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Optically isotropic liquid crystals for next-generation displays

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Optically isotropic liquid crystals have seen recent progress toward reducing operating voltage and suppressing hysteresis.

LCDs have become indispensable in our daily lives. They are used everywhere, such as in cell phones, computers, television sets, and data projectors. Based on continuous innovation, their overall display quality has reached a satisfactory level. Viewing-angle restrictions are no longer an issue following implementation of multidomain structures and phase-compensation films, their contrast ratio has exceeded one million to one through local LED-backlight dimming, and sunlight washout has been overcome by employing transflective displays. LCD technology is, thus, relatively mature. However, some challenges still remain, including their relatively slow response time. This causes image blur for fast-moving objects and holds back adoption of color-sequential displays, which promise to triple light efficiency and resolution density.

Much effort has been devoted to improving LCD response times. With continuously improving low-viscosity liquid-crystal (LC) properties, device configuration, and driving methods, the response time has been reduced to 2–5ms.[1] However, it is still not fast enough to eliminate the color breakup observed in color-sequential displays. Suppressing this phenomenon requires LC response times of less than 1ms. To achieve this goal, optically isotropic LC is emerging as a potential next-generation display technology.

A conventional, nematic LC turns isotropic when the temperature exceeds the clearing point. Within a few degrees above the nematic-isotropic transition temperature, LCs can still be controlled by an electric field and exhibit ∼100ns response time.[2] However, the remaining phase is too small and the required operating voltage too high for display applications. By introducing a certain amount of chiral dopant and polymers into a LC host, polymer-stabilized LC composites can be made optically isotropic over a reasonably wide temperature range.[3]

Compared to conventional, nematic LCDs, this new optically isotropic LC exhibits several advantages. First, the system can be optimized to achieve submillisecond response time. Second, because the dark state is optically isotropic, its viewing angle is intrinsically wide and symmetric. In addition, the alignment layer for conventional LCDs is no longer needed, which simplifies the fabrication process and reduces cost, while the material's performance is insensitive to the LC-layer thickness. This cell-gap insensitivity is particularly desirable for fabrication of large-panel LCDs for which cell-gap uniformity is a significant concern.

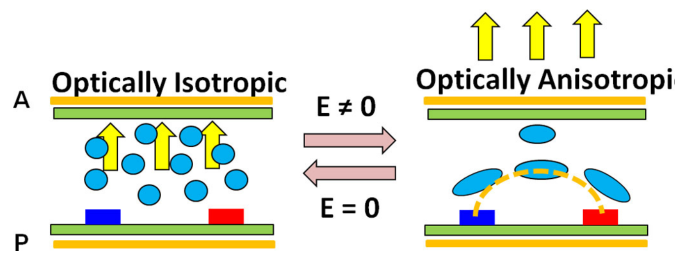

Figure 1. *Optically isotropic liquid crystals (LCs) in an in-plane-switching electrode cell. Left/right: Voltage-off/on. P: Polarizer. A: Analyzer. E: Electric field.*

However, several technical challenges (e.g., high operating voltage, hysteresis, and the relatively narrow characteristic temperature range) remain to be addressed before widespread commercialization can be realized. Our research team is working on material optimization and new device structures to lower the operating voltage and optimize display performance. Figure 1 illustrates the working principle of optically isotropic LCDs. We employ an in-plane-switching electrode to generate a horizontal electric field. In the voltage-off state, the LC composite appears optically isotropic. This results in blocking of the incident light by the top analyzer and, therefore, a dark state. Upon application of a lateral electric field, the refractive-index profile becomes anisotropic because of the Kerr effect.[4] Consequently, phase retardation occurs and the incident light is transmitted.

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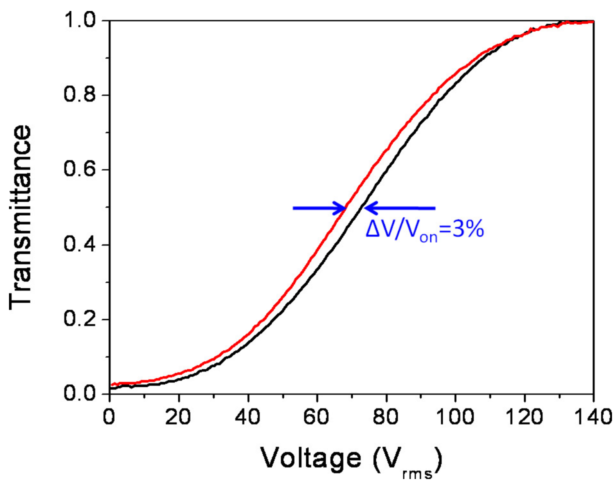

Figure 2. *Suppressed hysteresis in an optically isotropic LC composite. V_{on}: Peak transmittance voltage. ΔV: Voltage difference.*

To lower the driving voltage, a large induced birefringence (i.e., a large Kerr constant) is preferred. Through induced-birefringence measurements[5,6] we found that a LC host with a higher intrinsic birefringence, larger dielectric anisotropy, and higher concentration is helpful for voltage reduction. In a parallel effort, we also developed new electrode configurations to generate deeply penetrating electric fields.[7,8] We managed to reduce the operating voltage from 50 to $\sim 10V_{rms}$ while maintaining a reasonably high transmittance (65–85%, depending on electrode structure). This approach enables addressing of optically isotropic LCDs by amorphous-silicon thin-film transistors. To reduce hysteresis, we optimized the monomer concentration. The hysteresis—defined by $\Delta V/V_{on}$ at 50% transmittance, where V_{on} is the voltage corresponding to the peak transmittance—is merely 3% (see Figure 2).

Displays based on such optically isotropic, self-assembled LC composites are attractive because of their fast switching time, symmetric viewing angle, and simple fabrication process. Significant progress has been made toward lowering operating voltage, enhancing transmittance, and suppressing hysteresis. In addition to displays, this newly developed optically isotropic LC is also useful for photonics applications, such as polarization-independent adaptive lenses. We are continuing our research to overcome the technical challenges preventing commercialization of this novel display technology.

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