Flexible Display using Nano-encapsulated Liquid Crystal with Low Driving Voltage Characteristics

Hyunbae Park*, Minho Park, You-Jin Lee**, Chang-Jae Yu *,** and Jae-Hoon Kim *,****

***Department of Electronic Engineering, Hanyang University, Seoul 133-791, Korea**

**** Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea**

Abstract

We propose a flexible display using nano-encapsulated liquid crystal (LC) for in-plane switching mode. Because the size of the LC capsule is smaller than the wavelength of visible light, the LC layer shows optically isotropic characteristics for good display performance. And also, we suggested a bipolar driving method for low operating voltage.

Author Keywords

Flexible; Encapsulated LC; Optically Isotropic; Low Driving Voltage

1. Introduction

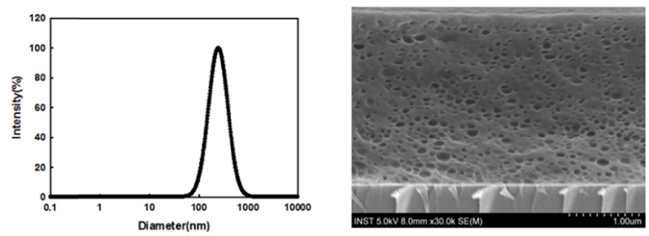
Nowadays the flexible display is one of the most attractive devices to several advantages such as flexibility, durability, and portability [1].The application range of flexible display is very wide from mobile applications to new-concept devices. Among technologies for fabricating the flexible display, the liquid crystal displays (LCDs) with plastic substrate are focused due to their various merits for example, full-color realization, well-established fabrication, higher contrast ratio, and good electro-optical characteristics [2–4]. One of the advantages of plastic LCD is that the cost effective roll-to-roll process can be adopted during fabrication. In order to achieve such merit, we should make a LC layer using coating process instead of filling in process.

Plastic LCD shows stable electro-optic characteristics under bending pressure because of the optical anisotropy of LC layer. Also LC molecules are protected by polymer layer. For these reasons many kinds of plastic LC modes have been studied, like polymer dispersed LC, polymer-network LC, and pixel-isolated LC, etc. [2, 5-6]. However, these modes could not be solutions for printing process nor solutions for stability under bending circumstance. And all these modes shows high driving voltage.

In this paper, we reported a flexible display using nano-encapsulated LC for in-plane switching (IPS) LC cell with low driving voltage. The droplets of LCs, which have a polymer shell, within nano-encapsulated LC layer have about 300 nm size, which is smaller than the visible light wavelength. Because the LC layer has optically isotropic properties, electro-optical characteristics could be stable under external pressure like bending. This mode is very suitable for flexible display, because nano-encapsulated LC layer can be formed by printing process and doesn't need alignment layer. Also due to very small size of the capsule the contact surface area between PVA and LC is enormously large which leads to very fast falling time. However, although there are many advantages alike other polymer LCDs driving voltage is high. So we suggest bipolar driving method to reduce the driving voltage of nano-encapsulated LCD.

2. Experimental

We used conventional coacervation method for LC nano-encapsulation [7]. We emulsified host nematic LC (HTW-106700, Jiansu Hecheng Display Technology Co.) into PVA (polyvinyl alcohol, Sigma-Aldrich) solution by membrane. After emulsifying process, we heated the emulsions up to cloud point, in order to phase separate PVA. After several hours of phase separation, PVA shell is cross linked with glutar aldehyde to reinforce the shell with good flexibility and durability. Without this step capsules are not strong enough to endure the external force.



(a) (b)

Figure 1 (a) Size distribution of nano-encapsulated LC (b) SEM image of coated encapsulated LC layer

The LC nanocapsule size was measured by dynamic light scattering method, which is effective way to measure size distribution of particles in submicron region. The measured size was about 200 ~ 300 nm, and the center peak was 245 nm, which is much smaller than the wavelength of the visible light. Figure 1(b) shows the cross sectional SEM image of nano-encapsulated LC layer by bar-coating process. The LC droplets are well distributed and the size was well matched with the results by dynamic light scattering measurement method.

Figure 2 Manufcaturing process of nano-encapsulated LC on flexible substrate

Figure 3 shows the manufacturing process of nano-encapsulated LCD on flexible substrate. The ITO electrode on a plastics substrate was patterned for IPS mode. The width of electrode and slit were 10 μm and 15 μm, respectively. Positive photo resist (PR, AG-GXR-601) was coated above ITO layer with spin coating method with 3000rpm for 20 seconds. After coating PR on the ITO layer, flexible substrate was heated at 100°C for 1min. To develop the PR layer UV light was exposed using shadow mask. UV was exposed for 13 seconds. Intensity of the UV light was $1mW/cm^2$. After exposing UV light PR was developed with the developer and ITO layer was etched with ITO etchant. PR residue was erased by acetone.

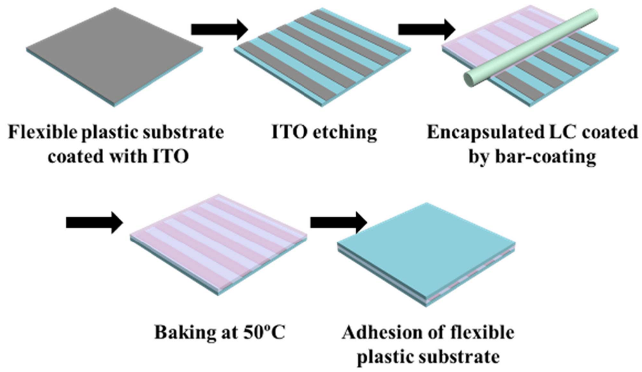


Figure 3 Manufcaturing process of nano-encapsulated LC on flexible substrate

We coated nano-encapsulated LC on the IPS patterned flexible display without using alignment layer because the LC molecules was covered by PVA. After coating encapsulated LC layer the substrate was heated at 50°C for 10 minutes. And then we covered a plastic substrate without electrode for conventional IPS structure.

3. Results

In their initial state without electric field, the director field of the LC molecules within capsules is bipolar axis because the polymer which encircled the LC droplets has planar alignment property. The nano-encapsulated LC layer shows optically isotropic property due to the small size of the capsule. So, the black and contrast ratio properties of the LC cell with crossed polarizers are excellent even though the plastic substrates are bent. When electric field is applied, the LC molecules within droplets aligns along the electric field direction, and the LC cell shows white state. Figure 3. Shows the voltage-transmittance characteristics of nano-encapsulated LC coated on flexible display. The red dots show the VT characteristics when the substrate is bended and the black dots show the VT characteristics while the substrate wasn't bended. As you can see there is no light leakage while the substrate was bent. But the maximum transmittance have been reduced while the substrate was bent.

However, the driving voltage of the cell is very high because LC molecules are surrounded by the polymer shell. To reduce the driving voltage, we used a bipolar driving method. For this, we prepared a LC cell with ITO plastic substrates as a common electrode, as shown in Figure 4. In experimental, the common electrode at the top substrate is set to a ground voltage (0V), and the interdigitated pixel electrodes have different polarities. Then, the effective electric field applied to LC layer is twice than normal driving method. In the normal driving method, polarity inversion driving method is used for dc-free property. For bipolar driving method, the polarity changed from nth frame to n+1th frame, as shown in Figure 4. So, voltage differences are same and driving voltages can be reduced.

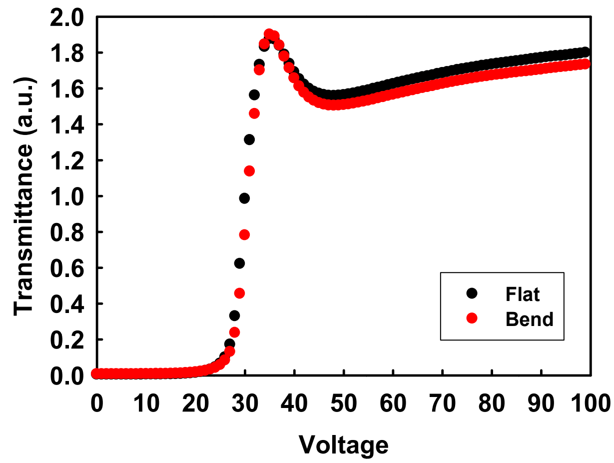


Figure 4. Voltage-transmittance characteristics of encapsulated LC on flexible display

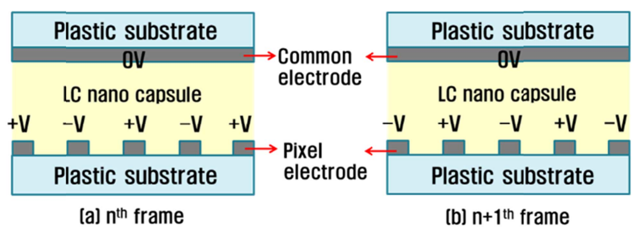


Figure 5. The schematic diagrams of bipolar driving method.

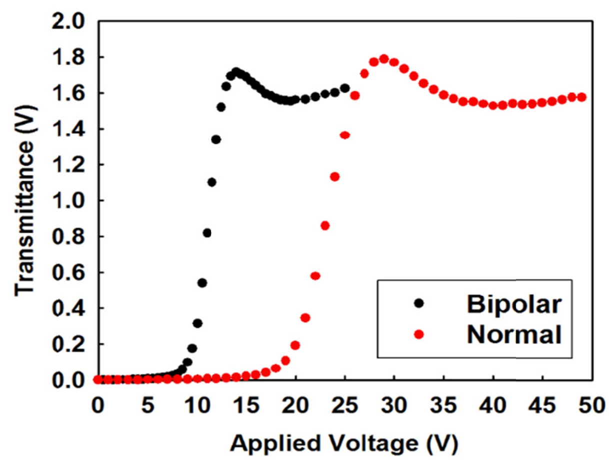


Figure 6. Voltage transmittance characteristics of encapsulated LC display by bipolar driving method and normal driving method

Figure 5 and 6 shows voltage-transmittance and voltage-response time characteristics respectively. The driving voltage was 30 V and 14 V for simple and bipolar driving method, respectively. The driving voltage was reduced about half. The response time when we use the bipolar driving method was 6.3 msec at 14 V, which is fast enough for moving pictures. Interesting thing is that flaling time of encapsulated LC mode is about 2ms. This is due to the hard anchoring energy of the capsule surface. The capsule structure increases the area of contact surface between PVA and LC. That means if the capsule size is reduced the anchoring energy will be enhanced achieving faster falling time. Also above 19V the total response time of the nano-encapsulated LC mode shows less than 3ms.

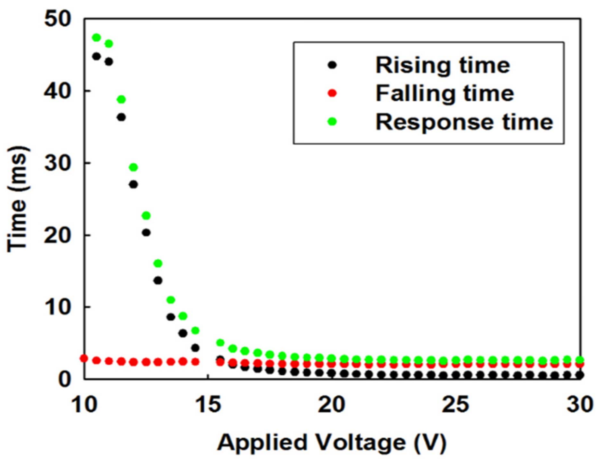


Figure 7. Voltage-response time characteristics of bipolar driving method

4. Conclusion

We proposed the flexible display using nano-encapsulated LC with high contrast ratio and low driving voltage. Since the size of the LC droplets are smaller than the wavelength of the incident visible light, the LC layer shows optically isotropic characteristics. Which is very useful for flexible display because it doesn't leak any light while the substrate is bent. Also due to small size of the capsule the area of the contact surface between PVA and LC increases and enhances anchoring energy, giving fast falling time. But still, driving voltage of nano-encapsulated LC mode is high due to PVA capsule. So, for the low driving voltage, we suggested the bipolar driving voltage method. By bipolar driving method we were able to achieve twice of the effect of applied voltage. Which means we were able to achieve 30V of voltage difference by applying 15V of voltage. As a result, we could reduce the operating voltage about 75% for a simple driving method for IPS LC mode.

5. Acknowledgement

This research was supported by a grant from the Fundamental R&D Program for Core Technology of Materials funded by the Ministry of Knowledge Economy (10049848), Republic of Korea, and Samsung Co., Ltd.

6. References

[1] G. P. Crawford, *"Flexible Flat Panel Displays"*, John Wiley and Sons: New York.

[2] S.-J. Jang, J.-W. Jung, H.-R. Kim, M. Y. Jin, and J.-H. Kim, Jpn. J. Appl. Phys. 44, 6670 (2005)

[3] J.- W. Jung, S.-K. Park, S. B. Kwon, and J. H. Kim, Jpn. J. Appl. Phys. 43, 4269 (2004)

[4] H. Sato, H. Fujikake, Y. Lino, M. Kawakita, and H. Kikuchi, Jpn. J. Appl. Phys. 42, 5302 (2002).

[5] J. L. Fergason, SID Symp. Dig. 16, 68 (1985).

[6] Q. Wang, J. O, Park, M. Srinivasaro, L. Qiu, and S. Kumar, Jpn. J. Appl. Phys. 44, 3115 (2005).

[7] S.-G. Kang, and J.-H. Kim, Opt. Exp. 21, 15719 (2013).