Advanced flexible liquid-crystal display technologies

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Novel flexible color moving-image television displays employ fast-response grayscale ferroelectric liquid-crystal, molecularly aligned polymers, large-size printing techniques, and flexible-backlight LEDs.

Flexible television displays employing plastic film substrates represent a next-generation technology, enabling creation of various display styles for human interfacing. At the same time, moving-image media services—including digital-television broadcasting—are making remarkable progress in the electronic information-network society. LCDs using glass substrates play significant roles in many aspects of our lives. New flexible light-weight LCD devices characterized by excellent portability and storage capacity will increase portability of applications from small- to large-area displays. Flexible nonemissive LCDs are also useful, with or without backlight, in transmissive/reflective ('transflective') mode for a range of illumination environments at indoor and outdoor venues. The intended purposes and targets of high-quality moving-image applications are different from those of recent developments in electronic-paper devices. The latter display still images with low power consumption because of their limited intrinsic image memory.

Such flexible devices must also have a minimum bending tolerance and be suitable for large-area fabrication. In conventional LCD structures the thickness of the liquid-state crystal layer cannot be kept constant between flexible thin plastic-film substrates. This is because conventional spacer particles (or ‘posts’) are not attached to both substrates. Thus far, several device structures using plastic supporting material have been used. For example, resin spacer posts previously attached to one substrate only by means of photolithography can be affixed to a second layer using thermal or UV-light-curable adhesives. However, the bending tolerance is limited by the small-area attachment structure of the spacer posts since bending causes strongly enhanced shearing forces on the spacers, which become stronger as panel size and bending degree increase.

We developed a new flexible LCD structure using molecularly aligned polymer crossing-lattice walls and polymer fiber networks (see Figure 1). The two rigid polymer structures covering the device plane function as plane-attachment spacers for firm substrate support. The polymer walls and networks cannot disorder the liquid-crystal (LC) alignment, because the molecular-alignment direction is parallel to that of the LCs. Therefore, the device will be affected by minimal light leaks, resulting in a high contrast ratio. We also adopted fast-response ferroelectric LCs (FLCs) to display high-quality moving images. The surface molecularly aligned fine-fiber networks stabilize the molecular alignment ('smectic' layers) of FLC bistable switches in one direction, resulting in a monostable electro-optic effect capable of rendering gray scales. The FLC/polymer composite device, equipped with crossed polarizers, is laminated with a flexible backlight film.

Figure 1. Cross-sectional structures of our ferroelectric liquid-crystal (FLC)/polymer composite device (left) and flexible display (right) using a flexible backlight film.

Figure 2. Printing and laminating processes employed for flexible-device fabrication.

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We also presented a new large-area fabrication method using LC/polymer phase separation and printing techniques. First, a high-viscosity solution of FLC and UV-curable liquid-crystalline monomer is coated onto a plastic substrate using a flexographic printing technique (see Figure 2). The solution film containing plastic spacer particles is sandwiched and pressed to uniform thickness by another plastic substrate using a laminating machine. At this time, the FLC and monomer molecules in the nematic-LC phase (where the molecules have no positional order but are positioned unidirectionally over large scales) are preferentially oriented between rubbed polyimide alignment layers on both plastic substrates. Subsequently, the rigid polymer walls (with typical widths and heights of 20 and 2µm, respectively) are aggregated by illuminating patterned UV light through a lattice-window photomask (at a pitch of 250µm). Finally, using uniform UV irradiation without mask, aligned polymer-fiber networks (of submicron diameter) are synthesized from the remaining monomers and segregated in the FLC layer. The two substrates are integrated into these polymers (see Figure 3), enabling production of a flexible A4-sized display device (see Figure 4).

We optimized the FLC electro-optic properties by precise control of the FLC/monomer concentration ratio, phase-separation temperature, and UV intensity and time in the two-step UV exposure. The device exhibits V-shaped symmetry for polarity-voltage driving, which is suitable for image operation. The low saturation voltage (several volts) is also useful for active-matrix driving using thin-film transistor (TFT) arrays for high-resolution display. The total rise and decay response time for the voltage pulse is less than 1ms, i.e., approximately 10 times faster than the equivalent times for conventional LCDs. The separation of FLC and polymer materials enables the low-voltage driving and fast response. We have succeeded in driving flexible FLC devices using a fundamental external-transistor-matrix circuit and—more practically—organic semiconductor (pentacene) and low-temperature polycrystalline-silicon TFT arrays deposited onto plastic substrates.

We fabricated two types of flexible backlight systems (see Figure 5) for the devices. The first is based on direct illumination of 2D arrays of low-profile LED chips sensitive to the three primary colors (red, green, blue: RGB) mounted on a flexible...
heat-resistant polyimide film. The backlight and FLC device are integrated using light-diffusion and optical-spacer films. The second is a flexible light-guide film of transparent silicon resin with edge-light sources consisting of thin RGB LEDs. The light-guide film is laminated with light-diffusion and prism-lens films. We demonstrated two types of color displays using microcolor filters and field-sequential-color driving (see Figure 6), where the FLC device is driven synchronously with intermittently RGB illumination lights at a high frequency of 180Hz. This system has a high light-use efficiency and low power consumption without optical loss.

Our next step will be to enhance the bending tolerance and contrast ratio of the displays by improving the device component materials and fabrication process. We also plan to use higher-resolution TFT technology for the plastic substrates.

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References