63.1: *Invited Paper:* Liquid Crystal Devices Based on Photo-Alignment and Photo-Patterning Materials

Vladimir Chigrinov, Hoi Sing Kwok
ECE Dept, HKUST, CWB, Kowloon, Hong Kong

Isa Nishiyama, Hirohi Hasebe, Haruyoshi Takatsu
Dainippon Ink and Chemicals Incorporated, Tokyo, Japan

Abstract
Liquid crystal devices based on photo-alignment and photo-patterning materials, were proposed, including patterned retarders for 3D applications, lenses with electrically tunable focal distance, LC based sensors, switchable q-plates, and optically rewritable E-paper. The photoalignment materials were mostly photosensitive azo-dye layers. The combination of azo-dye layers and liquid crystal polymers were also used for photo patterned phase retarders. The practical applications of new LC elements in 3D displays and other LC technology areas are envisaged.

1. Introduction
Photoalignment and photopatterning technology can make a sufficient contribution to the new classes of liquid crystal devices. Photoalignment possesses obvious advantages in comparison with the usually “rubbing” treatment of the substrates of liquid crystal display (LCD) cells. Possible benefits for using these techniques include [1]:

(i) Elimination of electrostatic charges and impurities as well as mechanical damage of the surface;

(ii) A controllable pretilt angle and anchoring energy of the liquid crystal cell, as well as its high thermo and UV stability and ionic purity;

(iii) New advanced applications of LC in fiber communications, optical data processing, holography and other fields, where the traditional rubbing LC alignment is not possible due to the sophisticated geometry of LC cell and/or high spatial resolution of the processing system;

(iv) Ability for efficient LC alignment on curved and flexible substrates;

(v) Manufacturing of new optical elements for LC technology, such as patterned polarizers and phase retarders, tunable optical filters, polarization non-sensitive optical lenses, with voltage controllable focal distance etc.

We report liquid crystal devices based on photo-alignment and photo-patterning materials, patterned retarders for 3D applications, lenses with electrically tunable focal distance, LC based sensors, switchable q-plates, and optically rewritable E-paper.

2. Results and Discussion
A tunable-focus liquid crystal (LC) lens was achieved using variable pretilt angle in LC layer obtained by exposing the photoalignment layer by UV light (Fig.1). The focal length of the LC lens can be worked out according to the retardation profile and it is electrically tunable. LC lens is compact, lightweight, low-cost, and highly efficient. The applications in adaptive optics, optoelectronics, machine vision, 2D/3D switchable LCD, and eyeglasses are envisaged. The focal distance of the lens was varied between 17 cm and infinity dependent on voltage [2].

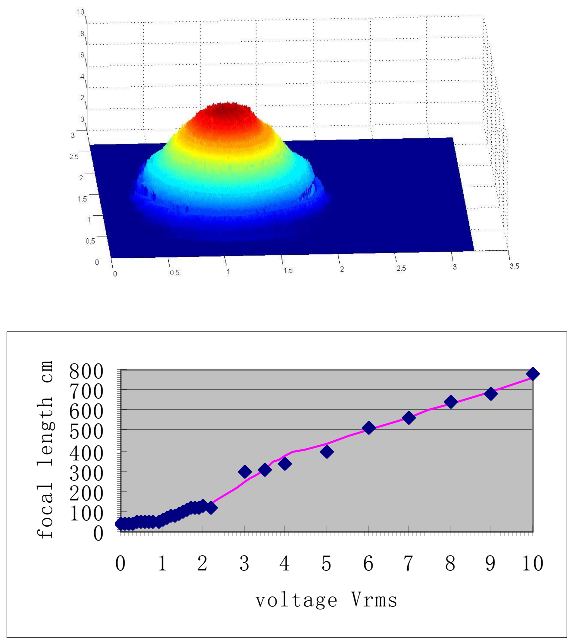

Figure 1. Tunable LC lens based on photoalignment materials. Top: 3D lens profile. Bottom: Voltage controlled focal length of the lens.

A photo patterned micro polarizer has been also proposed, based on the combination of photoaligned azo-dye layers and liquid crystal polymers [3]. We put together three layers, a linear polarizer, a quarter wave plate with the fast axis at 45°or -45° to the transition axis of the said linear polarizer and another quarter wave plate with the fast axis oriented at a angle θ. The light beam through the three layers will be linear polarized at an angle θ+45° or θ-45° (Fig.2). Photoalignment technology is used to make the patterns of the polarizer, and domain size can be made with several microns size. The same patterned polarizer can be used in photoalignment process to copy another, so the cost in production is greatly reduced. This photo patterned polarizer can be made to unlimited patterns and can be designed for any wavelength from

UV to IR. It can also be made to be broadband by broadband quarter wave plate. The applications in 3D displays based on micropatterned polarizers are envisaged (Fig.2).

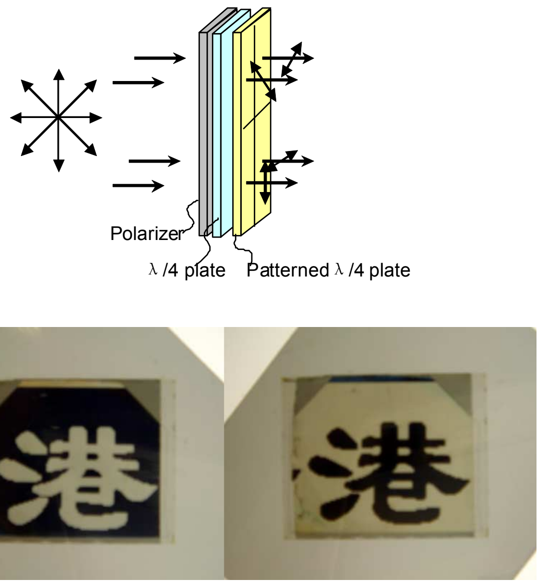

Figure 2. Photo-patterned polarizer. Top: Principal configuration. Bottom: Chinese characters image made by a photo-patterned polarizer.

A thin high spatial resolution, photo-patterned micropolarizer array for complementary metal–oxide–semiconductor (CMOS) image sensors was implemented for the complete optical visualization of "invisible" objects (continuous transmittance/reflectance and no color), using a simultaneous detection of all four Stokes parameters of output optical image (Fig. 3) [4]. A photopatterned polarizer is based on azo-dyes with a high photoinduced order parameter [1].

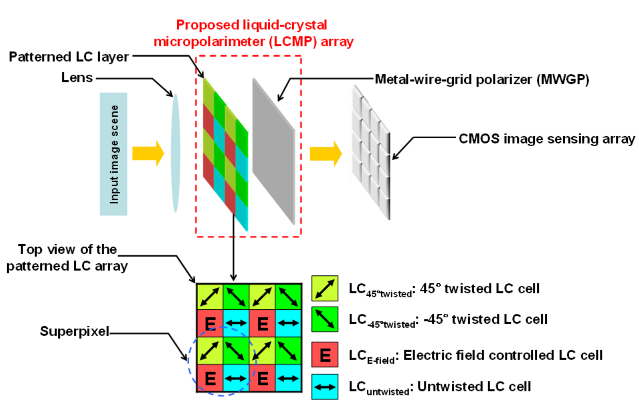

Figure 3. Photo-patterned micropolarizer array for a simultaneous detection of all four Stokes parameters of output optical image [4].

The device, called "q-plate" (QP) is essentially a birefringent wave plate with inhomogeneous patterned distribution of the local optical axis in the transverse plane. The pattern of the optical axis distribution is defined by semi-integer "topological charge" q. The photoalignment technology allows, in principle, to create of any topological semi-integer charge and does not need precise control of the cell gap of the sample. The orientation of the local optical axis, in case of the axial dependence only can be given by

$$\alpha(\varphi) = q\varphi + \alpha_0$$

where q is the topological charge, φ is the transverse azimuthal coordinate and α_0 is a real number. In case of $q = 1$ LC forms a circularly symmetric azimuthal or radial distribution of the optical axis. While the $q = 1$ QPs can be manufactured by rubbing, other patterns are not realizable with this method. We have employed photoalignment technique to manufacture LC QPs (Fig. 4) [5]. Topological charges $q = 0.5, 1.5, 3$, as shown in Fig. 4, were realized, however, any semi-integer charge can be realized with such technique. Such tunable birefringent q-plates based on electrical field controlled LC cell with special alignment (Fig.4) can found numerous applications in various fields of optics and displays.

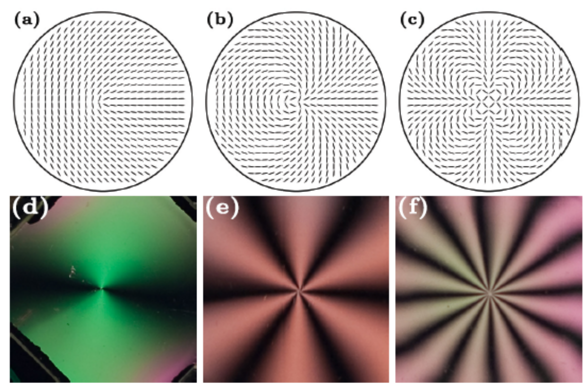

Figure 4. Examples of the LC patterns that correspond to different topological charges and the photos of the samples prepared under crossed polarizers. The simulated charges are (a) – q = 0:5, (b) – q = 1:5, (c) – q = 3 and (d), (e) and (f) are the corresponding q-plates [5].

Recent developments of optical rewritable (ORW) LC photoaligning display and progress in LC photoalignment have made it possible to separate e-paper display-unit and driving optoelectronics part (Fig.5) [6]. It has no electrodes, possesses grey scale capability, truly stable, and no power consumption of showing the image with wide viewing angles and high contrast. Our ORW e-paper structure can not only significantly decrease the complexity of device, but also have the similar properties and cost with pulp paper. The high durability and low consumable cost are the high competitive advantages of the ORW e-paper in the market. The most likely but not limited applications are price labels, light printable rewritable paper, labels and plastic card displays, E-albums, E-advertisements. Recently we developed passive STN LCD as a good choice for light mask. By using the optimized STN-LCD for the light of wavelength of 450nm, the images can be easily changed on ORW E-paper (Fig. 5).

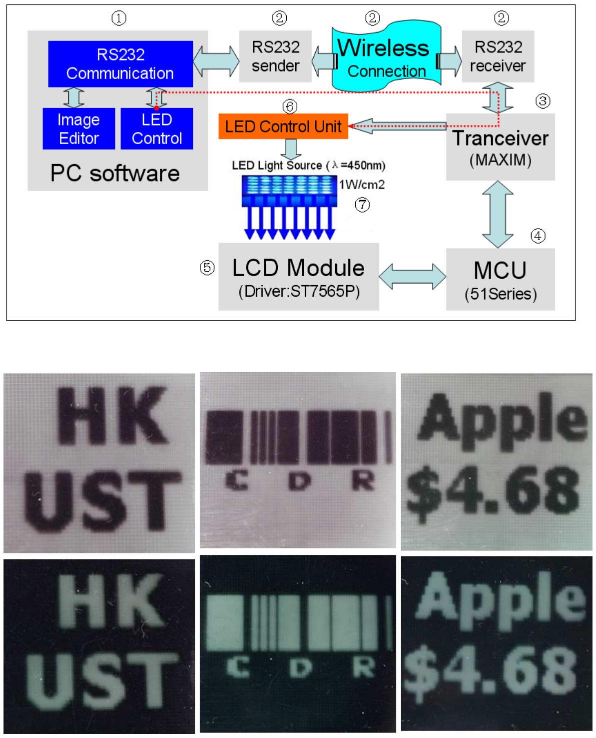

Figure 5. Light printer for optically rewritable E-paper (Top) and the images obtained by optimizad STN-LCD mask (Bottom).

3. Conclusion

New LC devices based on photoaligning and photopatterning technology were proposed, including–patterned retarders for 3D applications, lenses with electrically tunable focal distance, LC based sensors, switchable q-plates, and optically rewritable E-paper. The photoalignment materials were mostly photosensitive azo-dye layers, previously reported by us [1]. The combination of azo-dye layers and liquid crystal polymers were also used for photo patterned phase retarders. The practical applications of new LC elements in 3D displays and other LC technology areas are envisaged.

4. Acknowledgements

A support from HKUST grants CERG 612208, 612409, and 612310 is gratefully acknowledged.

5. References

[1] V.G. Chigrinov, V.M. Kozenkov, H.S. Kwok, *Photoalignment of Liquid Crystalline Materials: Physics and Applications*, Wiley, 2008.

[2] F. Fan, M. C. Tseng, A. A. Murauski, H. S. Kwok, V. G. Chigrinov, *Tunable-focus Liquid Crystal Lens using Stacked Alignment Layers*, ILCC 2010, July 2010, Krakow, Poland.

[3] T. Du, L. Yao, F. Fan, V. Chigrinov, H.S. Kwok*, Photo Patterned Micro Polarizer*, LCT2-4, IDW'10 Conference, Fukuoka, Japan, December, 2010.

[4] Xiaojin Zhao, Amine Bermak, Farid Boussaid, and Vladimir G. Chigrinov, *Liquid-crystal micropolarimeter array for full Stokes polarization imaging in visible spectrum*, Optics Express, Vol. 184, 17776, 2010.

[5] Sergei Slussarenko, Anatoli Murauski, Tao Du,Vladimir Chigrinov, Lorenzo Marrucci, and Enrico Santamato, *Tunable liquid crystal q-plates with arbitrary topological charge*, Optics Express, Vol. 19, No. 5, pp. 4085-4090 (2011).

[6] Vladimir Chigrinov, Anatoli Murauski, Qiang Yu, Hoi Sing Kwok, *Optically Rewritable Liquid-Crystal Technology: A New Green E-Paper Approach*, SID'10 Conference, 15-1, Seattle, Washington, , USA, May, 2010.