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Liquid Crystal Photoalignment: A New Challenge for Liquid Crystal Photonics

Vladimir G. Chigrinov*

Hong Kong University of Science and Technology, CWB, Kowloon, Hong Kong

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Abstract—Photoalignment possesses obvious advantages in comparison with the usually “rubbing” treatment of the substrates of liquid crystal display (LCD) cells. The liquid crystal photoalignment is nano-technology, as the thickness of the alignment layer is about 2-15 nm. The photoalignment materials can be very useful for a new generation of liquid crystals displays and Photonics Devices. The advantages of the photoalignment technology and its application to Photonics LC devices will be reviewed here based on research in HKUST.

Photoalignment has been proposed and studied for a long time. In fact, the subject of light-molecule interactions has been a fascinating subject of research for a long time and is still capturing the imagination of many people. Light is responsible for the delivery of energy as well as phase and polarization information to materials systems. In this particular case, the alignment of molecules takes place due to partial ordering of molecular fragments after a topochemical reaction of photoselection (Weigert's effect). While the first photo-patterned optical elements, based on polyvinyl-cinnamate films, appeared in 1977, the technology became a subject of interest for LCD only at the beginning of the 90’s. It was soon shown that these materials could provide high quality alignment of molecules in an LC cell. Over the past twenty years, a lot of improvements and variations have been made for photoalignment. Commercial photoalignment materials are now readily available. Many new applications, in addition to the alignment of LCD, have been proposed and demonstrated. In particular, the application of photoalignment to active optical elements in optical signal processing and communications is currently a hot topic in photonics research.

Photoalignment possesses obvious advantages in comparison with the usually “rubbing” treatment of the substrates of liquid crystal display (LCD) cells. Possible benefits for using this technique include:

(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) Possibility to produce the structures with the required LC director alignment within the selected areas of the cell, thus allowing pixel dividing to enable new special LC device configurations for transflective, multi-domain, 3D and other new display types;
(iv) Potential increase of manufacturing yield, especially in LCDs with active matrix addressing, where fine tiny pixels of a high resolution LCD screen are driven by thin film transistors on a silicone substrate;
(v) 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 an LC cell and/or high spatial resolution of the processing system;
(vi) Ability for efficient LC alignment on curved and flexible substrates;
(vii) Manufacturing of new optical elements for LC technology, such as patterned polarizers and phase retarders, tunable optical filters, polarization non-sensitive optical lenses, with a voltage controllable focal distance, etc.

The technique of azo-dye photoalignment does not involve any photochemical or structural transformations of molecules. Also, the new photoaligning films are robust and possess rather good aligning properties, such as anchoring energies and voltage holding ratios. They can be very useful for a new generation of liquid crystals devices as well as in new photovoltaic, optoelectronic and photonic devices based on highly ordered thin organic layers. The examples of such applications are light emitted diodes (OLED), solar cells, optical data storage and holographic memory devices. Novel and highly ordered layer structures of organic molecules may exhibit certain physical properties which are similar to the aligned LC layers. A brief summary of our research results is given below. The results have been published (see the Reference List).

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* E-mail: eechigr@ust.hk

New types of Photonics LC devices based on photoalignment technology:

We developed an *Optical Rewritable liquid crystal alignment technology (new e-paper)* that provides controllable patterned, reversible planar or vertical, liquid crystal alignment. The image is truly stable, can be written to a grey level with saturation and rewritten a large number of times with high reproducibility of properties. We come out with a low power-consuming high- efficiency ORW-device that consists of three major parts developed by us: optically rewritable azo-dye photoalignment and ORW LCD with polarizer-substrates, LED-exposure light source and phase-mask LCD polarization rotator. ORW technology is completely compatible with standard photolithography and enables a patterned LC alignment within a one-mask process. The new e-paper is light weight thin, paper-like image carrier with good brightness, high contrast and full viewing angle and is capable to display either 2D or both 2D&3D images. New optically rewritable (ORW) liquid crystal Photonics devices with a light controllable structure may include LC plane waveguides, LC polarization dependent elements, such as lenses and wave plates, LC polarization rotators and polarization controllers, light and voltage controllable diffraction gratings for optical filters etc.

We studied and experimentally investigated *liquid crystal (LC) alignment on silicon surfaces with submicrometer-sized straight and curved waveguide profiles*. Our analysis shows that surface profiles can strongly affect LC alignment near the waveguide edges, and thus the resulting LC-clad waveguide-based devices. LC alignment on this topological device surface is primarily affected by the alignment material. At zero applied electrical potential, the liquid crystal film is oriented by the bottom photoalignment layer and the top rubbed planar or homeotropic polyimide layer. Under an applied electric field, liquid crystal molecules are re-oriented with a tilt angle that depends on the applied field. The liquid crystal cladding refractive index is then varied according to the applied voltage, and subsequently the *microresonator resonance wavelengths are tuned.*

We have considered theoretically the possibility to create *liquid crystal lenses* with a voltage controllable focal distance. The LC deflectors and LC prisms are also envisaged. Non-uniform spatial distribution of anchoring energy, made *by photoalignment technology* is a new principle proposed by us.

A complete methodology using matrix representations for describing light transmission and reflection at an interface between an isotropic medium with a high refractive index and a uniaxial birefringent material where *total internal reflection (TIR)* could happen was described systematically. A new TIR-based liquid-crystal (LC) switch system was proposed and investigated in detail by using this analyzing method. The criteria of selection of critical parameters such as LC mixture, waveguide, and operation mode of the LC layer, etc., were developed. The dependence of transmission on incident angle and dynamic characteristics under an electric field was given for different cell gaps. The results give detailed and useful guidance in the fabrication of the LC switch system.

We have also proposed and checked experimentally a simple method *to control light beams in a plane waveguide using a sharp boundary between the regions of different LC orientations*, regulated by an electric field. Using different ITO templates, it was possible to create an LC switch and other different optical processing data elements, e.g. attenuators.

We calculated a *smooth collimating refractive interface that can be written by light* in front of the waveguide immerged into a liquid crystal. Such a passive LC structure is stabilized by photoalignment layers and does not need any applied voltage to operate. It can out-couple the s-polarized light, coming from the waveguide, into a collimated beam inside the LC bulk for further processing, while the p-polarized light can be guided by matching polarization maintaining LC waveguide. We suggest *the polarization independent design of the LC Photonic device* that can convert both polarization components out- coupled from polarization independent waveguide to one polarization for further process of light by the polarization dependent LC structure for routing or other purposes. The novel design consists of polarization maintaining LC waveguides, LC polarization dependent passive lens and active half wave plate (HWP).

A brief list of our journal publications on photoalignment is provided below.

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