Homeotropic liquid crystal cell without vertical alignment layers

Shie-Chang Jeng, Hsing-Lung Wang, Chia-Wei Kuo, Yan-Rung Lin and Chi-Chang Liao
Electronic and Optoelectronics Research Laboratories, Industrial Technology Research Institute
e-mail: scjeng@itri.org.tw

Abstract

This paper reports our observation that the addition of nanoparticles in the negative dielectric anisotropic liquid crystal (LC) cell can exhibit the properties of vertical alignment without using alignment layers. The electro-optical properties of this nanoparticles-induced vertical alignment in the LC cell are very similar to the conventional homeotropic LC cell with alignment layers. This technique can be used to fabricate a flexible LC display demanding low temperature process

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1. Introduction

Nanoparticles-doped liquid crystal (LC) has been widely investigated recently. This non-synthetic method to modify LC by adding nanoparticles in the LC is much easier than the conventional chemical synthetic methods, and it has expended the application of LC. Researchers have found that the LC-nanoparticles mixtures exhibit new EO properties, such as memory effect,[1,2] frequency modulation response,[3] fast response,[4,5] low driving voltage,[4,5] and reduced residual dc.[4-7] Recently, Sharp proposed a high performance LC cell by adding ~ 5% fullerenes in negative dielectric anisotropic LC without using alignment layers.[8] A LC display with a high contrast ratio of ~300 was obtained. In their invention, the LC molecules were vertically aligned on the fullerene surface and the LC layer was optically isotropic when the applied voltage was lower than the threshold voltage, and the arrangement of LC molecules was changed when the applied voltage was higher than the threshold voltage. Therefore, such LC device exhibited perfect dark state under crossed polarizers when the applied voltage was lower than the threshold voltage. This invention attracted our attention due to the reduction of required alignment layers in a conventional LC device. The LC structure without using alignment layers is especially suitable for the production of flexible plastic LC displays demanding low temperature process.[9] The typical post-curing temperature of a commercial-grade alignment layer, such as polyimide, is around 200℃ which is too high for a process using conventional plastic substrates.

Nanoparticles of polyhedral oligomeric silsesquioxanes (POSS) developed by Hybrid Plastics were chosen due to their better solubility than fullerenes in LC and possible vertical alignment of LC on their functional group. The diameter of the POSS molecules is in the range 0.7-30 Å, and the typical structure of POSS molecules is shown in Fig. 1[10], where R is the functional group. After adding POSS in LC, we found that the POSS in LC cell induced the properties of vertical alignment instead of isotropic alignment as Sharp's concept. This POSS-induced spontaneous vertical alignment in LC cell were both observed in the positive dielectric anisotropic LC (E7,$\Delta\varepsilon$= 3.1, Merck) and in the negative dielectric anisotropic LC (MLC6882,$\Delta\varepsilon$= −3.1, Merck). By using the property of POSS-induced spontaneous vertical alignment, we have fabricated an alignmentless homeotropic LC cell.

2. Experimental

The alignmentless homeotropic LC cell was fabricated by using two indium-tin oxide (ITO) glass substrates with a gap of ~6.3 μm maintained by photospacers. Few weight percent of POSS nanoparticles were dispersed in acetone solvent and LC by ultrasonic cleaner for few minutes. The LC/POSS mixture was drop-filling on the ITO glass substrate after evaporating the solvent, and the LC cell was assembled by pressure thereafter. An example of POSS-induced vertical alignment in LC cell with a uniform display area of ~16 cm^2 observed under crossed polarizers is shown in Fig. 2. The LC molecules were vertically aligned on the ITO substrate when the applied voltage was less than a threshold voltage, and they underwent optical transition when the applied voltage was higher than a threshold voltage. The POSS-induced vertical alignment exits in the LC cell as long as the concentration of POSS in LC is bigger than 3 wt % in this work. However, this concentration depends on the LC materials.

3. Results and discussion

The voltage-dependent optical transmission of the 4 wt % POSS-filled homeotropic LC cell between crossed polarizers measured by a 633nm He-Ne laser is shown in Fig. 3, where the pretilt angle is measured as 88.5° by Autronics TBA 107. Here, 100 % stands for the transmission of parallel polarizers without the cell. The applied voltage is 60Hz square wave. The results indicate the threshold voltage is around 2.1 V similar with a conventional homeotropic LC cell using the same material of MLC 6882.[12] The constant threshold voltage implies that the addition of few weight percent dopant does not significantly affect physical parameters of the LC layer such as dielectric anisotropic, elastic constant K_{33} or the ratio of $K_{33}/\Delta\varepsilon$, since the threshold voltage is proportional to $\pi(K_{33}/\varepsilon_0\Delta\varepsilon)^{1/2}$ in the homeotropic LC cell[14].

The switching properties of LC cell by applying 60 Hz square wave in the voltage range of 2.4 V to 4.0 V are shown in Fig. 4, where the applied voltage is turned on and off at T=0.1 sec and T= 1.1 sec, respectively. The rise time decreases as the applied voltage increases and the decay time does not significantly dependent on the applied voltage. Such switching dynamics are very similar to a conventional homeotropic LC cell, where T_{rise} and T_{decay} are given by[11]

$$T_{rise} = \frac{\eta d^2}{\pi^2 K_{33}}\left(\frac{|\Delta\varepsilon|}{\pi^2 K_{33}}V^2 - 1\right)^{-1} \quad (1)$$

$$T_{decay} = \frac{\eta d^2}{\pi^2 K_{33}}, \quad (2)$$

where η and d are viscosity and cell gap, respectively. However, the T_{rise} and T_{decay} of POSS-induced homeotropic LC cell are slower than a conventional one. For example, the T_{rise} and T_{decay} by 3.2 V are 93 ms and 32 ms respectively which are about 1.5 times slower than the conventional homeotropic LC cell with the same cell gap.[12]

It had been observed that the surfaces of substrates, such as glass, oxides and metals, exhibited the vertical aligning ability on liquid crystal while certain cleaning processes employed in the substrates.[13] However, the reproducibility and uniformity of this type of homeotropic alignment was poor to provide a reliable LC device. Spontaneous vertical alignment by adding polyamide resin has also been reported.[14] The authors speculated that the surfactant properties of the resin molecules helped to foster an alignment in which the elongated axis was normal to the substrate. The roles of the polyamide additive in Haas's work[14] and POSS in this work are still not clear. Whether the spontaneous vertical alignment is induced by the absorption of dissolved materials on the substrates or by the bulk effect of dissolved materials in LC layer needs further investigation. Nevertheless, the reduction of alignment layers in a LC cell can not only reduce the process of current manufacture but also is very adequate for manufacturing a flexible LC display demanding low temperature process.

4. References

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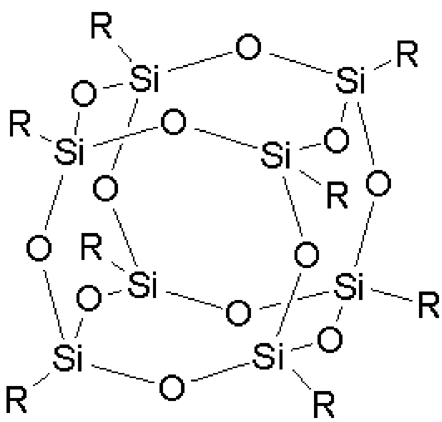
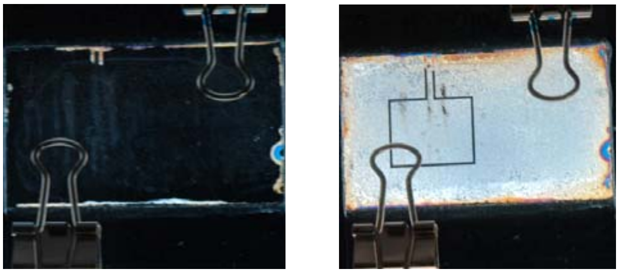


Fig. 1. Representation of a POSS.[10]



V < Vth

V > Vth

Fig. 2. An alignment-less homeotropic LC observed under crossed polarizers.

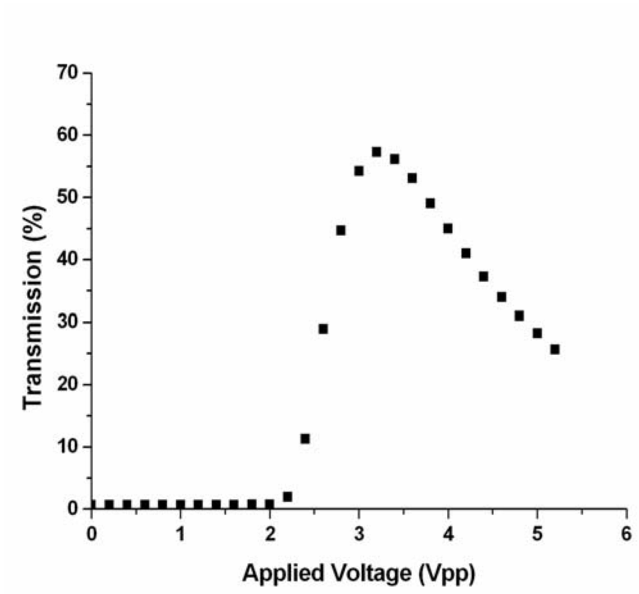


Fig. 3. Voltage dependent transmission curve of POSS-filled alignment-less homeotropic LC.

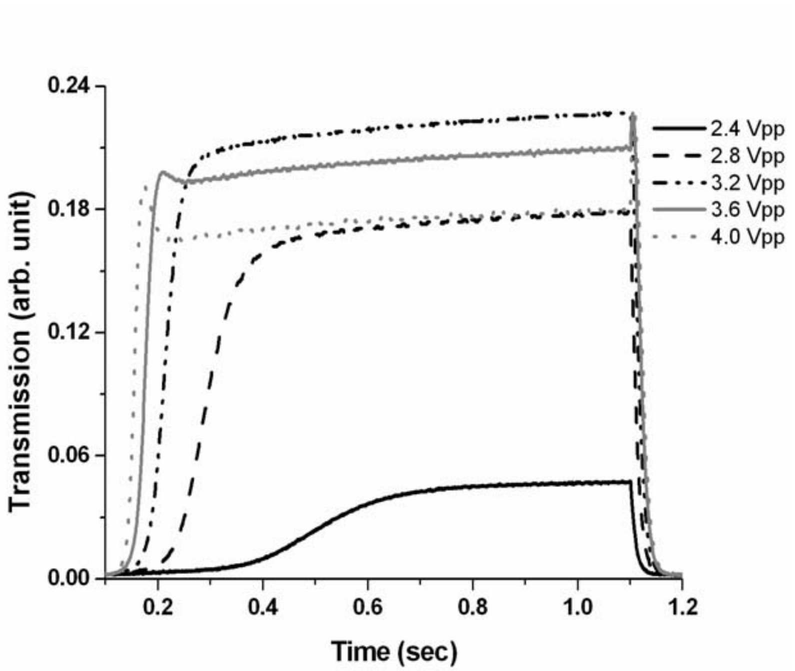


Fig. 4. Optical transmission upon electrical switching for different applied voltage, where switching times for voltage-on and voltage-off are set at 0.1 sec and 1.1 sec, respectively.