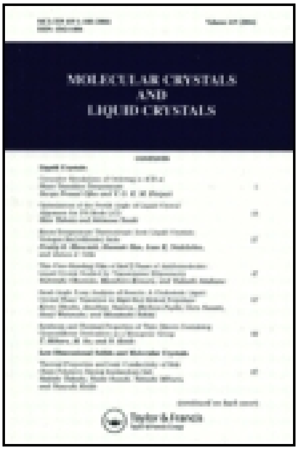

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Optical Properties of Colloid Liquid Crystal Composites

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Optical Properties of Colloid Liquid Crystal Composites

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Colloid-liquid crystal composites are a recently discovered class of soft solid comprising a dense dispersion of spherical colloidal particles in a liquid crystalline host with unusual mechanical properties. We applied this class of system to a variety of liquid crystal device modes such as twist nematic, homogenous aligned, White-Taylor GH and reflective cholesteric devices. The observed electro-optical response suggests that the local viscosity (controlling molecular reorientation) is decoupled from the (much higher) bulk viscosity. Over a wide range of particle concentrations across the full temperature range of the nematic phase, strong electro-optical switching is observed for 5CB and several of the commercially available liquid crystal mixtures. Contrast ratio, viewing angle characteristics, switching time and optical hysteresis exhibit a significant dependencies on particle density. We also demonstrate that how morphologies of the liquid crystal confined between the substrates affect the optical properties.

Keywords: colloid; liquid crystal; Optical properties; display device

Introduction

Colloid-liquid crystal composites (CLCC) are a recently discovered class of soft solid formed from concentrated dispersions of colloidal particles in mesogenic hosts[1,2,3,4,5]. In the accompanying paper[6], we have shown

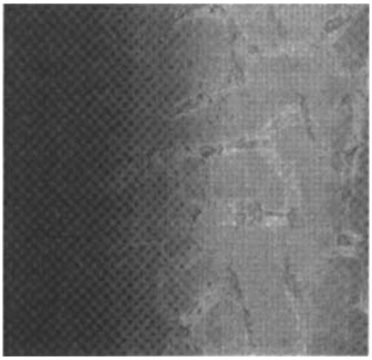

Fig. 1 Confocal micrograph of a CLCC material taken within a 10 μm test cell and prepared in a 5CB host material. Particle aggregates are visible as are regions of disrupted nematic order. The CLCC density is 1 wt. %. The picture size is 350 μm square.

that, at isotropic-nematic transition, these composites form a "cellular microstructure" where open LC-rich cavities are separated by patricle-rich interfaces (forms chains), leading to an anomalous increase in the visco-elastic shear modulus, which makes them rigid and self-supporting materials over a wide temperature range. Fig.1 shows the microstructure of the CLCC materials confined between narrow-spaced substrates using a laser scanning confocal microscope. A complex cellular microstructure is clearly evident. The LC domains within the cavities show a typical optical birefringence suggesting that all liquid crystal molecules are oriented along the surface alignment direction. Switching is easily observed in these cells though the network structure does not appear to be significantly disturbed during the switching process even over many on/off cycles. The materials show at least the same electro-optical switching characteristics as do the typical particle-free liquid crystal materials.

Despite lack of a thorough understanding of structure-property relationships in these materials, their unique combination of optical and mechanical properties and the fact that the cellular structure of the composites offers a potentially simple method by which to control, to some degree, liquid crystalline microdomains will make CLCCs potentially useful for novel device applications as innovations or improvements in display devices. At this early stage in the study of CLCC materials and properties we are interested in the possibility of controlling and exploiting the unique microstructure and mechanical properties to create polydomain in transmissive and reflective LC display devices. These polydomain structures may be utilized to reduce the angle-dependence of the display's viewing angle for a range of important device types, which are shown in the following sections.

Experiments

Colloid liquid crystal composites were synthesized using a liquid crystal host and nearly monodispersed polymethyl-methacrylate spherical colloidal particles of 190 nm in diameter. Test cells for electro-optical measurements were prepared from commercially available ITO (indium tin oxide)-coated glass slides, which are (if necessary) spin-coated with polyimide to control alignment. The cell gap was controlled by standard glass spacers. Transmittance measurements were made using a He-Ne laser as a light source and reflectance was obtained using a halogen lamp and a photometer. For viewing angle measurements, we employed an EZ Contrast system (ELDIM), where, in reflective measurements, diffuse illumination was used as the light source.

Results

(A) Homogenous aligned nematic cell

10 μm cells with both surfaces homogenously aligned were prepared. The liquid crystal used was 5CB. Fig. 2(a) shows the transmittance to voltage characteristics measured in transmissive mode, where crossed polarizers were placed with an angle of 45^0 relative to the liquid crystal director. Due to the inter-domain disorder, the maximum transmittance is lower than 1 with the worst case for the 2.5 % cell. The contrast ratio is 50 for 1% and 20 for 2.5%. Since Δnd is much higher than the optimum value, the curves show oscillation at low bias. The CLCC in the parallel-alignment geometry exhibits optical contrast states also in scattering mode where no polarizer is attached. In off state, the domains yield a light scattering due to inter-domain disorder induced by the colloidal inclusions. The application of voltage forces these domains to line up with the field, making the cell less scattering. Fig. 2(b) shows the transmittance as a function of the bias in this mode. The contrast ratio for 2.5% density was 3.8, which is not low considering that the birefringence of 5CB is not very high. Low contrast ratio for 1% density cell arises from the fact that there is little inter-domain disorder.

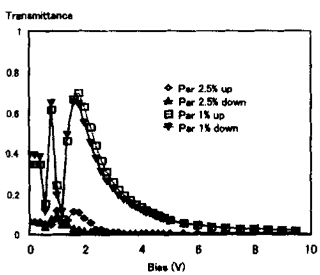

Fig. 2(a) Transmittance to voltage characteristics in birefringence mode for homogenous-aligned cells.

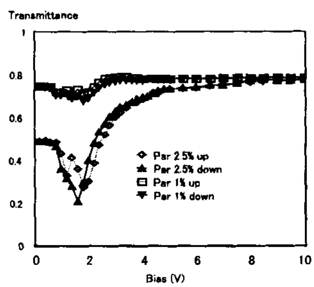

Fig. 2(b) Transmittance to voltage characteristics in light scattering mode for homogenous-aligned cells.

(B) Twist-nematic device

If a nematic liquid crystal is filled in a cell with unrubbed substrates, micro-domains where directors are aligned at different angles at the different domains can be induced. Fig. 3(a) shows the voltage to transmittance characteristics for cells prepared using CLCC suspension made of Merck ZLI-4792 with a helical pitch of 20 μm and 5μm thick cells with substrates coated with unrubbed polyimide (JSR AL1254). The contrast ratios were found to be approximately 100:1 or less at 5 V and a several hundreds to one at 10 V. The value at 5V is not as large as that of typical twist nematic cells due to the fact that light output now includes light scattering from the disordered domain boundaries. The transmittance at 0 V was around 0.7 due to disorder, where the directors inside the domains, twisting by a quarter-turn, have a 100% transmittance while the inter-domain directors have a smaller transmittance, resulting in less transmittance over the whole structure. When biased with 5V, the cell turns dark since the molecules line up along the electric field and the disclination loops started to disappear.

Generally, a monodomain twist-nematic device exhibits strong angular dependence of the luminance intensity, because the observed contrast between on and off states depends on the relative orientation of the effective optical axis and the viewing direction. In a CLCC TN device, the optical response is, in principle, an average over the microdomain orientations thereby reducing the overall optical anisotropy. An example is

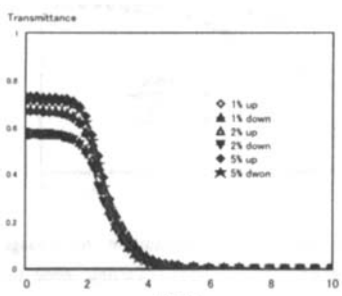

Fig. 3(a) Transmission vs. applied voltage for 5 μm twist nematic cells at 1%, 2% and 5% concentrations (by weight).

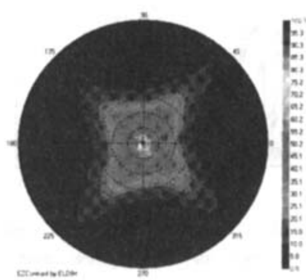

Fig. 3(b) Viewing angle for a 5 % sample for which the transmission vs. voltage is shown in Fig 3(a).

shown in Fig. 3(b). The viewing angle for this TN CLCC device shows partial averaging of the alignment direction in the polydomain structure.

In the voltage to transmittance curves, there is little hysteresis all over the bias range, despite of the disclination lines created and annihilated depending on whether the bias decreases or increases.

(C) White-Taylor GH device

This is a device that uses small amount of dye dopant in a host liquid crystal material for reflective display applications[7]. It is known to be subject to large hysteresis due to the appearance of stripe domains and is considered to operate only in bistable mode. Recent reports have suggested that careful temperature control in filling liquid crystal into a cell with unrubed polyimide can lead to amorphous surface alignment, which provides improved performance including grayscalability and wide viewing cone[8]. We have explored the effect of colloidal dispersions on the properties of guest-host devices fabricated in the White-Taylor design. CLCCs were obtained by blending a liquid crystal mixture (Merck ZLI-2293) with black dye materials (Mitsubishi Chemical LSY-116 at 0.72 wt%, LSR-405 at 0.19 wt%, LSB-318 at 0.97 wt%, LSB-335 at 1.06 wt% and LSR-652 at 0.48 wt%) to provide substantial light absorption and a chiral additive to induce a helical pitch of 12μm was introduced in a

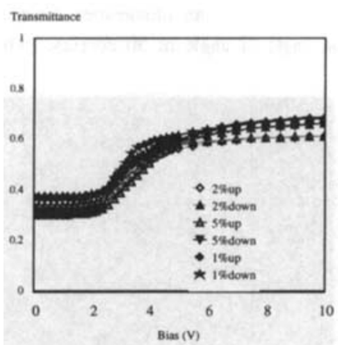

Fig. 4(a) Transmittance vs. applied voltage for 10 μm White-Taylor GH device at 1 %, 2 % and 5 % concentrations (by weight).

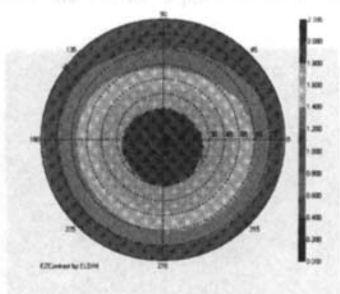

Fig. 4(b) Viewing angle for a 1 % samples for which the transmittance vs. voltage is shown in Fig 4(a).

cell with 10μm thickness. The substrates were coated with a polyimide (AL-1254) and not rubbed. Previous work on this device type focused on temperature treatment to control domain size, which is, in the CLCC system, affected by the particle density

Fig. 4(a) show the transmittance to voltage curves for different particle densities. This device exhibits transparent and dark states at higher and lower voltages with good grayscale characteristics in the middle range from 2 V to 6V. The viewing angle characteristics are significantly symmetric, as shown in Fig. 4(b).

(D) Reflective cholesteric device

In addition to the nematic liquid crystal devices, the CLCC can be applied to a device that takes advantage of the optical properties of cholesteric liquid crystal[9]. Using a commercial host material (BDH E-44) and chiral additive (a mixture of Merck S-811 and S-1011), we synthesized composites over a 1 to 10% concentration range. The composite were then introduced into 10 μm thick cells. Fig. 5(a) shows morphologies of the cell, which was made to reflect in green, in the planar (exhibits selectively reflective) and focal conic (weekly scattering) states. In both states the particles are localized in branches of a network. The weakly scattering mode in the focal conic state is, seemingly, stabilized relative to the reflective mode in the planar state by the presence of the colloidal dispersions.

Fig 5(b) shows the intensity as a function of wavelength for a 10% cholesteric composite in the planar and focal conic state (measured with illumination incident normal to the sample surface and a collection angle of angle of 30 degrees. The

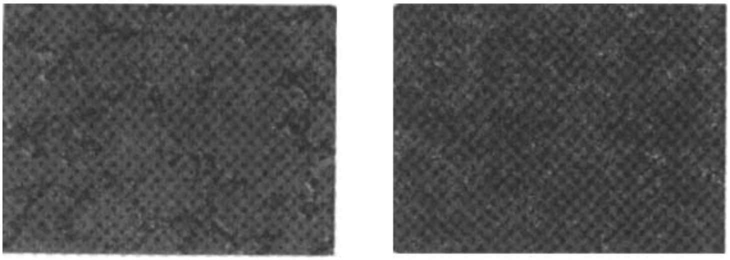

Fig.5 (a) Polarized microscopic images for a cholesteric texture with a CLCC of 2% at planar state (left) and focal state (right).

integrated luminance over this wavelength range implies a contrast ratio in excess of 10:1.

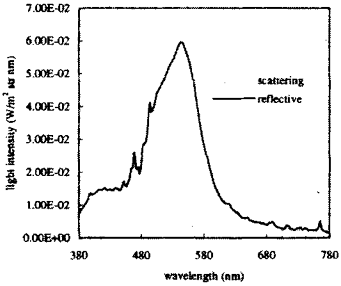

Fig. 5(b) Reflected intensity vs. wavelength for a 10 % CLCC cholesteric device in the focal conic and scattering states.

Conclusions

We have presented a survey of the properties of a unique class of liquid-crystal-based soft solid – the colloid liquid crystal composite with the aim of assessing its potential promise for use in display devices. In this report we have shown (1) that display devices can be fabricated from CLCC composites over a range of particle concentrations; (2) that the naturally-occurring cellular morphology of the composites provides a simple and widely applicable method of generating polydomain structures and (3) have shown that this can reduce the angular dependence of the viewing angle in a variety of specific display device types. There are also drawbacks to CLCC-based materials. In particular, there is increased light scattering in the devices, which arises from the presence of the particles, which has the effect of reducing contrast relative to particle-free systems. Since colloid liquid crystal composite materials are currently at a very early stage of development and links between their structure, processing and properties are not yet firmly established. It is of particular importance to work further on improved morphology control, non-spherical particles, and optimization of concentration for specific applications.

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