Transactions of the Materials Research Society of Japan. Vol. 20

Ferroelectricity and Electro-optical Properties of (Liquid Crystalline Polymer/Low Molecular Weight Ferroelectric Liquid Crystal) Composite System

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Ferroelectric liquid crystals (FLC) show strong transient light scattering during the molecular reorientation process when the polarity of an applied electric field is reversed. A display method utilizing this phenomenon is called transient light scattering mode (TSM). In this study, a ferroelectric liquid crystalline polymer (FLCP) has been mixed with a low molecular weight ferroelectric liquid crystal (LMWFLC) to improve the light switching contrast for TSM. The (FLCP/LMWFLC) composite systems show optically homogeneous chiral smectic C phase. The transmittance of the transparent state of the composite systems upon the application of a d.c. electric field are about the same as that for LMWFLC. The magnitude of light scattering for the composite systems upon the application of an a.c. electric field are larger than that for LMWFLC.

1. INTRODUCTION

A chiral smectic C (S_C*) liquid crystals exhibit ferroelectricity [1]. The several novel electro-optical effects with high response speed due to its spontaneous polarization have been realized [2-5]. The tilt direction of the long axes of ferroelectric liquid crystalline molecules (FLC) in the chiral smectic C phase processes around the layer normal keeping a constant tilt angle, resulting in the formation of a helical structure. Then, the spontaneous polarization generates along the direction perpendicular to the plane containing both the molecular long axis and the layer normal. When a d.c. electric field is applied perpendicular to the helical axis, the helical structure is unwounded and a uniform alignment of the molecular long axes is obtained. This homogeneous molecular alignment shows a highly transparent state due to the formation of an optically homogeneous structure. When the polarity of an electric field is reversed, a transient light scattering state occurs because of incoherent reorientation of molecules. A strong light scattering state can be continuously kept by repetition of polarization reverse upon applying an a.c. electric field with a proper frequency. Then, the light scattering and transparent states can be switched reversibly by changing a.c. and d.c. electric fields alternately. The electro-optical effect for FLC was designated as transient scattering mode (TSM) by Yoshino et al [3]. Though TSM can be applied as a bright display with high speed properties, higher contrast is required for a display device. It should be expected that the light switching contrast of TSM can be improved by increasing the number of light scattering sources which correspond to incoherence during polarization reverse.

In this paper, the transient light scattering characteristics for the composite systems in a ferroelectric phase composed of ferroelctric liquid crystalline polymer (FLCP) and low molecular weight liquid crystal (LMWLC) have been investigated.

2. EXPERIMENTAL

The constituent materials for the composite system were shown in Figure 1. PEO8EMB (Idemitsu Kosan Ltd.) and CS1024 (Chisso Ltd.) were dissolved in acetone and then the composite systems were prepared by the solvent casting method.

The phase transition behavior of the composite systems were investigated on the basis of differential scanning calorimetry (DSC), polarizing optical microscopy (POM) and X-ray diffraction studies. The heating and cooling rates for DSC study and POM observation were 5 and 1 K·min^{-1}, respectively. A S_C* phase was identified by measuring of spontaneous polarization and dielectric relaxation phenomena. The magnitude of tilt angle was determined from POM observation. The magnitude of spontaneous polarization was evaluated by the triangular wave voltage method [6].

In order to measure the electro-optical properties of the composite systems, the composite system was sandwiched between two ITO (indium tin oxide)-coated glass substrates. Poly(vinyl alcohol)was coated on the substrate surfaces and rubbed in a single direction to obtain a homogeneous alignment of liquid crystalline phase. The cell thickness was adjusted to be 12 μm thickness by poly(ethylene telephthalate) film.

Figure 2 shows schematic diagram of the measurement system of the electro-optical properties for the composite systems. The electro-optical properties of the composite were studied using a He-Ne laser (λ=632.8 nm) as an incident light beam. The transmitted light intensity of the composite upon the application of an electric field was detected with a photodiode.

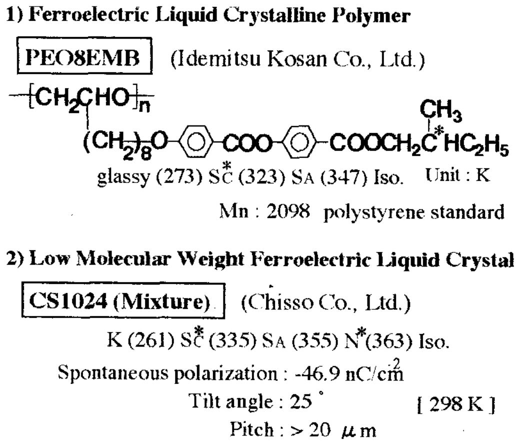

Figure 1. Component materials for the composite system.

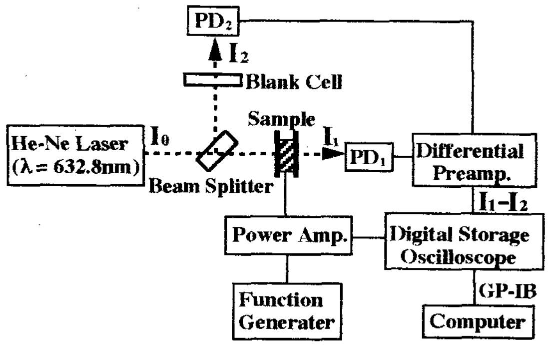

Figure 2. Schematic diagram of the measurement system of the electro-optical properties for the composite system.

3. RESULTS AND DISCUSSION

3.1 Aggregation states of the composite system

Figure 3 shows the phase diagram of the (PEO8EMB/CS1024) composite system. The glass transition temperature, Tg of PEO8EMB decreased with an increase in the CS1024 fraction. The decrease in Tg might be caused by the plasticizing effect of CS1024 to PEO8EMB. Since a single endothermic peak due to the mesophase-isotropic phase transition was observed in DSC, it is apparent that the composite systems form homogeneously mixed mesomorphic phase. Therefore, CS1024 is miscible over a whole concentration range of PEO8EMB in both isotropic and mesomorphic states. From measurement of spontaneous polarization and dielectric relaxation phenomena for the composite systems, it became clear that the composite systems which the fraction of PEO8EMB were below 40 wt% show ferroelectric phase in the temperature range same as CS1024. In POM observation for the composite systems, a single phase texture for a Sc* phase was recognized for a whole concentration range of PEO8EMB. The average orientation of the texture for the composite systems which the fraction of PEO8EMB were below 40 wt% reversibly changed when the polarity of an applied electric field was reversed. This indicates that molecular realingment was caused by polarization reverse for Sc* phase of the composite systems which the fraction of PEO8EMB were below 40 wt%, and therefore electro-optical properties were measured for such composite systems.

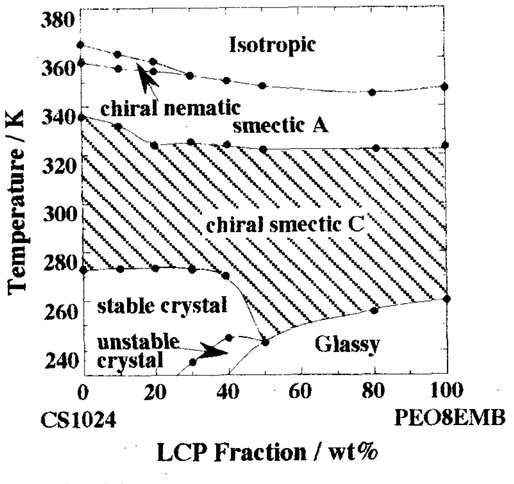

Figure 3. Phase diagram of the (PEO8EMB/CS1024) composite system.

3.2 Light scattering factors of transient light scattering for the composite system

In the case of transient light scattering of FLC, the light scattering might be caused by a spatial heterogeneity of refractive index due to the incoherent molecular reorientation. Therefore, one of the light scattering factors for the transient light scattering may be attributed to a change in birefringence against an incident light before and after polarization reverse. The magnitude of birefringence is determined by the tilt angle, that is the angle between the long axes of LC molecules and the normal direction to smectic layer. Figure 4 shows the temperature dependence of the tilt angle for the composite systems. The tilt angle scarcely changed with the addition of PEO8EMB to CS1024. This result indicates that the addition of PEO8EMB doesn't remarkably affect the magnitude of birefringence in the composite system.

Also, the intensity of light scattering for the composite system may strongly depend on the spatial distribution of the discontinuous points in refractive index in comparison with the wave length of incident light. That is, the magnitude of light scattering becomes larger when the discontinuous points in refractive index distribute with the similar distance to the wave length of incident light. It is expected that the structure of composite systems contain local heteromogeneous domains which were affected by the main chain of PEO8EMB. Then the distribution of the molecular realignment process become broaden with the addition of PEO8EMB to CS1024. If the distribution of the velocity of the molecular realignment process, the discontinuous points which have a distribution with the similar distance to the incident light might get larger and the magnitude of the transient light scattering get larger.

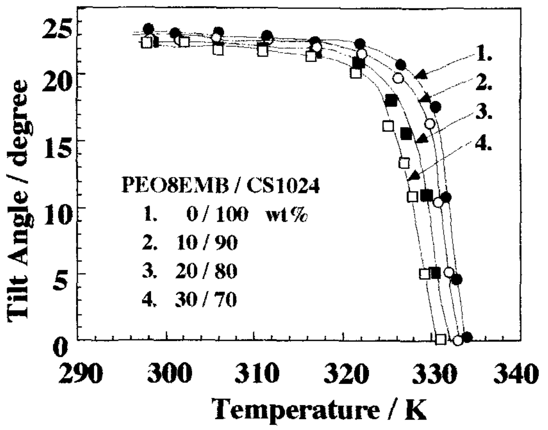

Figure 4. Temperature dependence of the tilt angle of the composite systems.

3.3 Electro-optical properties of the composite system

Figure 5 shows the light-switching curves for the composite system under the application of an electric field with a rectangular wave form. The composite system showed a transparent state upon the application of a d.c. electric field in a similar fashion to CS1024. In order to normalize the magnitude of transient light scattering intensity, we defined τ by the follow equation.

$$\tau d = -\log(T_1/T_2)$$

where, d, T_1 and T_2 are film thickness of the composite system, transmittance for the transient light scattering state and transmittance for the transparent state, respectively. τd=1 and τd=0 When the contrast , T_2/T_1 is ∞ and 1, respectively. Figure 6 shows the temperature dependence of τ for the composite systems. The magnitude of the light transmittance for the transparent state was slightly affected by the addition of 'PEO8EMB. The composite systems showed a transient light scattering state when the polarity of an electric field was reversed. The transmittance for the transient scattering state decreased with increase in the fraction of PEO8EMB. Then, this means that the magnitude of transient light scattering remarkably increase eventhough the birefringence of the composite did not apparently change by the addition of PEO8EMB. Therefore, it seems reasonable to conclude that an increase of the transient light scattering intensity may arise from the increase of the discontinuous points in refractive index which have distribution with the similar distance to the wave length of the incident light.

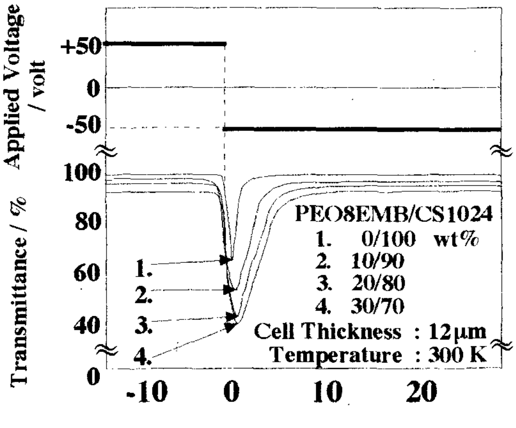

Figure 5. Light switching curves for the composite systems.

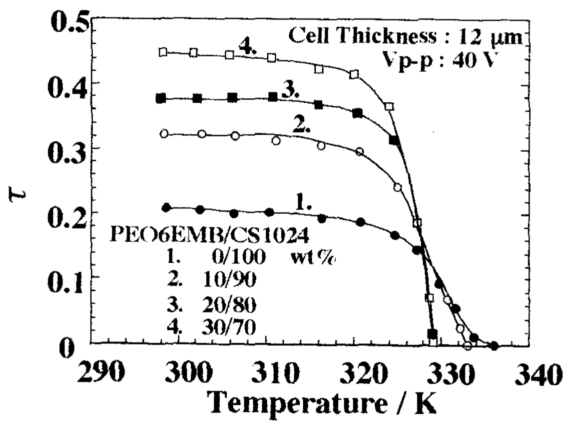

Figure 6. Temperature dependence of τ of the composite systems.

4. CONCLUSION

The (FLCP/LMWFLC) composite systems showed an optically homogeneous Sc* phase. It was revealed from the tilt angle measurement that the birefringence of composite system didn't change with increase in the fraction of FLCP. The composite system showed a transparent state upon the application of a d.c. electric field in a similar fashion to LMWFLC. The magnitude of light scattering for the transient light scattering state increased with increase in the fraction of FLCP, eventhough the birefringence of the composite did not apparently change by the addition of PEO8EMB. This might be resulted from the extent of the distribution of the velocity of polarization reverse.

ACKNOWLEDGMENT

The materials PEO8EMB and CS1024 were kindly supplied by Idemitsu Kosan Ltd. and Chisso Ltd., respectively.

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