P-12: Continuous Pretilt Angle Control of LC Alignment

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Abstract: We proposed two methods for controlling the pretilt angles in full range with wide process margin. The pretilt angles of liquid crystals are produced by anchoring competition between planar and vertical polyimides with respect to liquid crystals and controlled by tuning the thickness of vertical alignment layer in stacked two polyimide layers and of heterogeneous polyimide layer which is mixed with planar and vertical polyimides.

Keywords: Pretilt angle, LC alignment, surface anchoring

Introduction

Uniform alignment of liquid crystals (LCs) on an oriented solid surface is a crucial issue for liquid crystal display (LCD) with high image quality. Various techniques to align LC to a desirable direction in in-plane have been introduced to obtain a sufficient LC alignment [1-4]. By the way, relatively few experimental attempts to control out-of-plane LC orientation, so-called LC pretilt angle have been reported even though out-of-plane LC alignment as well as in-plane the orientation of LC is very important since it has seriously influence on electro-optical characteristics of LCD.

The pretilt angle of LC alignment is the one of the major factors in improving characteristics of LCD. Most LCDs are based on either planar alignment or vertical alignment of the LC director by using alignment materials. With the materials, we can easily obtain the low degree of pretilt angle (i.e. 0°-10° or 80°-90°) using rubbing or UV exposure techniques. However, the intermediate pretilt angle region (i.e. 10°-80°) is still under a challenge. If we can easily get the intermediate pretilt angles, various applications are possible and it also can be applied to the conventional LCD mode to improving electro-optic characteristics.

Several approaches have been developed to produce intermediate pretilt angles such as oblique deposition of SiOx [2], mixture of vertical and planar polyimides [5,6], microtextured formation by atomic force microscopic local oxidation [7], ion beam exposure of silicon carbide film, and fluorinated amorphous carbon film [8]. However such approaches have some problems such as stability, reproducibility, adapting to large size LCDs, high cost for manufacturing process and so on.

In this article, we propose new two alignment methods which can control the pretilt angles form 0° to 90° using the anchoring competition effect between planar and vertical alignment layers with respect to LCs.

Principle and Experimental result

The anchoring competition is controlled by the vertical alignment layer which is coated on planar alignment layer. The upper LC alignment layer has influence directly on LC. On the other hand, the polar anchoring energy of LC induced from the lower alignment layer is screened partially or entirely depending on the thickness of upper alignment layer. If the LC anchoring energy of the lower alignment layer is much larger than it of the upper alignment layer, the vertical anchoring competition occurs and the pretilt angle could be controlled continuously by tuning the thickness of upper layer in partially screened region. For tuning the thickness of upper alignment layer, we diluted the polyimide materials with the solvent which consists of mixture of n-methyl-pyrroidone, butyroactone and butoxyethanol according to each thickness condition. Figure 1 shows the result of pretilt angles with the various thickness of vertical alignment layer. As a result, we could get the pretilt angles over whole range (0°-90°). The proposed technique has very simple process to apply large size of LCDs as well as good thermal stability.

In general, the pretilt angle is measured by capacitance method, magnetic null method, and the crystal rotation method. The capacitance method determines the pretilt of LC from the capacitance of an LC panel using the dielectric constant of LC that is a function of the pretilt. This method has a simple measuring system but the cell thickness and the area of electrode must be known in advance and uniform to reduce measurement errors. The magnetic null method finds the pretilt, using a characteristic, in which the capacitance of LC cell does not depend on the magnitude of magnetic field when the long axis of LC is coincident with the direction of magnetic field. However, it requires large size electromagnet and long time for measuring. The crystal rotation method is most widely since it is very simple and easy in measuring system and has short time for measuring. However, this method is difficult to measure the intermediate pretilt angle because the measuring range of pretilt is narrow due to the limitation of the refraction angle at LC layer. It also needs very thick LC cell thickness to avoid ambiguous optically symmetric point in transmittance curve. In addition, in the case of the intermediate pretilt angle, the determination of a symmetrical center in the transmittance curve is difficult due to large Fresnel reflection on glass surface in region of high incident angle of light.

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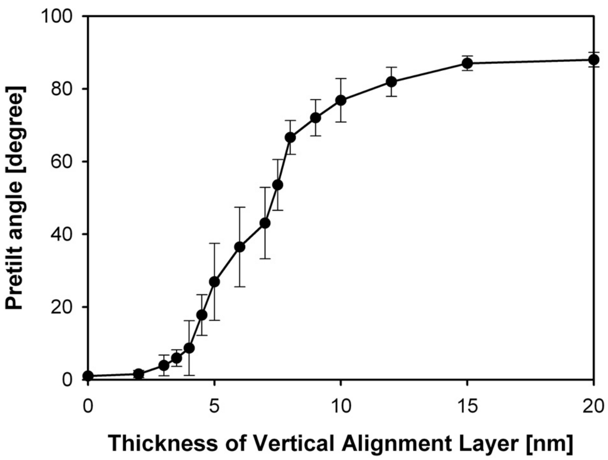

Fig. 1 Pretilt angles depending on the thickness of vertical alignment layer

Therefore, to obtain more exact value of LC pretilt generated in each experimental condition, we adopted the polarizer rotation method [9]. It rotates two polarizers with fixing the LC cell to arbitrary orientation as shown in Fig. 2 unlike the crystal rotation method rotating LC cell. This method is also very convenience and can measure the pretilt angle in full range from 0 to 90°. Furthermore, the accuracy of measurement is hight when high quality optical components, for example Glan-Thomson polarizer, and a PM tube detector are used.

In Fig. 2, the α is pretilt angle of LC in cell, the θ is a tilted angle of LC cell from x-y plane, and the ϕ_P and ϕ_A are the angles between x-direction and optic axes of polarizer and analyzer, respectively. The LC cell with horizontal LC alignment layer is positioned between the polarizer and analyzer. The rubbing direction of LC cell is set to x direction and the LC cell is tilted at an arbitrary angle θ from the x-y plan. In this case, the minimum transmittance is not obtained in crossed polarizer. Because of the pretilt angle α and tilt angle of LC cell θ, the minimum transmittance is not obtained in crossed polarizer. To obtain the minimum transmittance, we rotate optic axes of two polarizers and find the combination of them corresponding to pretilt angle through the minimum transmittance. The combination of ϕ_P and ϕ_A, determining a pretilt angle, in which transmittance becomes minimum is given by the following formula.

$$\tan\phi_P \tan\alpha = f_1(\theta, n_g, n_o, n_e) \qquad (1)$$

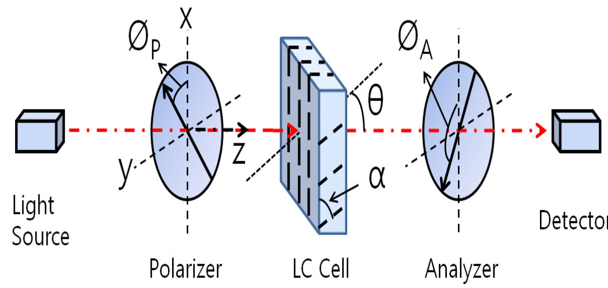

Fig. 2. Schemetic diagram of polarizer rotation method used pretilt angle measurement of this study.

where

$$f_1 = \frac{n_g \cos\theta + n_g^{-1}\sqrt{n_g^2 - \sin^2\theta}}{\cos\theta + \sqrt{n_g^2 - \sin^2\theta}} \cdot A$$

with

$$A = \frac{n_g\sqrt{n_o^2 - \sin^2\theta} + n_g^{-1} n_o^2 \sqrt{n_g^2 - \sin^2\theta}}{(\sqrt{n_o^2 - \sin^2\theta} + \sqrt{n_g^2 - \sin^2\theta})\sin\theta} .$$

In another formula,

$$\tan\phi_A = f_2(\alpha, \theta, n_g, n_o, n_e) \cdot \tan\alpha \qquad (2)$$

where

$$f_2 = -\frac{n_g \cos\theta + n_g^{-1}\sqrt{n_g^2 - \sin^2\theta}}{\cos\theta + \sqrt{n_g^2 - \sin^2\theta}} \cdot B$$

with

$$B = \frac{(n_g\sqrt{n_e'^2 - \sin^2\theta} + n_g^{-1} n_o^2 \sqrt{n_g^2 - \sin^2\theta})\sin\theta}{n_0^2(\sqrt{n_e'^2 - \sin^2\theta} + \sqrt{n_g^2 - \sin^2\theta})}$$

with

$$n_e'^2 = \sqrt{\frac{n_e^2 n_o^2 + (n_e^2 - n_o^2)\sin^2\alpha \sin^2\theta}{n_e^2 \sin^2\alpha + n_o^2 \cos^2\alpha}} .$$

Where n_g, n_o, and n_e are the refractive indices of glass, the ordinary and extraordinary refractive indices of LC, respectively. By rotating polarizer and analyzer, we can find the ϕ_P and ϕ_A corresponding to minimum transmittance. Then, from eqs. (1) and (2), we can determine the pretilt angle of LC cell. Consequently, the full range pretilt angle is measured by using the polarizer rotation method.

The previous pretilt production method, in spite of many merits, has low process margin to be applied to mass production. So, we propose another method to control the pretilt angle continuously with wide process margin. We use the mixture of homogeneous and homeotropic polyimides with several kinds of solvents. Contrary to the conventional method by nanostructured surfaces [2, 3], we control the pretilt angle by varying the thickness of the mixed PI layer. During hard baking process of polyimide, the separation process of the polyimides is occurred and the vertical polyimide is imidized with distributing randomly on the alignment layer. In our case, by controlling amount of solvent, we control the thickness of the polyimide alignment layer. So as to avoid perfectly the top-bottom-separation of two polyimides, ideally, if we control the thickness of it in the level of monolayer, the polyimide mixture will form a single layer without the separation of two polyimides and is distributed in the single layer. Consequently, by the horizontal anchoring competition between planar and vertical polyimides with LCs, the pretilt angle is determined. Therefore, we can control continuously the pretilt angle in the full range of 0°-90° by controlling the mixing ratio of the mixture. Moreover, the pretilt production by the horizontal anchoring competition has high process margin due to direct interactions with LCs of two components in the mixture unlike the vertical anchoring competition sensitive to the thickness variation, using the screen effect of non-retarded van der Waals force.

In the second method, we used the ØOIM23 (JSR, Japan) for homeotropic polyimide and the ROIM23 (JSR, Japan) for homogeneous polyimide. To improve the characteristic of mixing, spin-coating, and alignment, several solvents were added to the mixed polyimide. To modulate the thickness of the coated polyimide mixture, we controlled the content of solvents.

The mixed polyimide including solvents is spin coated on indium-thin-oxide (ITO) glass by two steps. The first step is 1000 rpm for 10s and second step is 3000 rpm for 20s. To remove the solvents, the substrate is pre-baked at 80°C for 10 minutes. Subsequently the substrate is hard-baked at 180°C for 1 hour for polymerization of imides. Two substrates are rubbed anti-parallel by rubbing machine with velvet. The cell thickness of fabricated sandwich cells was 3 um in all cases and maintained by glass space. The nematic LC of ZKC-5085XX (Δn=0.15, Chisso Ltd.) is injected to the cell.

Figure 3 shows that the pretilt angles are corresponded to a concentration of the vertical polyimide in the mixture of the planar and vertical polyimides.

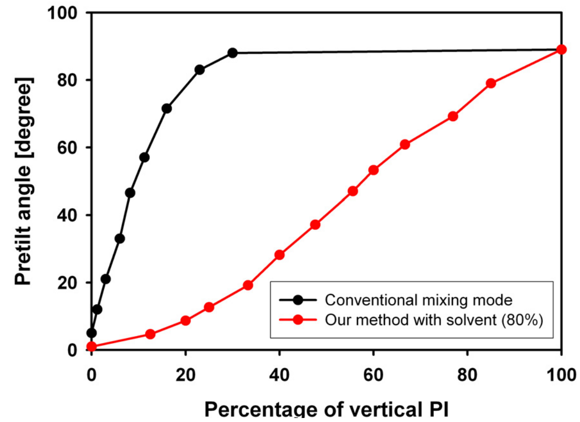

Fig. 3 Pretilt angles corresponding to concentrations of homeotropic polyimide

As increasing the mixing ratio of solvent, the thickness of the polyimide mixture is decreasing. The thickness of polyimide layer is about 20 nm at the concentration of solvent of 80%. Actually, the thickness range of 15~20 nm is thin enough to reduce drastically the layer separation. So, the changing rate of pretilt angle becomes gradual, which means that wide process margin could be gotten. In this LC pretilt production method, the polarizer rotation method was used to measure pretilt angle of LC too.

Conclusion

We proposed the two methods for controlling the pretilt angles in the full range. The pretilt angles are produced by anchoring competition between planar and vertical polyimides with respect to LCs and controlled by tuning the thickness of vertical alignment layer in stacked two polyimide layers and by tuning the concentration ratio of vertical polyimide in heterogeneous polyimide layer which is mixed with planar and vertical polyimides. Our methods have very simple process and good thermal stability. In addition, they do not require any modification of polyimide materials and conventional processes. We expect that it can be used to various LCD applications.

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