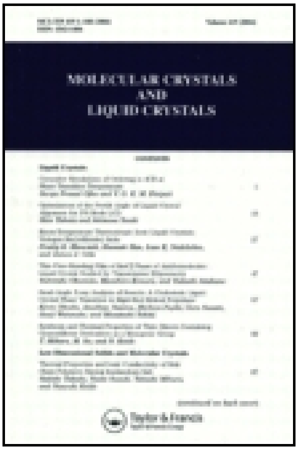

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ELECTRIC FIELD-INDUCED DIRECTOR ORIENTATION OF SMECTIC-A DOMAINS IN AN ISOTROPIC PHASE

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Electric Field-Induced Director Orientation of Smectic-A Domains in an Isotropic Phase

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Electric field-induced director orientation of smectic-A phase in an isotropic phase has been studied with a polarizing microscope using the binary mixture of octyloxycyanobiphenyl and dodecyl alcohol. Electric field is applied to the samples in which spherical smectic-A domains with and without defects in an isotropic phase are observed. Field-induced orientation of smectic-A director is observed for spherical smectic-A domains with defects but not observed for those without defects below electric field strength of 1.0 V/μm, indicating that the presence of defects facilitates the director orientation. The threshold field for the smectic-A director orientation varies from smectic-A domain to domain, suggesting that the threshold field is dependent on the structure of defects.

Keywords: smectic-A phase; electric field-induced director orientation; homeotropic alignment; defect

INTRODUCTION

A smectic-A (Sm-A) phase, having a layer structure, in an isotropic phase exhibits a rich variety of geometrically interesting shapes, such as spheres, cylinders and unduloids. These beautiful patterns have motivated a number of experimental and theoretical studies [1]. Since one of the many fascinating properties of the liquid crystal phase is the ability of relatively weak fields to align the director, the effect of electric field application on the patterns of a Sm-A phase in an isotropic phase has been studied. It has been found that Sm-A domains in an isotropic phase are deformed by the application of electric field. The deformation has been found in the electric-field range of 0.35 - 0.5 V/μm, but the complete alignment of the Sm-A director along the electric field in the Sm-A domains was not observed in the field range [2].

The nature of the alignment of the director in a nematic phase by an external field is well understood, both experimentally and theoretically. In marked contrast far less is known about the field-induced alignment of Sm-A phases. Recently, a deuterium nuclear magnetic resonance study for electric field-induced alignment of the Sm-A directors has been reported in both monodomain Sm-A slabs [3] and droplets of the Sm-A phase suspended in an isotropic liquid [4]. In this context it would clearly be of interest to observe the optical texture of Sm-A phase subjected to electric field and for this purpose Sm-A domains grown in an isotropic phase are an attractive system because the role of defects in field-induced Sm-A director orientation is easily observed.

We present here the results of a study of the effect on a Sm-A phase of applying electric field to align the Sm-A director. The alignment process has been observed by a polarizing optical microscope, and the Sm-A phase is suspended in an isotropic phase, which causes fast field-induced alignment process. We show a role of defects in Sm-A domains for the alignment process and a threshold value for the aligning field.

EXPERIMENT

The liquid crystalline material used here was the binary mixture of octyloxycyanobiphenyl (8OCB) and dodecyl alcohol (DODA) (a molar ratio of 8OCB to DODA was 4 to 6) [5]. In this binary mixture, the Sm-A and isotropic phases coexist over the temperature range of 41 - 38 °C. The liquid crystal cells of dimensions 10mm × 5mm and of thickness 36 μm bounded by indium-tin oxide (ITO) precoated glass plates were prepared. Polyimide layers were coated on the surfaces to avoid charge carrier injection from the electrodes. Polyimide layers are usually used to align the liquid crystalline molecules homogeneously or homeotropically but in the present study no effects of the polyimide layers on the field-induced alignment process of the Sm-A director or on the patterns of Sm-A domains were found. The liquid crystal cells were cooled from an isotropic phase at -0.2 °C/min and the cooling was stopped in the coexisting region of the Sm-A and isotropic phases. The ac square-wave electric field (2 kHz) was applied in the direction perpendicular to the glass substrates. This frequency is sufficient to suppress the influence of ionic impurities without affecting the vaule of the dielectric anisotropy $\Delta\epsilon$ of 8OCB. Because of the positive $\Delta\epsilon$ of 8OCB, the director is expected to be aligned parallel to the electric field. The sample temperature was controlled using a hot stage with high temperature stability (Instec HS1-i). The textures of Sm-A domains were observed with a polarizing microscope (Nikon X2TP-11) equipped with a digital camera (Olympus DP-11) as the electric field strength was increased from 0 to 1.09 V/μm at a constant rate of 9.0×10^{-3} V/μms.

RESULTS AND DISCUSSION

On cooling the samples from the isotropic phase, the Sm-A phase initially appears in the form of a number of spherical droplets which grow in size and then start elongating into cylindrical structures. The cylinder, whose diameter is $\sim$ 5 μm, grow rapidly and become long and entangled threads. The entangled threads suddenly collapse forming spherical Sm-A domains on the glass plates [1,5]. The spherical domains with and without defects are found, and their shapes are essentially unchanged at a constant temperature. The samples were retained at the temperature for at least one hour before the electric field is switched on.

We applied ac electric field to the samples in which the spherical domains were observed. Figure 1 shows the polarizing microscope images of a spherical domain without defects before and after electric-field application. It has been shown from a comparison of the computer-generated

(a) (b)

Figure 1 Polarizing microscope images of a Sm-A spherical domain without defects (a) before electric field is switched on and (b) after electric field is switched on. Electric field strength is 1.0 V/μm. The bars indicate 50 μm.

Figure 2 Polarizing microscope images of a Sm-A spherical domain with defects (a) before electric field is switched on, (b) after electric field is switched on, and (c) after electric field is switched off. Electric field strength is 1.0 V/μm. The bars indicate 50 μm.

texture with that in Fig. 1(a) that the Sm-A director is parallel to the surface normal of the spherical domain [6]. We note from Fig. 1 that the polarizing microscope images are not influenced by the electric-field application below 1.0 V/μm. Figure 2 shows the polarizing microscope images of a spherical domain with defects before and after electric field is switched on, and after electric field is switched off. In contrast to the results in Fig. 1, the central part of the texture turns dark and the diameter of the texture becomes larger after an electric field is switched on. The texture transition begins at the defects and the time required for the texture transition from Fig. 2(a) to Fig. 2(b) is less than 1 s. After the electric field is switched off, again a spherical domain with defects appears as shown in Fig. 2(c) but the texture in Fig. 2(c) is different from that in Fig. 2(a). The central area of the texture in the presence of electric field remains dark even when the sample stage of the microscope was rotated. It is expected that the dark central area result from homeotropic alignment of Sm-A director parallel to electric field. To confirm the homeotropic alignment we carried out conoscopic observation but the conoscopic image was not clearly observed. Instead of the observation we examine the polarizing microscope texture of the sample when the sample was tilted by 24° with respect to the axis made an angle of 45° to the polarization direction. The sample configuration is schematically illustrated in Fig. 3(a) and the texture observed in this configuration is shown in Fig. 3(b). It can be seen that the dark central area in Fig. 2(b) is changed to the bright area in Fig. 3(b). We therefore conclude from these observation that the dark central area in Fig. 2(b) result from homeotropic alignment of Sm-A director parallel to electric field. In addition we stress that the presence of

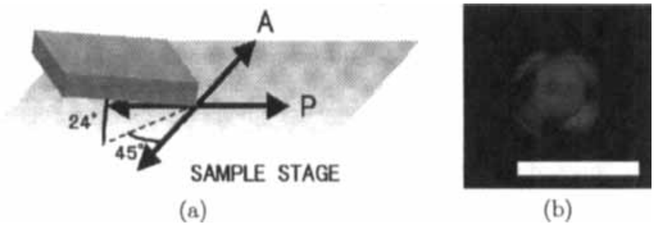

FIGURE 3 (a) Schematic illustration of the sample configuration. The sample on the sample stage was tilted by 24° with respect to the axis made an angle of 45° to the polarization direction. P and A denote the polarizer and the analyzer, respectively. (b) Polarizing microscope images of Fig. 2(b). Electric field strength is 1.0 V/μm. The bar indicates 50 μm.

defects in the Sm-A spherical domains enables the Sm-A director to align parallel to electric field.

We examine the threshold field for field-induced orientation of Sm-A director and find considerable scatter in the threshold field from 0.4 - 1.0 V/μm. The result suggests that the threshold field is dependent on defect structures that exist in the Sm-A domains before the electric field is switched on, which is consistent with the experimental observation that the texture of Sm-A domains with defects varies from domain to domain.

In a recent study of the field-induced alignment of Sm-A phase from monodomain director, it is suggested that the initial disruption of the layer structure plays a crucial role for the field-induced alignment of Sm-A director and this disruption is facilitated by the presence of defects in the spatial ordering [3]. This mechanism of the alignment of the Sm-A director is consistent with our present observation in the sense that the field-induced alignment of the Sm-A director is observed in the Sm-A spherical domains with defects and not observed in the domains without defects. We note that Sm-A domains in an isotropic phase observed in the binary mixture of 8OCB and DODA is suitable for elucidating the field-induced alignment of Sm-A director and the role of defects in the alignment process.

CONCLUSIONS

We have studied the electric field-induced orientation of Sm-A directors

in an isotropic phase. The polarizing microscope observation reveals the characteristic features of field-induced orientation of Sm-A director. The main features may be summarized as follows:
(1)The Sm-A director in the spherical domains without defects does not align in the direction of applied electric field up to 1.0 V/μm.
(2)The Sm-A director in the central part of the spherical domains with defects aligns homeotropically parallel to electric field. The alignment of the Sm-A director is initiated at the defect structures in the domains.
(3)The threshold field for homeotropic alignment of the Sm-A director varies from domain to domain and ranges from 0.4 V/μm to 1.0 V/μm. The variation in the threshold field would originate in difference in defect structure of each domain.

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