Research News

Liquid Crystal Alignment and Switching in Porous Chiral Thin Films**

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Optimization of optical properties in liquid crystal (LC) devices requires control over the long-range orientation of the LC molecules. A variety of techniques are used to produce alignment in LC devices such as the familiar liquid crystal display (LCD). One well-known technique involves surface treatment of cell substrates by coating with thin polymer films such as polyimides that are subsequently rubbed.[1] These treatments are used to produce a known orientation of the LC molecules at the surface. For example, rubbed layers may be used to align rod-like nematic LC molecules near the substrate with their long axes parallel to the direction of rubbing. The twisted nematic LCD, as an example, has the rubbing direction of the two substrates of the display cell perpendicular to each other to generate a 90° twist in the nematic orientation aided by a small amount of chiral dopant. A second technique for controlling LC orientation is the use of obliquely deposited thin films as alignment layers which generate a certain “tilt” of the LC molecules at the substrates.[2,3]

These types of orientation layer techniques influence LC orientation near the substrate surfaces only and are reliant on the LC molecules “settling” into some minimum potential energy arrangement which gives the desired properties. The major drawback of these surface alignment layer techniques is that they are unable to provide significant influence on LC orientation further from the substrate surfaces. Maintenance of the desired LC orientation in thicker switching cells, particularly with chiral or cholesteric LCs (CLC), becomes especially difficult. This leads for instance to irreversible switching when the LCs do not settle back into their original arrangement under influence of the alignment layer after having been addressed.[4]

For better control over LC alignment, a technique which induces LC alignment throughout the cell is required, rather than influencing the LC orientation near the substrate surfaces only. This can be accomplished, for instance, by phase separation in polymer-dispersed liquid crystals (PDLC) or photopolymerization to “freeze” in the desired LC alignment.[5] These techniques, however, may come at the sacrifice of the ability to switch the LC.

A recent innovation in LC alignment was made by Robbie, Broer, and Brett[6] who embedded LCs into porous thin films with engineered microstructures. These porous thin films are fabricated using glancing angle deposition (GLAD), a physical vapor deposition technique which allows the fabrication of highly porous thin films with columnar microstructure controllable on the sub-micrometer scale. GLAD uses highly oblique or glancing angle deposition (typically at vapor incidence angles of \( \alpha > 75^\circ \), measured relative to the substrate normal) to accentuate the atomic shadowing effects, leading to thin films with porosities tunable from 10% to 90%.[9,10] Computer control of substrate motion during

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Fig. 1. Example of a chiral GLAD film: A left-handed helical film with 8.4 turns of pitch 410 nm is shown. The film pitch is the thickness of one turn of the helix and relates to the wavelength at which peak chiral optical activity is observed.
deposition[7,11] allows shaping of the film microstructure during deposition.

GLAD films possessing “helical” or chiral microstructures (Fig. 1) have been shown to exhibit optical activity and circular Bragg reflection similar to CLCs.[12,13] The unique chiral optic response of chiral GLAD films arises from the structural chirality and the index difference between the film material and the void material (air). Using GLAD, the microstructure parameters such as helical rise angle, pitch, and handedness are easily controlled. Structures such as pitch gradients and stacked layers of different pitch and/or handedness are easily produced. Creation of similar textures using chiral LCs is difficult, if not impossible, to achieve.

Robbie, Broer, and Brett[6] filled the pores of GLAD films with nematic LCs and found that the helical GLAD film acts as an alignment or “backbone” structure for the LC material, inducing orientation of non-chiral nematic LCs in chiral nematic-like phases. The addition of LCs was found to improve substantially the chiral optic response compared to that of the unfilled film. Recently, we have demonstrated electro-optic switching of the LC component in a display cell structure fabricated from helical GLAD films filled with nematic LCs.[14]

Porous, chiral GLAD films of SiO₂ (n = 1.47) were deposited using GLAD (Fig. 1) by electron-beam evaporation onto glass substrates coated with indium tin oxide (ITO) transparent conductor for fabrication of the LC switching cells. This film is composed of left-handed helical columns with 8.4 turns and pitch p = 410 nm. The pitch is the thickness of each turn of the helix, that is, the spatial periodicity along the helical axis. The pitch in a helical GLAD film is controlled by the ratio of deposition rate to substrate rotation rate, while the handedness is controlled by the direction of rotation.

LC switching cells were constructed by using a second ITO-coated glass substrate to form a “sandwich” with the GLAD film in between. The cells were filled with LCs in an evacuated oven by dipping one edge of the cell into a pool of the LC. The cells fill by capillary action and then are sealed. The two glass substrates were offset slightly to permit electrical contact to the ITO layers. We used nematic LC E7 from Merck (nₑ = 1.5216, nₑ = 1.7462 at 25 °C).

A UV-vis spectrophotometer was used to perform the measurements. The light path consisted of: light source, depolarizer, linear polarizer, quarter wave retarder oriented at ±45° to the polarizer axis, sample, depolarizer, and detector. Left- (LCP) or right-circularly polarized (RCP) light was produced by the combination of the linear polarizer and the quarter wave plate (560 nm). Transmission was measured for both LCP and RCP, from which difference spectra were calculated.

Figure 2 shows measurements of LCP and RCP transmission from the cell prior to filling with the LC (“unfilled film”) and after filling it, in addressed and unaddressed modes. In the unaddressed state (no voltage applied), enhanced circular dichroism as compared to the unfilled film is observed (“unaddressed” versus “unfilled film”). LCP, the circular polarization which matches the handedness of the film, is selectively scattered/reflected by the sample, as consistent with previous work and theoretical investigations.[6,15] A remarkable effect was observed when the cell was addressed with a 1 kHz, 200 V (peak-to-peak) signal. In the addressed state, all transmission difference between LCP and RCP vanished (“addressed”). The application of the electric field causes the LC molecules to change their alignment from the quasi-chiral nematic phase to a homeotropic state (perpendicular to substrates, parallel to the applied electric field). Transmitted light through the cell thus “sees” the ordinary index of the LC, nₒ (1.52 for E7), which is an approximate index match for the GLAD film material (SiO₂, n = 1.47), causing the chiral nature of the film to be effectively cancelled and resulting in the loss of circular polarization transmission difference. When the electric field was removed, the cell reverted to its unaddressed state.

Using glancing angle deposition, we can fabricate porous chiral thin films with tailorable microstructure. The pores of these thin films have been embedded with liquid crystalline materials to produce a new type of hybrid optical material. Helical GLAD films have been shown to induce chiral alignment in nematic LCs which do not form chiral phases on their own, resulting in enhanced chiral optic response over that of the GLAD film alone. Reversible electro-optic switching of the LC component of these devices has been demonstrated wherein the chiral optic response vanishes with application of an electric field. GLAD films embedded with LCs are envisioned for a wide range of applications such as new types of displays.