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Photo-alignment of liquid crystals using a crosslinked discotic film

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Preliminary communication

Photo-alignment of liquid crystals using a crosslinked discotic film

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A new photo-alignment layer using a crosslinked discotic compound was demonstrated. This discotic compound exhibits excellent solubility in common organic solvents, the possibility of low temperature processing and good thermal stability. A linearly polarized long wavelength ultraviolet (LPUV) light ($\lambda = 350$ nm) was used to initiate the crosslinking process and induce liquid crystal alignment on the discotic film surface. The induced LC directors were found parallel to the electric field direction of the LPUV light. A 1.2° pre-tilt angle was achieved using a single exposure at a 30° oblique angle.

The surface rubbing technique has been commonly used for fabricating large liquid crystal display panels. However, the rubbing process may cause electrostatic charges, dusts, or scratches that tend to reduce the manufacturing yield. Several non-rubbing methods, such as the use of Langmuir–Blodgett films [1], stretched polymers [2], photolithography [3], stamped polymers [4] and linearly polarized ultraviolet light (LPUV) exposure of polymers [5–7] have been developed. Among them, photo-alignment is promising for overcoming the drawbacks caused by the rubbing process and providing multi-domain structure for widening the viewing angle [8].

Many types of polymers, e.g. polymers doped with photo-isomerized azo-compounds [9–11], poly(vinyl cinnamate) derivatives [12–15] and polyimides (PIs) [16–19] have been proposed for photo-alignment purpose. Among these alignment agents, poly(vinyl cinnamate) film showed insufficient thermal stability at elevated temperatures. On the other hand, PIs possess excellent thermal stability except that a strong UV light ($\lambda = 254$ nm) is required for generating LC alignment. These high energy UV photons would decompose the polymer backbones and form charge trapping centers on the LC and PI interfaces which, in turn, cause image sticking during active matrix addressing [20].

In this paper, we report a thermally stable, crosslinked discotic photo-alignment film processed via long wave LPUV ($\lambda = 350$ nm) irradiation. The long wave LPUV initiates the crosslinking process without decomposing the discotic compound. As a result, no charge trapping centre is formed. The structure of the discotic compound used in this study is shown in figure 1. It can be easily dissolved in common organic solvents such as ethyl acetate, chloroform, tetrahydrofuran and methyl ethyl ketone. Thus, the film fabrication process is relatively simple.

In preparing the crosslinked discotic photo-alignment layer, 100 mg of discotic monomer and 2 mg of photoinitiator (diphenyliodonium hexafluoroarsenate) were

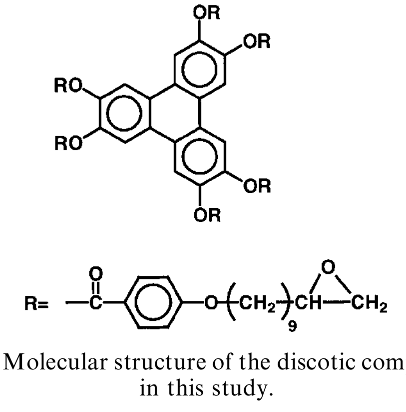

Figure 1. Molecular structure of the discotic compound used in this study.

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dissolved in 2 ml of methyl ethyl ketone and spin coated onto a glass substrate. The substrate was baked at 60°C to evaporate the solvent. Afterwards, the film was exposed to a LPUV light for 2 h to obtain crosslinked structure. During the experiment, a typical discotic film was peeled off from the glass substrate and was found to be insoluble in any of the solvents studied. This confirmed the formation of a crosslinked structure.

Figure 2 shows the experimental set-up for the UV exposure system used in this study. The UV exposure was performed using a long wave UV light (Rayonet Photochemical Reactor, Model RPR-100, $\lambda = 350\,\mathrm{nm}$) filtered with an Oriel UV linear dichroic polarizer (Model 27320). The light intensity at the sample surface was measured to be $0.65\,\mathrm{mW\,cm^{-2}}$. If the UV flux was increased, the exposure time could be reduced proportionally. These discotic films were highly transparent and their thickness was measured to be about 220 nm, using a Dektak^3 ST (Vecco USA) α stepper instrument.

To study the LC alignment characteristics, several parallel cells with a 25 μm cell gap were assembled using these UV-irradiated discotic films. Five Merck LC mixtures: ZLI-4792, ZLI-2806, ZLI-5600-100, E7 and 5CB (4-cyano-4′-*n*-pentylbiphenyl) were used for alignment studies. The cells were inspected under a polarizing optical microscope. Under the crossed polarizer condition, ZLI-4792, ZLI-2806 and ZLI-5600-100 showed birefringence colours. Rotating the cell along the polarization plane led to high contrast bright and dark states. This is clear evidence of homogeneous alignment. In contrast, the 5CB and E7 cells formed homeotropic alignments; the reason for this is not yet completely understood. Since E7 consists of mainly cyanobiphenyl homologues, we speculate that the cyano group is adsorbed to the discotic core so that the first monolayer is aligned nearly perpendicular to the substrate surface. This monolayer then influences the bulk to form homeotropic alignment.

For comparison purposes, an unpolarized UV light was also used to irradiate the discotic films; no single domain was obtained. By contrast, all the films exposed to LPUV light produced single domain LC alignment.

Pretilt angle is an important parameter for a LC cell in the elimination of disclination lines. The discotic film with LPUV exposure at normal angle showed no pretilt angle, so that when the applied voltage exceeded the Fréedericksz transition threshold, disclination lines appeared, as shown in figure 3 (*a*). To increase the pretilt angle for eliminating disclination lines, the discotic films were exposed at an oblique angle θ, as sketched in figure 2. Figure 3 (*b*) shows a uniform image without disclination lines at $5\,\mathrm{V_{rms}}$. This implies that a pretilt angle on the discotic surfaces was indeed generated.

We measured the pretilt angle of a homogeneous cell using the crystal rotation method [21]. Figure 4 depicts the measured (solid lines) and fitted (dashed lines) results for the ZLI-4792 cell exposed at $\theta = 30°$. From fitting, the pretilt angle is found to be 1.2°.

To determine the photo-induced LC molecular orientation direction with respect to the incident UV light polarization axis, a homogeneous ZLI-4792 cell doped with 1 wt % dichroic dye, M137 (from Mitsui Chemicals, $\lambda_{max} = 638\,\mathrm{nm}$) was prepared and measured at $\lambda = 638\,\mathrm{nm}$) using a spectrophotometer and a linear polarizer. The linear polarizer was consecutively rotated from 0° to 360°; 0° represents that the linearly polarized red light is parallel to the LPUV exposure direction. Figure 5 shows the resulting angular-dependent absorption diagram of the dye-doped ZLI-4792 cell. The cell axis, indicated by arrows, is defined as the electric field

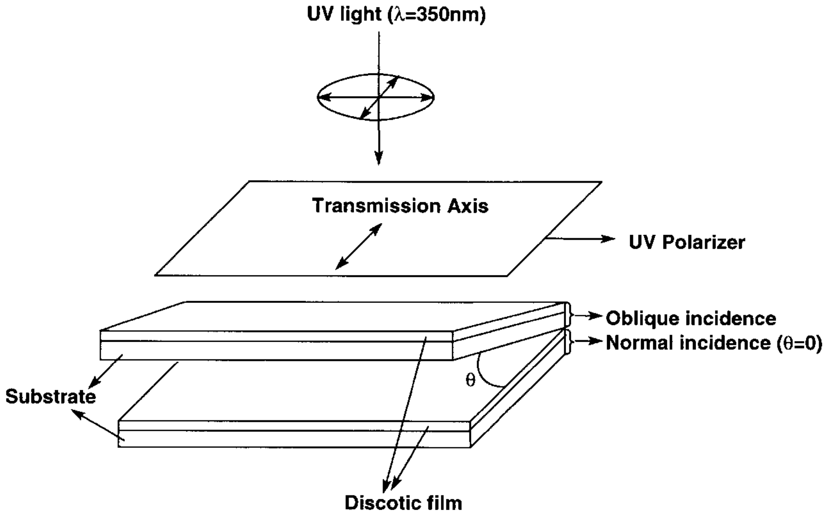
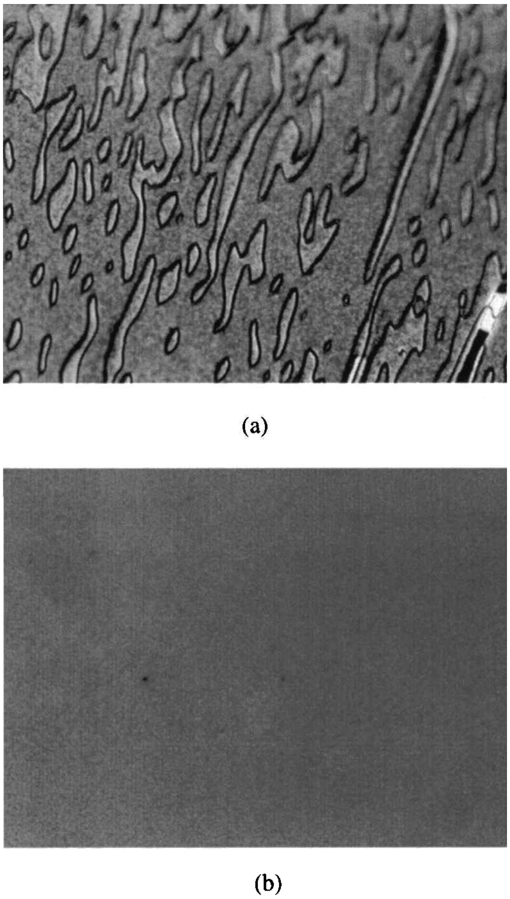


Figure 2. Experimental set-up for the UV-induced LC alignment at normal and oblique incident angles.


(a)

(b)

Figure 3. Optical microscope photographs of the disclination lines of photo-aligned ZLI-4792 cells. (*a*) $\theta = 0$, (*b*) $\theta = 30°$; θ is the exposure angle shown in figure 2. $V = 5\ V_{rms}$ and polarizers are crossed.

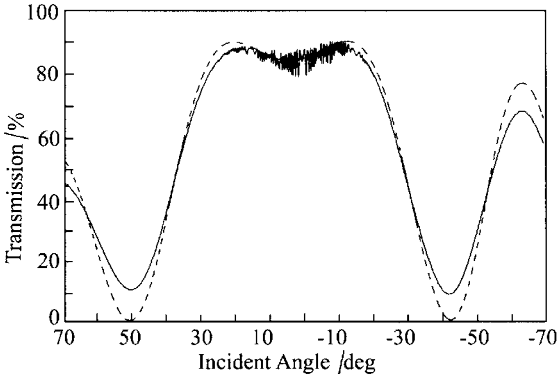


Figure 4. Pretilt angle measurement of the ZLI-4792 cell exposed at 30° oblique angle. Dashed lines represent the fitting results. From fittings, the pretilt angle is found to be 1.2°.

vector of the LPUV light during the exposure process. From figure 5, the photo-induced LC directors are found to be parallel to the electric field direction of the incident LPUV light.

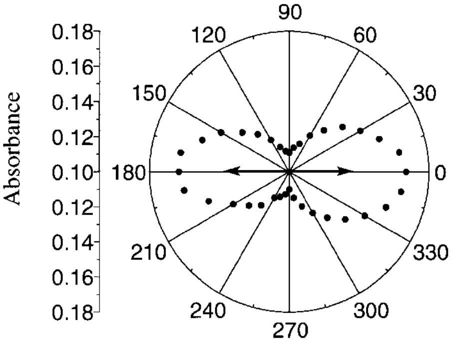


Figure 5. Angular-dependent absorption diagram of a dye-doped homogeneous ZLI-4792 cell. Dye = 1 wt % M-137, $\lambda = 638$ nm. Arrows indicate the polarization axis of the incident linearly polarized UV light.

To evaluate the thermal stability of the LPUV-induced discotic alignment films, the ZLI-4792 and 5CB cells were kept in an oven at 120°C for one week. No degradation in the LC alignment was observed. This high thermal stability is attributed to the crosslinked structure within the film.

In conclusion, we have demonstrated a new cross-linked discotic film for serving as a photo-alignment layer. Long wave UV light ($\lambda = 350$ nm) was used to initiate the crosslinking reaction as well as to induce photo alignment on the film surface. These new photo-alignment layers possess good thermal stability and a low processing temperature. The long axis of the nematic LC molecules was found to be parallel to the electric field direction of the LPUV light. A 1.2° pretilt angle of the discotic alignment films was generated under a single UV exposure at 30° oblique angle. The potential application of this discotic compound for low temperature polysilicon TFT-LCDs is foreseeable.

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