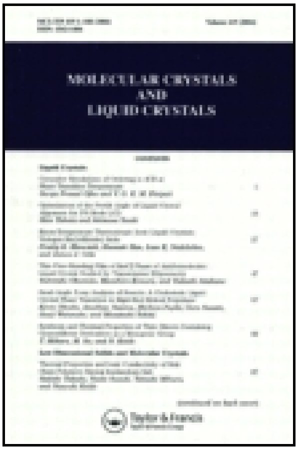

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Alignment and Dynamics of SiO_2 Particles in Liquid Crystal under Applied Electric Field

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 367, pp. 37-43
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Alignment and Dynamics of SiO_2 Particles in Liquid Crystal under Applied Electric Field

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The alignment characteristics and dynamics of SiO_2 particles dispersed in a liquid crystal (LC) under an applied electric field have been studied. In the system composed of LC, surfactant and SiO_2 particles, a well-ordered aggregation of particles has been observed under the applied electric field. For this aligned aggregation of particles, phase separation behavior between the LC and surfactant, and electrohydrodynamic flow at the LC/surfactant interface seem to play an important role. The possibility for the fabrication method of photonic crystal is also discussed.

Keywords: photonic crystal; particle alignment; particle migration; smectic layer

1. INTRODUCTION

Suspensions of small dielectric particles in isotropic dielectric liquids have been studied for a long time, as one of electrorheological fluid, in which mechanical properties such as viscosity can be controlled by the electric field [1]-[3].

Recently, dispersions of small dielectric particles in anisotropic dielectric liquids such as liquid crystals (LCs) have attracted much attention from both fundamental and technological points of view. Fundamental interests include new type of colloidal anisotropic interactions because of strong elastic distortions of the liquid crystal host, which can be useful in the design of new composite materials with potentially useful applications and formation of desired structures with controlled ordering at different length scales. Especially, anisotropic interactions between particles in the nematic phase have been reported recently [4].

On the other hand, also in smectic phase, some interesting behaviors of particles should be observed. So far, we have reported the dynamic behavior of SiO_2 particles in a smectic LC. In layered structure, the particles moved along the smectic layer [5]. In addition, the regular aggregation of particles has been observed in chiral smectic C (SmC*) phase [6].

In this study, we investigate the alignment characteristics and dynamics of particles dispersed in the LC under the applied electric field.

2. EXPERIMENTS

The LC used in this study is CS-1029 (CHISSO Co.), which has a phase sequence of isotropic – chiral nematic (N*) – smectic A (SmA) – chiral smectic C (SmC*). A small amount of SiO_2 spherical particles of 2 or 3μm in diameter was mixed into the LC. For an hour an ultrasonic stirring was performed above N* - Isotropic phase transition temperature to ensure the spatial homogeneity of the mixture. Some of particles were treated by hydrophilic surfactant; polyoxyethylene sorbitan monolaurate (TWEEN 20, KISHIDA CHEMICAL Co.). The sample was filled by a capillary action into a sandwich cell, which consists of two indium-tin-oxide (ITO)-coated glass plates. The cell gap was 9 μm. The movement and aggregation behaviors of the particles were observed using an optical microscope with a charge coupled device (CCD) camera.

3. RESULTS AND DISCUSSIONS

Under ac applied voltage of rectangular shape (60 Hz), the dynamic movement of the particles was observed. In the isotropic and N* phases, the particles migrated on a circular trace. On the contrary, the particles migrated linearly along the smectic layer in the layered smectic phases as reported by us [5].

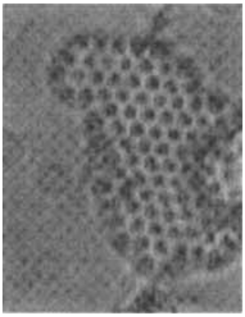

FIGURE 1 The well-ordered aggregation of the SiO_2 particles in the smectic liquid crystal

On the other hand, as shown in Fig.1, we have observed the regular aggregation of the particles, whose surfaces were treated by surfactant, under ac applied voltage of rectangular or sinusoidal shapes (100 Hz). The formation mechanism of this regular aggregation of the particles might be interpreted as follows, and schematic explanation is shown in Fig.2.

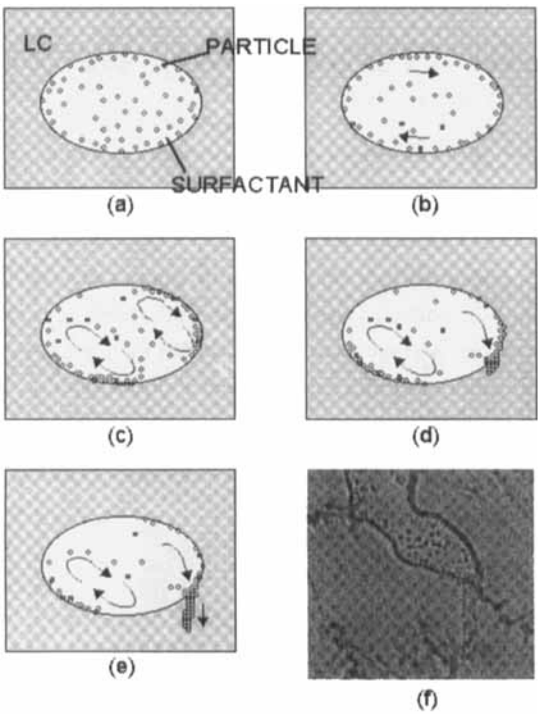

FIGURE 2 Schematic explanation of the construction mechanism of the aligned aggregation of the SiO_2 particles (before application of electric field (a) and under applied electric field (b) – (e)), and optical micrograph of formed aligned aggregation of the particles (f).

First of all, as mentioned above, the mixture of LC, small amounts of particles and surfactant is stirred above N* - isotropic phase transition temperature to ensure the spatial homogeneity. After this procedure, a phase separation between LC and surfactant was observed, and the particles were all included in the surfactant region as shown in Fig.2 (a). It might be because there is the difference in wettability between two phases, and the particles tend to be included in the more wettable surfactant phase. Upon the application of rectangular or sinusoidal voltages (100 Hz), particles in surfactant phase, at first, move to and along the LC/surfactant interface as shown in Fig.2 (b). Subsequently, they gradually swam and migrate along the interface (Fig.2 (c)), and gather at the corner of the domain such as a dislocation (Fig.2 (d)). Finally, these gathered particles were pushed out into the LC domain (Fig.2 (e) and (f)). In the smectic phase, the migration behavior of particles is restricted by the layer structure, so that there might be some correlation between the direction of this particle alignment and that of particle migration. Beside this mechanism, there seemed to be another one. In this case, the surfactant itself migrated by the application of electric field, and sometimes particles remained and aggregated regularly in the LC phase. Such aggregation of particles isolated from surfactant phase was very stable and destroyed only when applied voltage exceeded 80 V as shown in Fig.3.

Photonic crystals, which have a periodicity of optical wavelength, have attracted much attention from both fundamental and practical points of view. In this system, novel physical concepts such as photonic band gap (PBG) have been theoretically predicted and various applications of them have been proposed [7], [8]. So far, various approaches for the realization of photonic crystal have been proposed. In this study, we have confirmed the formation of the regular array of SiO_2 particles in the LC. In other words, the electric field induced formation of regular aggregation of silica particles might be expected for one of candidates for fabrication technique of photonic crystal. A tunable photonic crystal, in which PBG can be tuned as desired by controlling some parameters, has been proposed in a LC infiltrated synthetic opal constructed with SiO_2 spheres [9]. The system studied here is a reversed geometry of it. Namely, not "LC in the photonic crystal" but "photonic crystal in the LC".

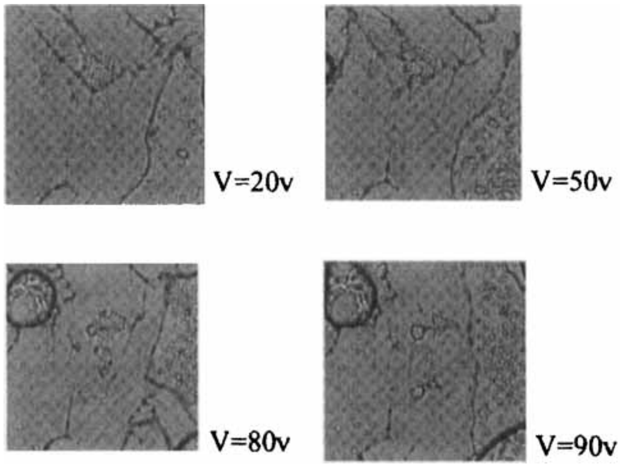

FIGURE 3 The aligned aggregation of SiO_2 particles isolated from surfactant. Only under high applied voltage (> 80 V), these aggregation was destroyed.

4. CONCLUSIONS

We investigated the alignment characteristics and dynamics of silica particles dispersed in the LC with surfactant under the applied electric field. In the system the LC, surfactant and SiO_2 particles, the regular aggregation of particles was observed under the applied electric field. Phase separation into the LC and surfactant domains, and electrohydrodynamic flow at the LC/surfactant interface might be required for this regular aggregation of particles. This electric field induced formation of regular aggregation of dielectric SiO_2 spheres also can be considered to be one of candidates for fabrication techniques of 2D photonic crystal.

References

[1] W. Winslow, *J. Appl. Phys.*, **20**, 1137 (1949).
[2] S. Fraden, A.J. Hurd and R.B. Meyer, *Phys. Rev. Lett.*, **63**, 2373 (1989).
[3] J.E. Martin, J. Odinck, T.C. Halsey and R. Kamien, *Phys. Rev. E*, **57**, 756 (1998).
[4] P. Poulin, H. Stark, T.C. Lubensky, D.A. Weitz, *Science* **275**, 1770 (1997).
[5] T. Togo, K. Nakayama, M. Ozaki and K. Yoshino, *Jpn. J. Appl. Phys.*, **36**, L1520 (1997).
[6] S. Lee, K. Nakayama, M. Ozaki and K. Yoshino, *Proceedings of ICDL '99.*
[7] S. John, *Phys. Rev. Lett.*, **58**, 2486 (1987).
[8] E. Yablonovitch, *Phys. Rev. Lett.*, **58**, 2059 (1987).
[9] K. Yoshino, Y. Shimoda, Y. Kawagishi, K. Nakayama and M. Ozaki, *Appl. Phys. Lett.*, **75**, 932 (1999).