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OBSERVATIONS OF DEFECTS IN A SMECTIC-A PHASE COEXISTING WITH AN ISOTROPIC PHASE

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Several defects in a smectic-A phase in an isotropic phase have been observed in the binary mixture of octyloxycyanobiphenyl and dodecyl alcohol using a polarizing microscope. Polarizing-microscope images are simulated to determine the structures of the smectic-A defects. The observed defect structures are classified according to the strength of the defects ($2\pi m$). The values of m observed here are confirmed to be an integer or a half integer and are $|m| \leq 1$.

Keywords: binary mixture; defects in a smectic-A phase; polarizing-microscope images; strength of the defects

INTRODUCTION4

The smectic-A liquid crystal consists of a periodic stacking of liquid layers, and the director of the liquid crystal molecules is parallel to the layer normal. Within each layer, their positions are random. A variety of patterns have often been observed in smectic-A liquid crystals grown from an isotropic phase because of its symmetry [1]. A study of pattern formations of the smectic-A phase in an isotropic phase has therefore attracted much attention [1–4]. In addition, the smectic-A phase in an isotropic phase is an attractive system to study defect structures since unique defect structures of smectic-A phase in an isotropic phase, which have not clearly been observed in smectic-A slabs, can easily be observed. Defect structures in the smectic-A slabs are the focal conic domains. However, those structures are influenced by substrate surfaces. Smectic-A domains observed here are not influenced by substrate surfaces, and the outermost layer forms a

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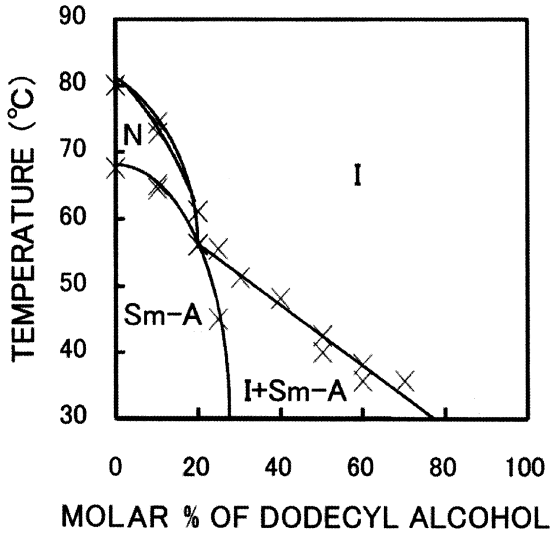

FIGURE 1 Phase diagram for a mixture of 8OCB and DODA [3].

closed surface because of the positive interfacial tension anisotropy in 8OCB [4]. Since the defect structures are isolated in an isotropic phase, this system is suitable for observing the unique geometries of defect structures in a smectic-A phase. In this paper, we show the observation of several types of defects in the smectic-A phase in an isotropic phase. These defect

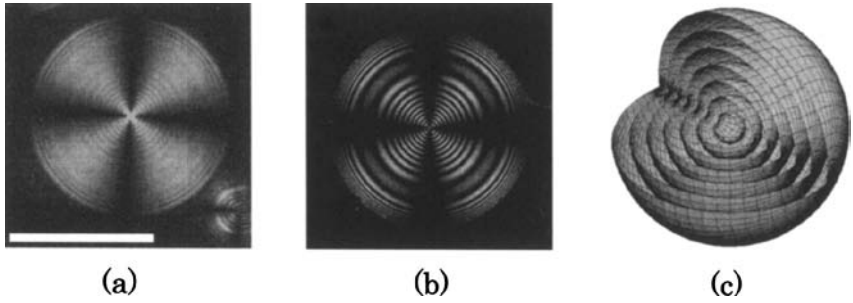

FIGURE 2 A smectic-A domain observed with the analyzer and polarizer crossed (a) and the simulated polarizing-microscope image at 546 nm (b) for a spherical smectic-A domain, and schematic illustration of a partial cross section of the layer structure for the spherical smectic-A domain (c) (a point defect is located at the center of the domain). The shape remains unchanged at 37.5°C for a few hours. The bar indicates 50 μm.

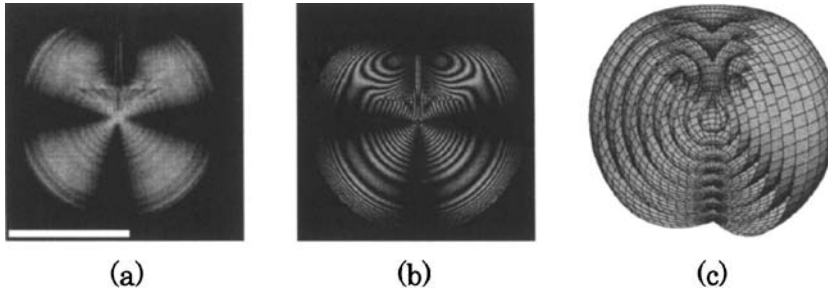

FIGURE 3 A smectic-A domain observed with the analyzer and polarizer crossed (a) and the simulated polarizing-microscope image at 546 nm (b) for a smectic-A domain with defects, and schematic illustration of a partial cross section of the layer structure for the domain (c) (the upper part of the sphere is filled with a focal conic domain with defect lines; straight and circular lines). The domain retains its shape at 37.5°C for around half an hour. The bar indicates 50 μm.

structures are identified by using computer simulation of microscope images and are classified according to the strength of a defect.

EXPERIMENT AND RESULTS

The liquid crystal (LC) material used here was the binary mixture of octyloxycyanobiphenyl (8OCB) and dodecyl alcohol (Figure 1 shows the phase diagram of a mixture of 8OCB and DODA [3]). LC cells with dimensions of

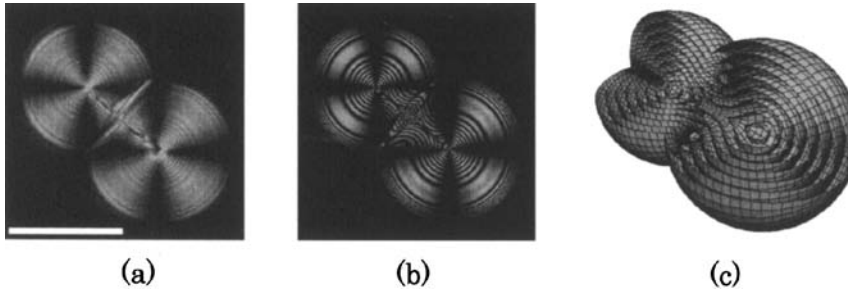

FIGURE 4 A smectic-A domain observed with the analyzer and polarizer crossed (a) and the simulated polarizing-microscope image at 546 nm (b) for a smectic-A domain consists of two spherical domains, and schematic illustration of a partial cross section of the layer structure for the domain (c) (two spherical domains are connected by a focal conic domain). The shape remains unchanged at 37.5°C for a few hours. The bar indicates 50 μm.

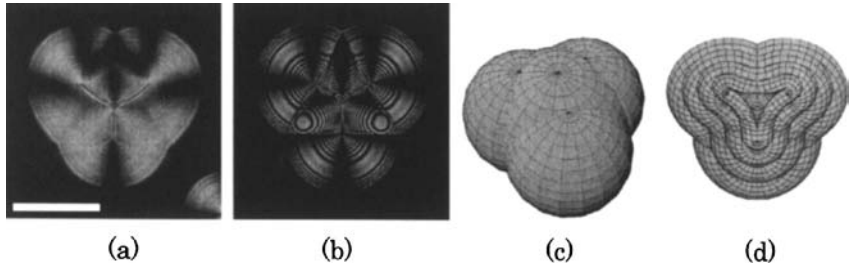

FIGURE 5 A smectic-A domain observed with the analyzer and polarizer crossed (a) and the simulated polarizing-microscope image at 546 nm (b) for a polygonal smectic-A domain (c) and (d). (c) and (d) are the outside shape of (a) and the cross section of (c), respectively (four domains are connected by three focal conic domains, and a point defect is located at the center of the polygonal domain). The shape remains unchanged at 37.5°C for a few hours. The bar indicates 50 μm.

10 mm × 10 mm and of thickness ∼100 μm were prepared. The LC cell temperature was controlled in a hot stage (Instec HS1-i) with an accuracy of ±0.01 at 40°C (the magnitude of temperature gradients is also within the accuracy of ±0.01 at 40°C). Defect structures in the smectic-A phase were observed with a polarizing microscope (Nikon X2TP-11) equipped with a color digital camera (Olympus DP-11) using a monochromatic light whose wavelength was 546 nm. The LC cells with 40% of a molar concentration of 8OCB were cooled from an isotropic phase at −0.1°C/min, and the cooling was stopped at ∼38°C in the coexisting region of the

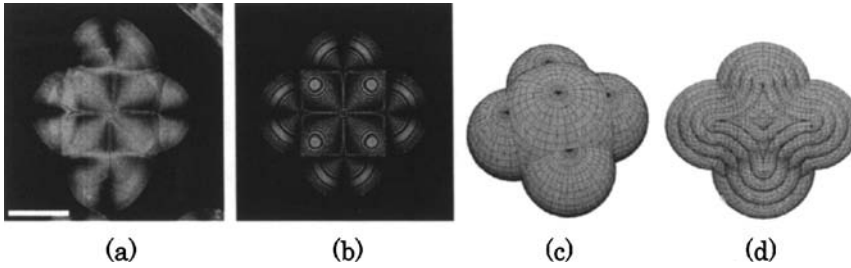

FIGURE 6 A smectic-A domain observed with the analyzer and polarizer crossed (a) and the simulated polarizing-microscope image at 546 nm (b) for a polygonal smectic-A domain (c) and (d). (c) and (d) are the outside shape of (a) and the cross section of (c), respectively (five domains are connected by four focal conic domains, and a point defect is located at the center of the polygonal domain). The domain retains its shape at 37.5°C for around half an hour. The bar indicates 50 μm.

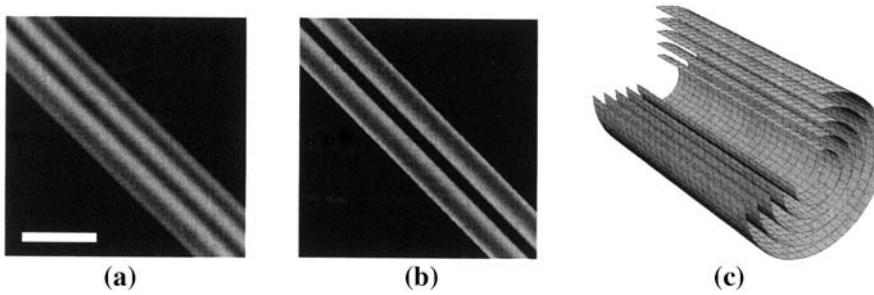

FIGURE 7 A smectic-A filament observed with the polarizer and analyzer crossed (a), simulated texture at 546 nm (b) for a cylindrical smectic-A filament which outer and inner radii are 2.5 and 0.5 μm respectively, and schematic illustration of a partial cross section of the layer structure for a smectic-A filament (c) (a line defect is located on the axis of the filament). The filament appears when the LC cell is cooled at -0.1°C/min. The bar indicates 5 μm.

smectic-A and isotropic phases. Several types of smectic-A domains with defects are formed in the LC cells (Fig. 2(a) ∼ Fig. 9(a)). These defect structures have not been clearly observed in smectic-A slabs bounded by two glass plates [5].

DISCUSSION

Point and line defects are observed in a smectic-A phase (Fig. 2(a) ∼ Fig. 9(a)). To determine both director distributions and defect structures

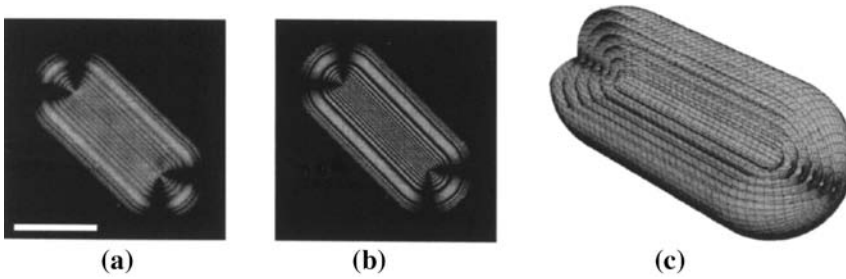

FIGURE 8 A smectic-A domain observed with the analyzer and polarizer crossed (a), and the simulated polarizing-microscope image at 546 nm (b) for a smectic-A cylinder, and schematic illustration of a partial cross section of the layer structure for the smectic-A cylinder (c) (a line defect is located on the axis of the cylinder). The shape remains unchanged at 37.5°C for a few hours. The bar indicates 50 μm.

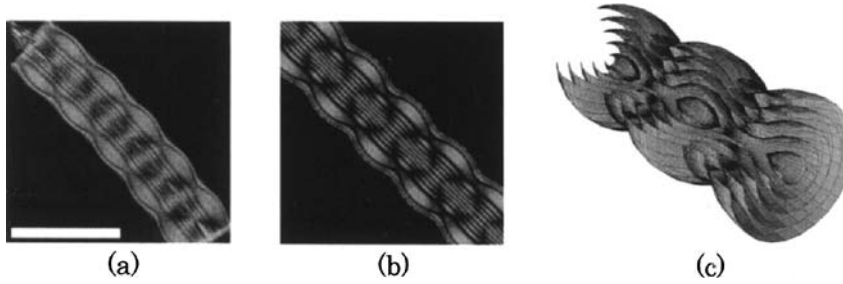

FIGURE 9 A smectic-A domain observed with the analyzer and polarizer crossed (a), and the simulated polarizing-microscope image at 546 nm (b) for an undulated smectic-A cylinder, and schematic illustration of a partial cross section of the layer structure for the undulated smectic-A cylinder (c) (sphere like domains are connected by focal conic domains in sequence). The domain retains its shape at 37.5°C only for a few minutes. The bar indicates 50 μm.

of smectic-A domains, we simulated polarizing-microscope images for smectic-A domains at 546 nm by means of a method described in Ref. [6]. In the simulations the following values were used: $n_o = 1.50$, $n_e = 1.66$, where n_o and n_e are the ordinary and the extraordinary indices of refraction, respectively. The simulated images (Fig. 2(b) $\sim$ Fig. 9(b)) for the corresponding layer structures (Fig. 2(c) $\sim$ Fig. 9(c), Fig. 5(d) and Fig. 6(d)) are in good agreement with the experimentally obtained images.

These defects are classified according to "strength" of a defect [7]. Schematic representation of fundamental types of layer structures is shown in Figure 10(i) $\sim$ (viii). "$2\pi m$" represents "strength" of the defects. The corresponding simulated microscope images are also shown in Figures 10(a) $\sim$ (m). In the experiments, the values of m were always an integer or a half integer ranging from -1 to $+1$. This means that if we put a vector at any point near a defect parallel to a director of smectic-A molecules, follow an arbitrary closed circuit around the defect and make one full turn while keeping the direction of the vector parallel to the director, then the vector was rotated $\pm\pi$ or $\pm 2\pi$. These results can be understood from the symmetry of the smectic-A phase; a turn by 2π around the defect restores the initial direction of the molecular axis. The rotation angle can change by π, 2π, 3π,... (in a smectic-A phase the states of director n and $-n$ are indistinguishable). Thus the values of m must be an integer or a half integer (defects that have a higher value of $|m|$ ($|m| > 1$) were not observed in the present experiments).

We have demonstrated that a smectic-A phase in an isotropic phase is suitable for the observation of defect structures of smectic-A domains that

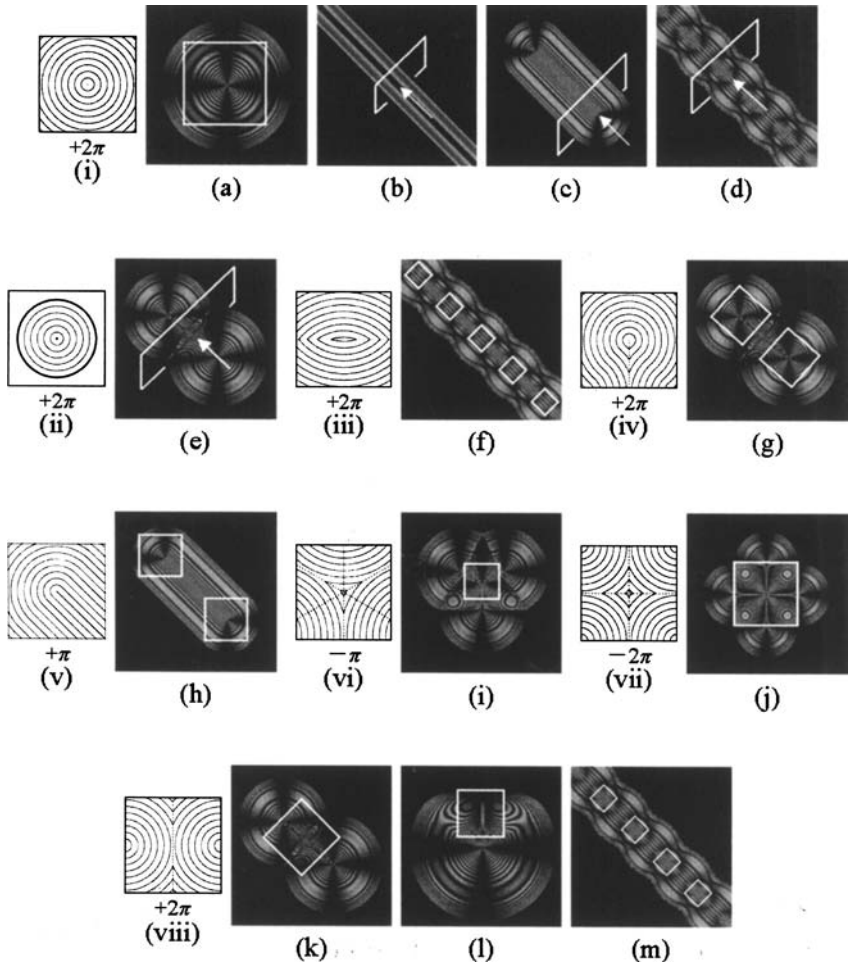

FIGURE 10 Cross sections of layer structures including defects (i) ∼ (viii) and corresponding parts of the simulated polarizing-microscope images (a) ∼ (m). "$2\pi m$" represents "strength" of the defects.

are not influenced by substrate surfaces. We have determined the 3-dimensional defect structures and director distributions of smectic-A domains by comparing the simulated images with the experimental images. The determination of the 3-dimensional defect structures and director distributions enables us to classify the defects according to the strength of a defect. The nature of defects of a smectic-A phase can be elucidated by growing a smectic-A phase with defects in an isotropic phase.

CONCLUSIONS

We have studied the defect structures of a smectic-A phase in an isotropic phase. Several defect structures have been observed using a polarizing microscope. Comparisons between the simulated and experimental images enable us to determine the 3-dimensional defect structures and director distributions of smectic-A domains, such as spherical domains, polygonal domains, cylinders and filaments. We have classified these observed defect structures according to the strength of a defect. The values of m were found to be $|m| \leq 1$. Defects that have a higher value of $|m|$ ($|m| > 1$) were not observed in the present experiments. In addition, we have demonstrated that a smectic-A phase in an isotropic phase is suitable for observing defects unique to smectic-A phase, and that the simulation of polarizing-microscope images can be used for the determination of director distribution and defect structures of smectic-A domains in an isotropic phase.

REFERENCES

[1] Naito, H., Okuda, M., & Ou-Yang, Z. C. (1993). Equilibrium shapes of smectic-A phase grown from isotropic phase. *Phys. Rev. Lett.*, *70*, 2912–2915; Naito, H., Okuda, M., & Ou-Yang Z. C. (1995). Preferred equilibrium structures of smectic-A phase grown from an isotropic phase: Origin of focal conic domains. *Phys. Rev. E.*, *52*, 2095–2098.

[2] Pratibha, R. & Madhusdana, N. V. (1992). Cylindrical growth of smectic A liquid crystals from the isotropic phase in some binary mixtures. *J. Phys. II France*, *2*, 383–400.

[3] Adamczyk, A. (1989). Phase transitions in freely suspended smectic droplets. Cottonmouton technique, architecture of droplets and formation of nematoids. *Mol. Cryst. Liq. Cryst.*, *170*, 53–69; W. E. & Pallfy-Muhoray, P. (1997). Phase separation in incompressible systems. *Phys. Rev. E*, *55*, R3844–R3846.

[4] Pratibha, R. & Madhusdana, N. V. (1995). In Spatio-Temporal Patterns, edited by Cladis P. E. and Palffy-Muhoray, P. *SFI Studies in the Sciences of Complexity*, *171*, Addison-Wesley.

[5] Chandrasekhar, S. (1992). *Liquid Crystals*, 2nd ed., Cambridge University, Press Cambridge: 327–333.

[6] Todorokihara, M. & Naito, H. (2000). Equilibrium shape of a smectic-A phase in an isotropic phase formed on substrate surface. *Mol. Cryst. Liq. Cryst.*, *347*, 137–146.

[7] de Gennes, P. G. & Prost, J. (1993). *The Physics of Liquid Crystals*., Oxford University Press: Oxford, 2nd ed., 163–171.