Emerging Technologies of Liquid Crystal Displays

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Abstract
The general features and the emerging technologies of liquid crystal displays are described from the viewpoints of wide viewing and fast response technologies. The device applications of liquid crystals for optical communications are also described.

1 Introduction
Liquid crystal displays (LCDs) currently play an extremely important role in high-performance information displays and future high-definition television (HDTV) sets. However, one of the most widely used LCDs, the twisted nematic (TN) LCD, has suffered from its narrow viewing and slow response problems. For many years, various technologies have been proposed to improve the dynamic image quality.

In this paper, we describe the general features and the emerging technologies of the LCDs from the viewpoints of wide viewing and fast response technologies. For non-display applications of the LCs, we also introduce many LC-based optical components with the electrical tunability used in the area of optical communications.

2 Optics in Liquid Crystal Displays
In the LCD configuration, the LC layer between transparent electrodes serves an optically active medium under two polarizers. Basically, the variable optical transmission through the LC layer resulting from the LC molecular reorientation by an electric field can be utilized for display applications in several device configurations.

Most of the LCDs manufactured currently adopt the TN mode operated in a passive driving scheme or in an active driving scheme with thin film transistor (TFT) arrays. The operation principle of the TN LCD is based on the waveguiding properties. If the polarization of the incoming light is parallel to the LC director at incidence, the polarization state of light will follow the twist structure of the local LC director as the light propagates through the LC layer. This leads to the rotation of the polarization state of the outgoing light. When an external electric field is applied, for the case of the positive dielectric anisotropy the LC molecules become aligned parallel to the field direction because of the dielectric coupling of the LC with an external electric field. In this case, no optical transmission is available through the LC cell under crossed polarizers since the optic axis of the LC layer is perpendicular to the substrates.

3 Wide Viewing Technologies
As discussed above, the TN LCD has suffered from poor viewing properties that originate intrinsically from the asymmetrical nature of the LC alignment. Various methods such as the multi-domain alignment and the in-plane switching (IPS) mode have been developed to improve viewing properties of the nematic LCDs. Except for the IPS mode, additional complex processes should be employed for the LC alignment.

Recently, a new configuration with self-formed micro-domains has been proposed to extend the range of viewing in the TN LCD [1]. In this configuration, the periodic microdomains were spontaneously formed in each pixel of the TN LCD having the dielectric surface gratings (DSG) when the grating fringe field (GFF) effect was combined with the topographical LC alignment factors governed by the periodicity of the DSG. The self-formed micro-domains in each pixel of the TN cell with the DSG tend to eliminate the contrast inversion of the TN LCD.
4 Fast Response Technologies

The response time of the nematic LCD modes are limited by the collective molecular reorientation driven dielectrically. A variety of display configurations using ferroelectric liquid crystals (FLCs) with spontaneous polarization have been extensively studied to obtain the dynamic image at video-rate. However, it is difficult to obtain uniform alignment in large area.

Recently, using a deformed helix ferroelectric (DHF) LC with short pitch, a vertical configuration (VC) having in-plane electrodes was proposed to improve the image quality including fast response and wide viewing properties [2]. In this geometry, smectic layers arrange themselves parallel to the substrates and thus extremely uniform alignment of molecules in large area is naturally achieved without additional processes.

In the absence of an electric field, the average optic axis is parallel to the helix since the helical pitch of the DHFLC is shorter than the wavelength of visible light. This situation corresponds exactly to a homeotropically aligned nematic structure, and therefore the complete extinction is obtained under crossed polarizers. On the other hand, when an electric field is applied, the molecules rotate oppositely on the smectic C* (Sm C*) cone in two sub-pixels for given polarity of the electric field. In this configuration, the optic axis becomes continuously tilted away from the surface normal and reaches the maximum value of the molecular tilt in the Sm C* state as the electric field increases. This VC-DHFLC mode provides the analog gray scale capability, fast response, and wide viewing properties in large area.

5 Non-Display Applications

In addition to the LCDs described above, there are many other applications of LCs such as wavelength filters, optoelectronic networks, and optical interconnection areas. Particularly, many electrically tunable optical devices based on LCs have been developed in the area of optical communications. An electrically tunable Fabry-Perot (FP) filter with a LC film, used in wavelength division multiplexing systems, allows for low operating voltage, relatively wide tuning range, compact, and easy fabrication. In a conventional LC FP structure, however, the wavelength selection is usually highly sensitive to the polarization state of the input beam with respect to the optic axis of the active LC layer.

Recently, it has been reported on a polarization-insensitive LC FP filter in an axially symmetric hybrid configuration [3]. The in-plane axial symmetry was produced using homeotropic alignment of the LC molecules on one mirror surface of the FP cell and axially homogeneous alignment on the other. The wavelength tunable LC FP filter with axial symmetry is completely independent of the input polarization in contrast to conventional LC FP filters.

An electrically tunable polarizing beam splitter (PBS) using LC binary gratings is recently proposed [4]. The LC PBS structure consists of alternating striped domains with homeotropic and hybrid geometries. A linearly polarized light parallel to striped domains experiences periodic refractive index modulation. For suitable amplitude of periodic refractive index modulation controlled by an applied electric field, the first order diffracted light is maximized and the zero-th order is absent. However, there is no diffraction for the incident light perpendicular to striped domains and the zero-th order is maximized since the medium is homogeneous. Therefore, the incident light can be decomposed into the zero-th and first orders depending on their polarization states.

6 Conclusion

The TFT-LCDs with fast response and wide viewing properties are currently one of viable contenders to replace cathode-ray tubes for monitors and HDTV sets. Moreover, since the LCs offer large optical anisotropy, fabrication flexibility, and processing simplicity, the LCs are useful for many electrically tunable optical devices in the area of optical communications.

7 References
4 J.-H. Park et al., to be submitted.