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Studies on the electro-optical properties of chiral nematic liquid crystal/aerosil particle composites

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Chiral nematic liquid crystal (N*-LC)/aerosil particle (AP) composites were prepared. After the composite was sandwiched between ITO glass substrates, the inner surfaces of which had been treated for homogeneous orientation of LC molecules, the LC molecules tended to be aligned with planar texture. Upon the application of an electric filed, a focal conic texture with memory effect was induced and the composite exhibited light scattering. An electric field-induced homeotropic state was obtained after the application of a high electric field. The effects of the content of the APs and the pitch length of the N*-LC on the transmittances of the initial state and the focal conic texture, the driven voltage and the memory effect were investigated.

1. Introduction

In a chiral nematic (N*) phase, the long axis of the liquid crystal (LC) molecules rotates about a helix. The pitch length, p, of the helix corresponds to a 2π molecular rotation [1]. When a N*-LC is sandwiched between ITO glass substrates, the inner surfaces of which have been treated for homogeneous orientation of the LC molecules, the LC is in the planar state at zero-field, in which the helical axis is perpendicular to the substrates. The N*-LC with a planar texture is transparent if the pitch length is much larger or smaller than the wavelength of visible light [2]. When an electric field is applied to a N*-LC with positive anisotropy, the N*-LC is changed into a polydomain focal conic state, in which the helical axes of the domains are more or less randomly oriented and the composite exhibits light scattering because of the abrupt change of the refractive indices at the domain boundaries. The planar texture is stable and the stability of the focal conic texture increases with decreasing pitch length at zero-field. If the pitch of the N*-LC is short enough, the energy barrier between the planar and focal conic textures is larger and both the textures are stable [3, 4]. In recent years, N*-LC devices with two stable states have been widely investigated [5, 6], resulting from the stabilities of the planar and the focal conic textures at zero-field. These devices are promising for use in e-books as well as other low-power or even no-power devices. Once displayed, the information is memorized for a long time, ranging from seconds up to months, depending on the application needs. However, when the pitch of a N*-LC is long enough (typically several μm), the energy barrier between the two textures is small and the focal conic texture becomes unstable. Then, the bistable effect disappears [4].

Nematic LC/aerosil particle (AP) composites have been studied extensively [7–10], and unique characteristics have been found [11, 12]. In such heterogeneous systems, the APs can give rise to a light scattering and to a memory effects due to the orientation defects generated by them, as well as the particular interaction between LC directors and their surfaces. However, the effects of APs on N*-LCs and the stability of their textures have been less reported.

In this study, N*-LC/AP composites were prepared and the effects of the pitch length and the content of the APs on the electro-optical properties of the composites investigated.

2. Experimental

2.1. *Materials*

The N*-LC was prepared by mixing a nematic LC, SLC-1717 (Slichem Liquid Crystal Material Co, Ltd), with a chiral dopant, CB-15 (Merck Co, Ltd). Both were used without any further purification. The pitch length, p, of the N*-LC cells is controlled by the content

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of CB15 [13]. In this experiment, the weight ratios of CB15/SLC1717 are 2.0/98.0, 4.0/96.0 and 6.0/94.0, respectively, for samples A_0, B_0 and C_0, which contained no APs. The pitch lengths of samples A_0, B_0 and C_0 were 7.5 µm, 3.7 µm and 2.5 µm, respectively, as measured by the Cano wedge method [14]. The hydrophobic APs, Aerosil® R812S (Degussa–Hüls Co, Ltd), have a primary size of 7.0 nm. The compositions of the samples studied, A_0–A_5, B_0–B_5 and C_0–C_5, are listed in table 1. The N*-LC/AP composites were dissolved in acetone and sonicated for about 1.0 h in order to achieve good dispersion. Then, acetone was evaporated off slowly for about 24 h above 316 K before the samples were placed in a vacuum system at 10^{-3} Torr for 24 h at 323 K.

2.2. *Fabrication of the cells*

The inner surfaces of the indium–tin oxide (ITO) glass substrates were coated with a thin 3.0 wt % polyvinyl alcohol (PVA) layer and buffed in antiparallel directions to achieving homogeneous alignment. PET (polyethylene terephthalate) films of 15 µsm thickness were used as cell spacers and the mixtures were filled into the cells by capillary action in their isotropic phases.

2.3. *Measurements*

The electro-optical properties of the composites were measured using a liquid crystal display parameters tester (LCT-5016C, Changchun Lianchen Instrument Co, Ltd). The transmittance of air was normalized as 100%. An electric field with a square wave (100.0 Hz) was used.

The textures of composites were observed by polarized optical microscopy (POM) (Olympus, BX51).

3. Results and discussion

3.1. *Electro-optical properties of the samples*

Figures 1 shows the voltage dependence of the transmittances for samples A_0–A_5, B_0–B_5 and C_0–C_5. As shown in figure 1, the initial transmittances of samples A_0–A_5, B_0–B_5 and C_0–C_5 decreased strongly with the increasing AP content. This is because of defects generated in the liquid crystalline phase by the APs [11], but, due to the low content of the APs in the composite, not because of the mismatch of the refractive indices between the APs and the LC phase [7].

Table 1. The composition of samples A_0–C_5.

Sample	A_0/R812S / wt %	Sample	B_0/R812S / wt %	Sample	C_0/R812S / wt %
A_0	100/0.0	B_0	100/0.0	C_0	100/0.0
A_1	99.9/0.1	B_1	99.9/0.1	C_1	99.9/0.1
A_2	99.8/0.2	B_2	99.8/0.2	C_2	99.8/0.2
A_3	99.7/0.3	B_3	99.7/0.3	C_3	99.7/0.3
A_4	99.6/0.4	B_4	99.6/0.4	C_4	99.6/0.4
A_5	99.5/0.5	B_5	99.5/0.5	C_5	99.5/0.5

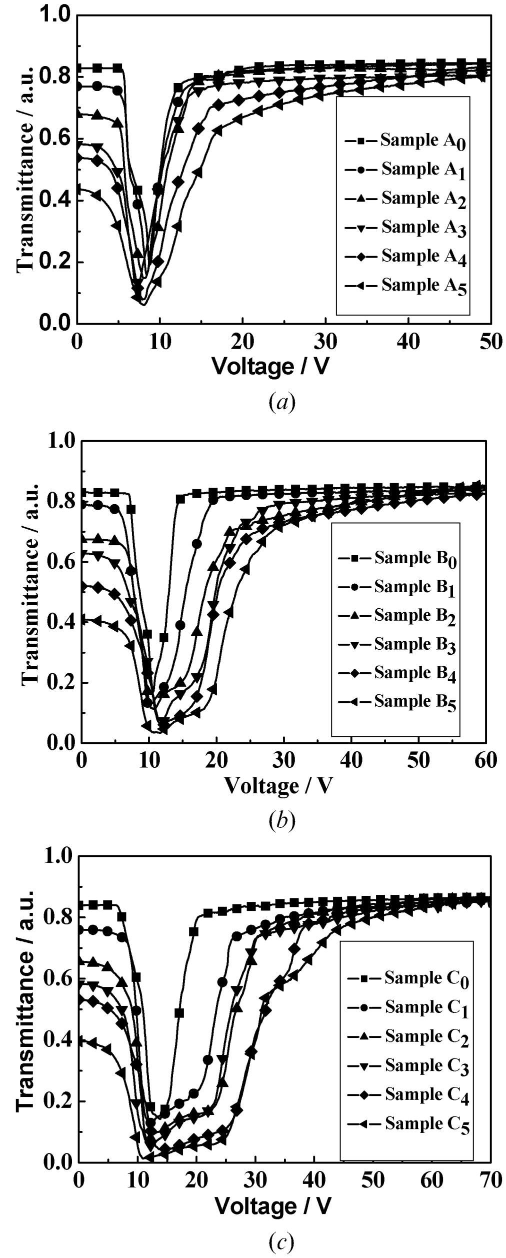

Figure 1. Curves of applied voltage versus transmittance for samples A_0–A_5 (a), B_0–B_5 (b) and C_0–C_5 (c).

Figure 2 shows the POM micrographs of the textures of samples B_0–B_5. Without APs, a planar texture with the helical axis of the N*-LC perpendicular to the cell surfaces formed, as shown in figure 2a, which shows the POM micrograph of sample B_0. The defects in the planar texture increased with increasing the content of the APs, as shown in figures 2b–2f. The interaction

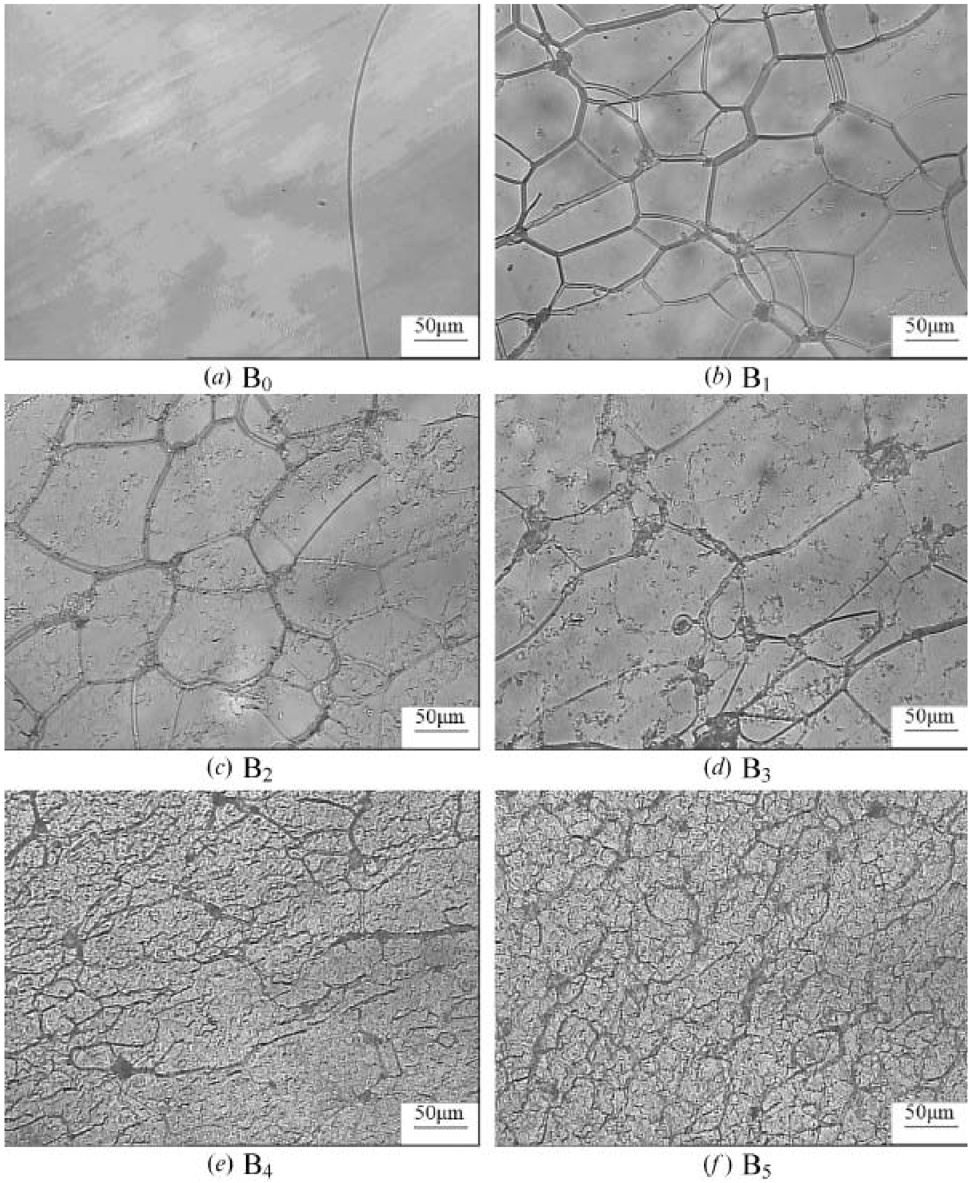

Figure 2. POM micrographs of the textures of the initial states of samples B_0–B_5.

between the LC molecules and the APs disturbed the orientation of the LC molecules, resulting in the decreased initial transmittance of the composite with increasing the content of APs.

When the applied voltage was higher than a threshold voltage, denoted V_{th1} here, the transmittance of the sample began to decrease sharply, changing from a transparent state to a light scattering one, as shown in figure 1. This is because the planar texture was changed into a focal conic one. The value of V_{th1} decreased with increasing AP content. The transition from the planar texture to the focal conic one, which is achieved by applying an electric field, is a nucleation process. Defects such as disclination lines, impurities and surface roughness serve as nucleation sites [15]. Therefore, the higher the AP content, the easier the transition from planar texture to the focal conic one, due to the increased amount of nucleation sites, and the more the value of V_{th1} decreased.

As shown in figure 1, the transmittances of the electric field-induced focal conic textures of samples A_0–A_5 decreased in the sequence, as also observed for samples B_0–B_5 and C_0–C_5. This means that the transmittance decreased with increasing AP content. Figure 3 shows the POM micrographs of the electric field-induced focal conic texture of samples B_0–B_5. As shown in figure 3, the dispersed APs generated more defects with increasing AP content. Therefore, there is a more abrupt change of the refractive indices at the domain boundaries and thus the transmittance of the focal conic texture decreased.

When the applied voltage increased above a second threshold voltage, denoted V_{th2} here, the samples were switched into an electric field-induced homeotropically oriented state; the helical structure of the samples became untwisted with the LC director perpendicular to the cell surfaces and the samples became transparent. Here, the saturation voltage (V_{sat}) is defined as the applied voltage for the transmittance to reach 90% of the maximum transmittance of the transparent state. Figure 1 shows that V_{th2} and V_{sat} increased with increasing AP content. This is due to the fact that compensating for the high elastic energy of unwinding the helical structure needs more electric energy in a local region close to the APs because of the stronger anchoring of the LC molecules at its surface [16]. At

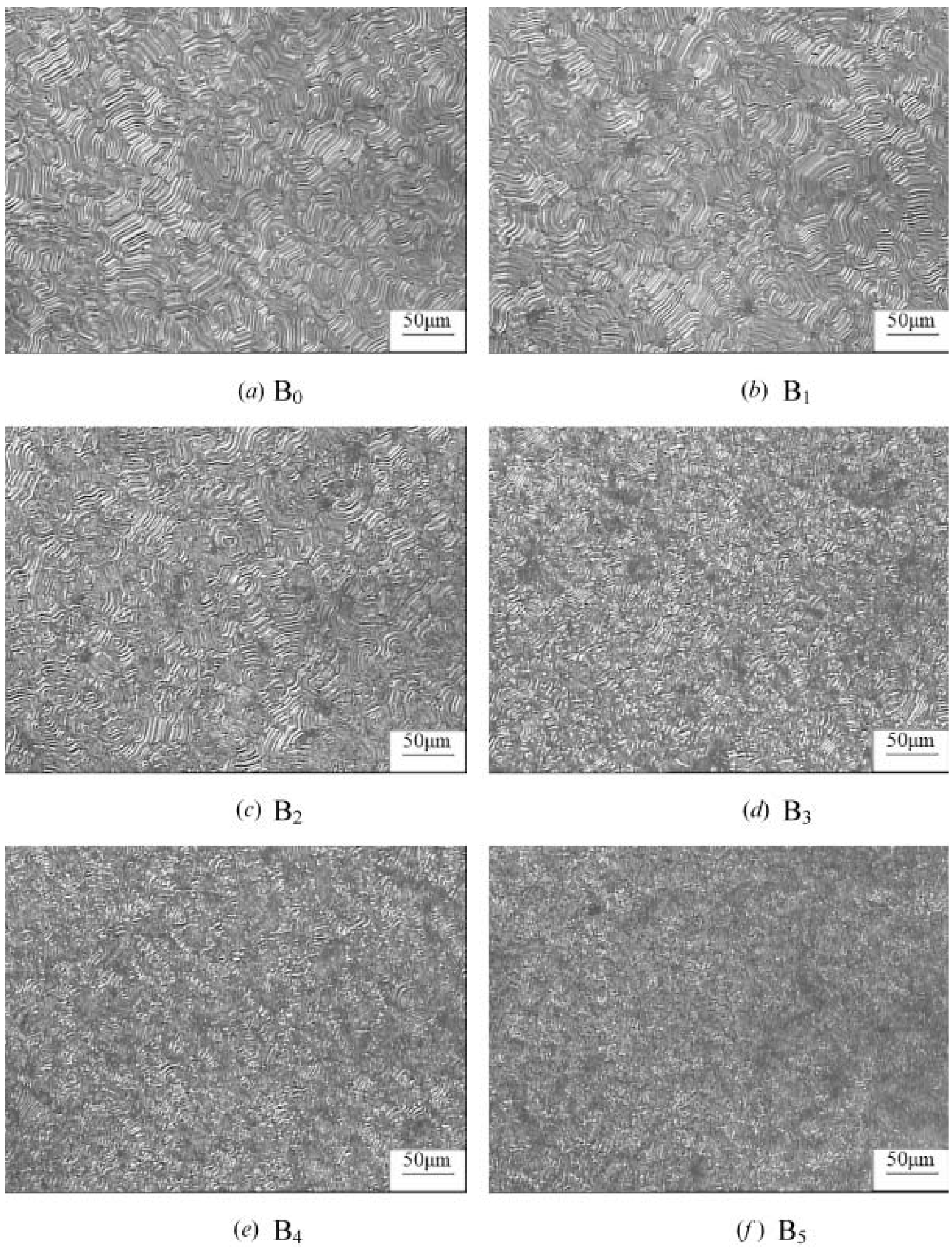

Figure 3. POM micrographs of the textures of the electric field-induced focal conic texture of samples B_0–B_5.

the same time, it was also found that the transmittance of the homeotropic states of the samples was affected only a little by APs because of the LC molecules being oriented well and the diminution of the defects.

Meanwhile, it was found that the values of V_{th1}, V_{th2} and V_{sat} of the samples increased with decreasing the pitch length, p. Then the energy barrier for the transition from the planar texture to the focal conic one increased with decreasing the pitch length [3, 4], which resulted in V_{th1} increasing with decreasing p. Meanwhile, the values of V_{th2} and V_{sat} increased with decreasing p, since more energy is necessary to unwind a helical structure with shorter p, as described by de Gennes's theory [2].

3.2. *Memory effect of the focal conic textures*

Figure 4 shows POM micrographs of the textures of samples B_0–B_5 taken 1 h after removing the applied electric field from the electric field-induced focal conic texture. Because the inner surfaces of cells had been treated for homogenous orientation of the LC

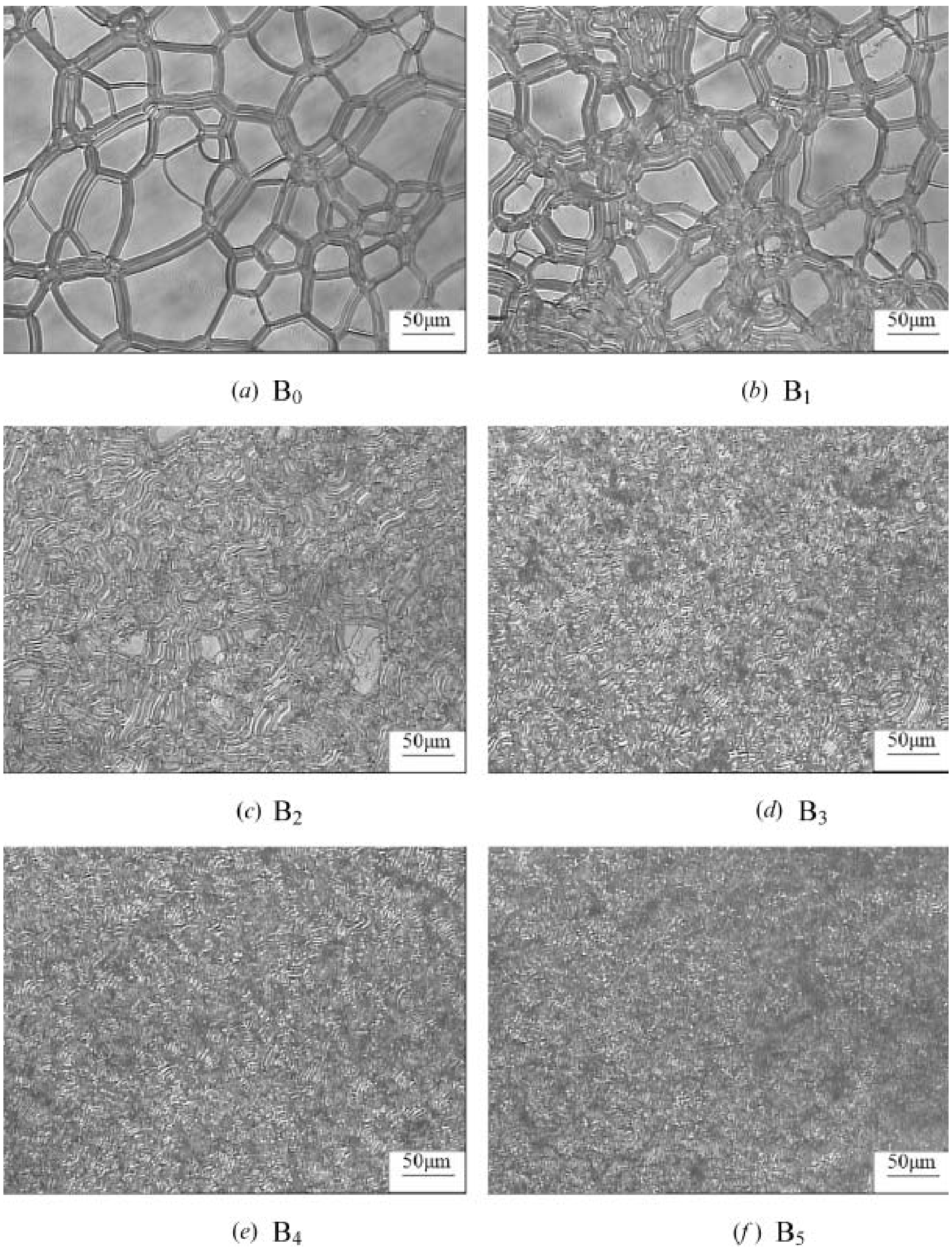

Figure 4. POM micrographs of the textures of samples B_0–B_5 taken 1 h after removing the applied electric field from the electric field-induced focal conic textures.

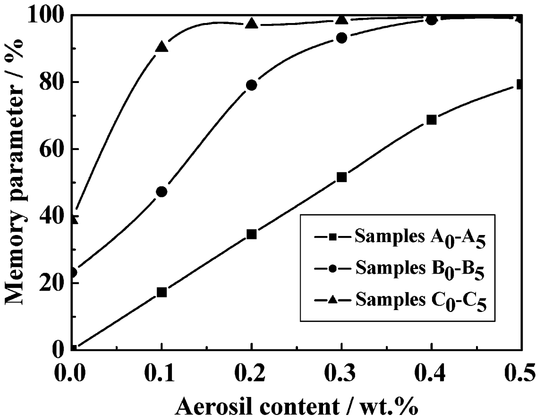

Figure 5. Curves of the memory parameter versus AP content for samples A_0–A_5, B_0–B_5 and C_0–C_5.

molecules, the N*-LC molecules had a tendency to adopt planar texture gradually, as shown in figure 4a. However, this tendency to change from the focal conic texture to the planar one decreased with increasing AP content, as shown in figure 4. This means that the memory effect of the focal conic texture increased with increasing AP content.

To describe the memory effect of the focal conic texture, a memory parameter, $M=(T_r - T_o)/(T_f - T_o)$ is introduced [9], where T_o, T_f and T_r are, respectively, the initial transmittance of the samples, the minimum value of the transmittance of the samples of the electric field-induced focal conic texture and the residual transmittance 1 h after removing the field. Figure 5 shows the curves of M versus the content of the APs for samples A_0–A_5, B_0–B_5 and C_0–C_5. The M values of samples A_0–A_5, B_0–B_5 and C_0–C_5 gradually increased from 0.0% to 79.3%, from 23.2% to 99.1% and from 38.8% to 99.3%, respectively, with increasing AP content. It is apparent that the APs effectively enhance the value of M because of the increase of anchoring energy on the N*-LC molecules at the AP surfaces.

For samples A_0, B_0 and C_0 containing no APs, the values of M are 0.0%, 23.2% and 38.8%, respectively. This means that the memory effect increased with decreasing pitch length of the N*-LC [3, 4].

For sample A_5 with 0.5 wt % APs, the value of M was 79.3%; however, for samples B_3 and C_1 containing 0.3 wt % and 0.1wt % APs, respectively, the values of M were both more than 90%. This indicates that the shorter of the pitch length in the N*-LC, the lower content of the APs needed to be dispersed in the N*-LCs to stabilize their focal conic texture.

4. Conclusion

The electro-optical properties and the memory effect of the N*-LC/AP composites were investigated. Due to the fact that the APs tended to generate defects in the N*-LC, the initial transmittance and that of the electric field-induced focal conic texture of the composites decreased with increasing AP content.

The value of V_{th1} decreased with increasing AP content because the APs decreased the stability of the planar texture of the composite.

Because anchoring energy on the N*-LC molecules at the APs surfaces increased with increasing AP content, the values of V_{th2} and V_{sat} and the memory effect increased with increasing AP content.

Because the energy barrier between the planar textures and the focal conic one increased with decreasing pitch length, the value of V_{th1} and the memory effect of the focal conic texture increased with decreasing pitch length. Both V_{th2} and V_{sat} increased with decreasing pitch length because more energy is needed to unwind the helical structure of molecules with a shorter pitch length.

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