTRODUCTION

POLYIMIDE alignment layers are used to provide the surface boundary conditions for the liquid crystal molecules and are an important part of a liquid crystal display (LCD). Anchoring energy is an important measure of how strong the alignment layer interacts with the liquid crystal molecules. If the anchoring energy is large, then it is difficult to deviate from the initial conditions of alignment and the alignment angles are given by the easy axes directions. Most alignment layers are made of polyimides (PI). Polyimide is well known for its ability to align liquid crystal molecules by mechanical rubbing. A rubbed polyimide layer can induce an alignment direction and a pretilt angle in the order of 0–5 deg. The anchoring energy of the polyimide is determined by the chemistry of the polyimide material and is generally in the range of 10^{-4} to 10^{-3} J/m². Different methods of measuring the azimuthal [1], [2] and polar anchoring energy have been reported previously [3]–[5].

In this paper, an alignment layer with a controllable anchoring energy is proposed and demonstrated. It is based on a nanostructured surface consisting of a mixture of conventional polyimide and another polymer that has weak or no anchoring power. Precisely controlled anchoring energy is achieved. The basic principle is similar to a recent investigation of mixing vertical and homogeneous polyimides to achieve controllable pretilt angles from 0 to 90 deg [6], [7]. In both cases, the nano-domains are achieved by controlled phase separation in a special solution of two types of materials. Variable anchoring energy alignment layer is important for LCD fabrication especially for bistable displays that needs asymmetric anchoring [8].

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Fig. 1. An example of nanostructured surface variable anchoring alignment layer. (a) Mixture of PI and PVP. (b) mixture of PI and PMMA

II. METHODOLOGY

To prepare the nanostructured surface, a liquid mixture of polyimide and another polymer in a solution form is first obtained. For the nonaligning polymer, we have tried both polyvinylpyrrolidone (PVP) or polymethyl methacrylate (PMMA) successfully. PVP has no anchoring properties while PMMA provides a weak alignment. By controlling the condition of the coating and the baking process, a nanostructured surface is formed. Fig. 1 shows one of the examples of such a surface. Due to the immiscibility of the two materials, two types of domains are formed upon drying and baking. As the domains are very small (<100 nm), there is no visual defect to the LC cell. The entire surface behaves as a homogenous alignment layer, as in the case of the mixed polyimides. Experimentally, the process is very repeatable and reliable.

The nanostructured surface is rubbed in the usual manner to achieve alignment. It is obvious that depending on the ratio of the two types of domains, the anchoring energy can range from

Fig. 2. Retardation $R(V - V_o)$ vs $V - V_o$ for the measurement of polar anchoring energies. The solid line represents the best fit of the $R(V - V_o)$ versus $V - V_o$ from 5 to 20 V.

Fig. 3. Dependence of polar anchoring energy as a function of the concentration of PI.

that of the PI (strong) to that of the polymer (no anchoring). Thus by controlling the ratio of the polymer to the polyimide in this composite alignment layer, we can control its anchoring energy. We have tried many combinations of commercially available polymers in our experiment. The results reported here were obtained with polyimide JALS-9203-R2 from Japan Synthetic Rubber Company. For the weak or nonaligning polymer, PMMA and PVP were used. Actually PMMA has some anchoring properties. It has been shown that PMMA can provide some anchoring, though it is rather weak [9], [10].

Electric field techniques are used to measure the polar anchoring energies [11]. This technique is based on the measurement of retardation versus applied voltage. Fig. 2 shows the retardation $R(V - V_o)$ versus $V - V_o$ of an 18 μm ECB cell with pretilt angle 3° . The alignment of this sample is made by mixing 50% PVP and 50% PI. The sample cells are filled with LC 5700-000 from Merck. For azimuthal anchoring energies, a 90° twist cell is made to measure the actual twist angle of the cell.

Fig. 4. Dependence of azimuthal anchoring energy as a function of the concentration of PI.

Fig. 5. π -BTN cells at bistable states with: (a) 2.5 μm cell gap and (b) 5 μm cell gap.

Polar anchoring energy W can be obtained by using the slope $= 2k_1/Wd$ in Fig. 2 [11]. K_1 is the splay elastic constant of LC and d is the cell gap of the sample cell.

Azimuthal anchoring energy can be calculated by using the following formula:

$$W_{azi} = \frac{2\phi K_2}{d \sin\left(\frac{\pi}{2} - \phi\right)} \quad (1)$$

where ϕ is the measured twist angle of the sample cell, K_2 is the twist elastic constant of LC, d is the measured cell gap.

Figs. 3 and 4 show the dependence of polar and azimuthal anchoring energies as a function of concentration of PI, respectively. If there is no PI, the alignment layer consists only of the polymer. For the case of PMMA, it can be seen that even the pure polymer has reasonable anchoring energies. In fact, the polar anchoring energy is only 40% lower than pure PI, while

TABLE I
SPECIFICATIONS OF THE π -BTN LCD

Parameter	Value I	Value II	Units
Twist angle	22.5°, 202.5°	112.5°, 292.5°	degrees
Polarizer angle	45°	45°	degrees
Analyzer angle	67.5°	-22.5°	degrees
Cell gap – birefringence product	0.546	1.045	μm
d/P ratio	0.3125	0.5625	

the azimuthal anchoring energy is about 9 times lower. However, for the case of PVP, the pure polymer provides no anchoring at all. These results are as expected. For the case of 100% PI, the anchoring energies are also in agreement with published results. The most interesting result is the continuous change of anchoring energies between these two limits. Essentially all intermediate values can be obtained if the ratio of the polymer to PI is adjusted properly.

III. APPLICATION: BISTABLE LCD

Thus anchoring energies can be adjusted using this technique of nanostructured alignment surface. There are many applications of such surfaces. As an example, we studied the case of bistable twisted nematic LCD or π -BTN. For this π -BTN to switch between the bistable 0 and π -twist states, asymmetric anchoring is needed. Basically the alignment layers on the two sides of the liquid crystal cell needs to have different anchoring energies to achieve anchoring breaking. It has been shown that for reliable switching, the difference in polar anchoring energy should be at least a factor of two when a dual frequency liquid crystal is used [12]. If the difference in polar anchoring energy increases, the switching voltage of such bistable devices will decrease. Therefore, large cell gap bistable TN devices can be made with low switching voltage when a weak anchoring nanostructured alignment layer is used.

Asymmetric anchoring is an important feature and has to be carefully designed in order to allow our bistable device to work properly. There are several methods of obtaining such asymmetric anchoring for the liquid crystal cell. The simplest method is making good use of ordinary polyimides and mixed PI/polymer. Two π -BTN LCD samples were made with pure PI on one side and mixed PI/polymer on the other side. For reliable switching, the difference in anchoring energy should be at least a factor of two. Fig. 5 shows the samples at the two bistable states for 2.5 μm and 5 μm cell gap respectively. The 5 μm π -BTN can be switched with a low voltage when a 50% PVP + 50% polyimide alignment layer is used. It is confirmed that the samples are truly bistable with almost infinite lifetimes. The contrast between the 0 and π -twist states depends on the cell gap and the birefringence of the LC material. It can be optimized to give the best contrast and transmission efficiency [13]–[15].

Actually, it is somewhat surprising that the present alignment layer works for the π -BTN. In order to switch a π -BTN, anchoring breaking is needed on the weak alignment side. For the composite weak alignment layer being used, the individual nano-domains are actually either strong anchoring or no anchoring. Thus our positive results indicate that anchoring

breaking of the strong anchoring domains can be induced by anchoring breaking in the non-aligning domains. This is probably the result of overall elastic energy minimization. Further theoretical work is necessary to fully understand this phenomena.

The rubbing directions of the top and bottom alignment layers determine the twist angle of the liquid crystal layer. The twist angle and retardation of the liquid crystal cell can be calculated in order to obtain bistability. In our study, we use the values listed in Table I. The d/P ratio is used to control the bistability of the liquid crystal layer. This ratio has to be within the range of 0.3–0.4 and 0.5–0.6 for a 2.5 μm and 5 μm π -BTN, respectively, in order for bistability to occur for the π -BTN display.

IV. CONCLUSION

In summary, we have demonstrated a new nanostructured alignment layer which can provide controllable anchoring energies. Such an alignment layer is important to the fabrication of many devices such as the bistable TN LCD. Bistable switching can be obtained at large cell gap when a weak anchoring alignment layer is used.

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