45.4: Azo-Dye Alignment for Displays and Photonics

Vladimir Chigrinov and Hoi Sing Kwok
Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
Hirokazu Takada, Haruyoshi Takatsu, and Hiroshi Hasebe
Corporate R&D Division, Dainippon Ink and Chemicals Incorporated, Japan

Abstract

Liquid crystal photo-alignment using azo-dyes for display and photonics applications is discussed. Various types of the glass and plastic substrates are used. Special types of 3D LC alignment, LC alignment inside thin micro tubes, and LC cladding layers in Si based waveguides and grating surface are concerned. The azo-dye photoalignment of polymerized LC films used as optical elements, such as polarizers and phase retarders is also considered. Optically rewritable liquid crystal display for plastic cards applications is shown.

1. Introduction

The field of liquid crystal (LC) photo-alignment is very rapidly developing and a vast amount of the new materials, techniques and LCD prototypes based on photo-alignment (PA) technology have appeared recently [1]. The effect of LC photoalignment is a direct consequence of the appearance of the photo-induced optical anisotropy and dichroic absorption in thin amorphous films, formed by molecular units with anisotropic absorption properties [1]. In this paper, we shall report some new results related to the processing conditions using these azo-dyes [2,3]. We will consider various types of azo-dye photoalignment on glass and plastic substrates [4]. Special attention will be paid to new types of LC photoalignment, such as 3D surface [5], thin micro tubes [6], and cladding layers in Si based waveguides [7]. We will also consider azo-dye photoalignment of polymerized LC films used as optical elements, such as polarizers and phase retarders [8]. A new optically rewritable liquid crystal display for plastic cards applications will be also shown [9].

Results

2.1 Azo-dye aligning layers

The azo-dye molecules, are tending to align their long axes perpendicular to the UV-light polarization resulting in anisotropic dichroism or birefringence of the PA film [1]. Actually the photo-aligned azo-dye molecules produce a very smooth and uniform structure with the thickness between 3 and 12 nm. The order parameter S of a sulphuric azo-dye SD1 measured from the absorption spectra is equal to -0.4 at λ_m= 372 nm (absorption maximum), which is 80% from its maximum absolute value S_m = -0.5 in our case. However, there exist another absorption peak at about 450 nm, which seems to be important, if we like to use for photoaligning a highly efficient UV-LED source [9]. Improvement of durability against temperature (250^0C UV light exposure (175 MJ/m^2) in the LC cell using thermal polymerization of azo-dye layers was also confirmed [1].

The temperature stable pretilt angle of 5.3^0 was obtained by a two-step exposure of azo-dye film using a normally incident polarized light followed by oblique non-polarized light. The azimuthal anchoring energy W_φ of a photo-aligned substrate was very high and > 10^{-4} J/m^2, which is the same as the anchoring of the rubbed polyimide (PI) layer. The value of voltage holding ratio (VHR) for the photo-aligned LC cell (>99% at 80^0C) and residual DC voltage (<50mV) was even better than those for rubbed PI layers.

The sensitivity of SD-1 was considerably improved in later synthesized azo-dye derivatives, so very low dosage of UV-light was sufficient for a perfect uniform alignment of LC cell: 150mJ/cm^2 for a non-polarized light and 20 mJ/cm^2 for a polarized light, which makes it possible to use roll-to-roll technology in LCD production on flexible substrates [10].

2.2 Special types of azo-dye alignment

We have investigated the properties of *azo-dye alignment on plastic substrates* using azo-dye layers [4]. Excellent alignment with a high anchoring energy was achieved with the exposure energy less than 1.0 J/cm^2, which corresponds to the azimuthal anchoring energy > 10^{-4} J/m^2. The LC pretilt angle of about 5^0 on the plastic substrate was made by a double exposure method. The electrooptical performance of the photo-aligned plastic display was very similar to common TN-LCD fabricated for comparison by usual rubbing method on glass substrate. The prototype of the plastic display for smart cart application using photoaligning material has been made [4] (Fig.1).

Figure 1. Azo-dye photoaligning for plastic displays in smart cards [4].

We have also fabricated ferroelectric LC cell on plastic substrates stabilized by a polymer net with a perfect bistable switching (Fig.2). The contrast ratio was about 100:1 and the

 ISSN/007-0966X/07/3802-1474-$1.00

switching times were measured to less than 300µs in both directions for ±5 V switching pulses.

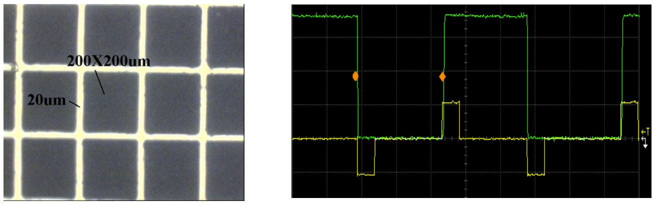

Figure 2 Left: polymer net used for FLC stabilization on plastic substrates; right: bistable response of azo-dye phto-aligned FLC on plastic substrates.

A uniform alignment formation on the 3D profiled surface (substrate with bulk relief) by photo-alignment was demonstrated [5]. The following three steps exposure process results in a uniform surface alignment on the 3D profiled surface (Fig.3). The new types of LCDs and photonics devices with a perfectly uniform LC alignment on a complicated surface profile are envisaged.

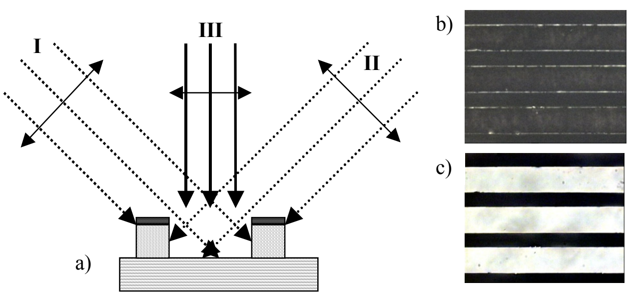

Figure 3. Optical scheme of three step 3D-substrate illumination (a); Profiled substrate LC cell between crossed (b) and parallel (c) polarizers [5].

We have developed the technique of photo-configurable azo-dye LC photoalignment in glass micro tubes and in photonic crystal fiber [6]. The order parameter of LC has been obtained from FTIR spectroscopy data and has demonstrated good alignment quality (Fig.4). Presented technique can be used as non-contact method of LC alignment in complex structure used for display and photonics applications.

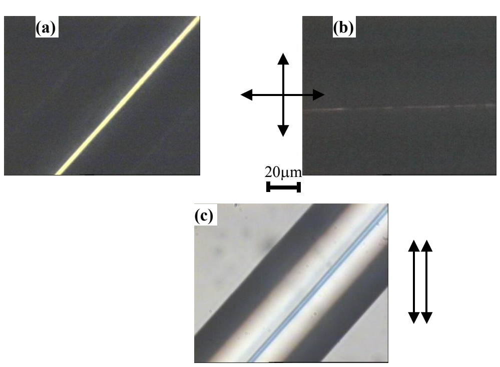

Figure 4. Glass tube of inner diameter 4 µm filled with homogeneous oriented nematic 5CB: (a, b) between crossed polarizers; (c) between parallel polarizers of microscope. Angle between polarizer and tubes axis is (a, c) 45°and (b) 0°.

An electrically tunable micro-resonator using photoaligned liquid crystal as cladding layers, where a photoalignment layer on the device surface define the orientation of the liquid crystal molecules, and the transmission property of the Si waveguide-coupled micro-resonator is electrically tuned by varying the cladding refractive index under an applied electric field in the vertical direction was proposed [7]. Based on our initial measurements, the free spectral range (FSR) is differed for ~ 4 % between the planar and vertical oriented liquid crystal cladding, thus suggesting a relative resonance wavelength shift of ~ 2.5 nm (Fig.5).

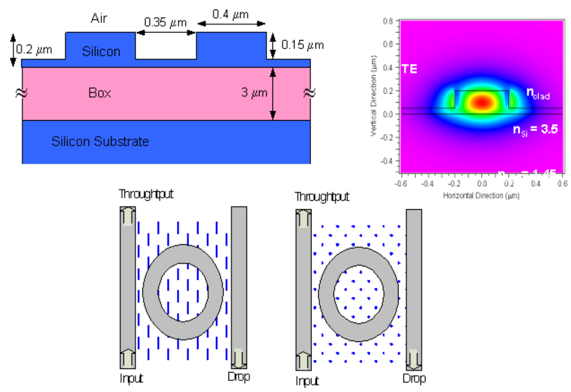

Figure 5. Active microring resonator using electrically tuned azo-dye photo-aligned LC cladding [7].

Azo-dye SD1 and similar dyes can be effectively used for the photoalignment of polymerizable LC (PLC) films and preparation of new optical elements, such as polarizers and phase retarders [8]. The SD1 layers can also be effectively used to align dyed PLC particularly needed for dichroic polarizers. The alignment of neat and dyed PLC can be easily patterned that is topical problem of patterned compensation films and polarizers requested by modern developments of LCD (multidomain wide viewing angle LCD, transflective displays, 3D imaging, etc.) (Fig.6).

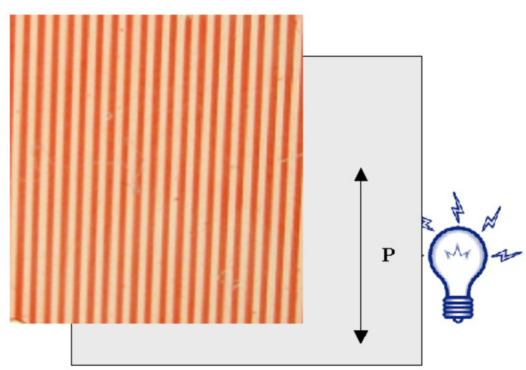

Figure 6. Azo-dye photo-aligned PLC film doped with dispersed red 1 dye from Aldrich [8]. This film contains alignment patterns with the 90° difference in the alignment directions. The oriented PLC layer containing dichroic dye works as patterned linear polarizer adsorbing light polarized in the direction of azodye orientation and transmitting the light polarized in perpendicular direction. The dichroic ratio is 5-6 achieved can be substantially increased by using PLC with highly ordered smectic LC.

The indisputable advantage of a sulphuric azodye SD1 dye is a very low photoalignment dose (<50 mJ/cm^2) that allows to speed up the production process, e.g. roll-to-roll technology becomes possible [10]. It can be basically used to manufacture any functional film containing aligned PLC layer or a stack of them.
Remnant high efficiency polarization gratings were created in nematic liquid crystal cell by photoaligned layer of azo-dye molecules deposited on the cell substrates and exposed to "interfering" beams with opposite circular polarizations [11]. The diffraction efficiency was controlled by electric field applied across the LC cell (Fig.7).

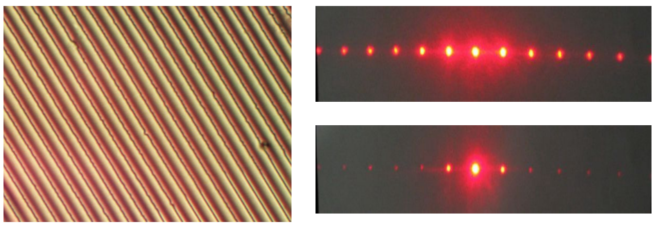

Figure 7 Left: Microscope photos of LC polarization grating between crossed polarizers; Right: Diffraction patterns from the LC polarization grating for different voltages: U=0V (up), U=15V (bottom) for linear polarized (*p* polarization) probe [11].

Obtained polarization gratings can be used for electrically controlled discrimination and detection of polarized components of light. All molecules of LC are reoriented to uniform homeotropic state at high voltage and there is no more modulation of LC alignment in the cell. The applications in projection LCD and LC switches are envisaged.

2.2 Optically rewritable LC display

We proposed an optically rewritable nematic liquid crystal display (ORW-LCD), based on photoaligning technology [1,9]. ORW-LCD does not require an electronic scheme, a power supplier, conductive layers inside devices, which provides a possibility to use this type display in plastic cards, registration and other systems. An optically rewriteable LC display shows a high contrast and a long life time. We propose to use ORW-LCD cell with special alignment layers and without conductive layers. In our display we change LC orientation on the alignment layer by a polarized light. Our photosensitive azo-dye material SD-1 reversibly changes the orientation in the plane of the substrate, while the other substrate keeps a strong azimuthal anchoring energy. It gives a possibility to change the twist angle in LC cell. Any gray level can be realized in such an image, as azimuthal anchoring energy and consequently the apparent twist angle are proportional to the intensity of UV light passed through the mask [1,9]. The technology was implemented into an extremely simple design of optical rewritable liquid crystal display for plastic cards directly on polarizers [9]. No backlight is required as reflective type polarizer is used as the bottom substrate. The image is truly stable, can be written to grey level with saturation and rewritten a large number of times with high reproducibility of properties. Finally, we come out with 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 one-mask process. Fig. 8 shows, that 450 nm LED light can effectively write and erase the image in 20s, if the light intensity (power) on the cell is about 20 mW/cm^2. The application for cheap rewritable plastic displays for credit cards is envisaged.

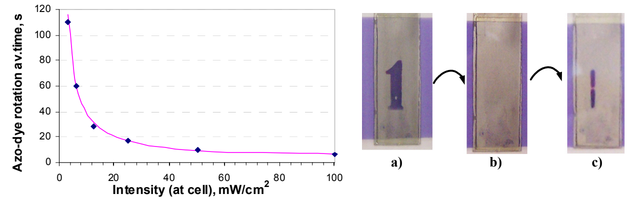

Figure 8 Left: Azo-dye rotation / LC twist angle formation average time dependence on light intensity; Right: ORW sample image is written, erased and rewritten through polarizer NPF-F1025VDU, Nitto Denko Co, Japan (LED light source, best operating wavelength range is 440-460nm).

3. Conclusion

In this paper we have briefly reviewed new types of LC alignment, which can be easily implemented by azo-dye photo-aligning technology for display and photonics applications. A new type of optically rewritable LC display on plastic substrates was also demonstrated. We foresee further application of azo-dye photoaligning technology for the new types of display and photonics devices.

4. Acknowledgements

The support from HKUST grant CERG 612 406 is acknowledged.

5. References

[1] V. G. Chigrinov, H.S. Kwok, H. Takada, H. Takatsu, New Developments in Liquid Crystal Photo-Aligning by Azo-Dyes, SID'06 Digest, pp.1253-1256, San-Francisco, June, 2006.
[2] V. Chigrinov, E. Prudnikova, V. Kozenkov, H. Kwok, H. Akiyama, T. Kawara, H. Takada, H. Takatsu, Synthesis and properties of azo dye aligning layers for liquid crystal cells, Liquid Crystals, Vol. **29**, no.10, pp. 1321-1327, 2002.
[3] H.Takada, H. Akiyama, H. Takatsu, V. Chigrinov, E. Prudnikova, V. Kozenkov, H.S. Kwok, Aligning Layers of Azo Dye Derivatives for Liquid Crystal Devices, SID'03 Digest**,** pp.620-623, Baltimore, May, 2003.
[4] Jesper Osterman, Au Ping Tong, Kent Skarp, Vladimir Chigrinov, and Hoi Sing Kwok, Properties of azo-dye alignment on plastic substrates**,** J. of SID, Vol.**13**, pp.1003-1009 (2005).
[5] A. Muravsky, V. Chigrinov, S. Studentsov, V. Brezhnev, N. Zhukov, B. Gorfinkel, Photo-induced alignment technology for 3-D surface profiles of LCD substrates, Intern. Workshop on Liq. Cryst. For Photonics, Gent, Belgium, April 2006, Book of Abstracts, O-02.
[6] Vladimir V. Presnyakov, Zhijian J. Liu, Vladimir G. Chigrinov, Infiltration of photonic crystal fiber with liquid crystals, Proc. SPIE , Vol. **6017**, pp.102-108, 2005.

[7] V.G. Chigrinov, L. Zhou, A.A. Muravsky, A.W. Poon, Electrically tunable microresonators using photoaligned liquid crystals as cladding layers**,** US Provisional Patent Application No. 60/794,128, filed on 24, April, 2006.
[8] Oleg Yaroshchuk, Jacob Ho, Vladimir Chigrinov, Hoi-Sing Kwok, Azodyes as Photoalignment Agents for Polymerizable Liquid Crystals, IDW'06 Digest, pp.83-86, Otsu, Japan, December 2006.
[9] A. Muravsky, A. Murauski, Xihua Li and V. Chigrinov, High Efficiency Optical Rewritable Device, IDW'06 Digest, pp.609-612, Otsu, Japan, December 2006.
[10] K. Maruyama, Y. Ono, Y. Suzuki and T. Ikariya, A Plastic Color TN-LCD using a Photo Alignment Method, IDW'05 Digest, pp.141-144, Takamatsu, Japan, December 2005.
[11] Vladimir Presnyakov, Karen Asatryan, Tigran Galstian, and Vladimir Chigrinov, Optical polarization grating induced liquid crystal micro-structure using azo-dye command layer, Optics Express, Vol. **14**, No. 22, pp. 10558-10564 (2006).