Novel LCD's and novel LCD manufacturing:
A new world of LCDs opened up by Photo-Rubbing

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ABSTRACT

A novel photo-alignment scheme using normally incident periodically intensity-modulated UV light has been developed and demonstrated to efficiently yield a stable pretilt angle of nematic liquid crystals by single exposure. The scheme, referred to as the "photo-rubbing", consists in unidirectional scan of the intensity-modulated UV light over the photo-alignment film, which causes asymmetrical photo-reactions in the film. We show here its successful application to multi-domain alignment processing. Thanks to the normal incidence, the photo-rubbing removes the instrumental disadvantages of the conventional oblique incidence technique, thereby providing a true practical solution for photo-alignment.

1. Introduction

The market of LCD-TVs for the digital broadcasting will see a seminal expansion by societal implementation of digital broadcasting technology. Considering the positive forecast, many companies are striving to promote the development of the large and high-performance LCD TV panels. The sixth and seventh generation facilities are complementary in meeting the technology road map requirements for large and wide TVs of 32, 37, 42 and 47-inch display.

Surface alignment of Liquid crystals is essential to produce high-performance LCDs. Although the rubbing method has been and is still in use, its inherent drawback is becoming even more evident today to obtain sufficiently uniform molecular alignment on the large glass substrate beyond 7G. As a non-contact alignment technique, photo-alignment method has been investigated for over a decade [1-10] along with other candidates such as the ion beam irradiation technology. Even though the initial problem of insufficient anchoring strength has been solved, there remains an issue as regards the generation of stable tilt bias (pretilt) angles in such as to meet the requirements from variety of different display modes in addition to the relatively low throughput of the photo-alignment process.

As one approach to obtain the prettily angle, the slanted exposure method has been introduced and demonstrated a partial success. The induced pretilt angle, however, cannot as yet be sufficiently stable and/or reproducible to allow its wide industrial applications. Furthermore the photo-alignment technique still falls short of real industrial applications due to the stringent instrumental constraints posed by the slanted exposure (Fig.1).

As an alternative to the conventional slanted exposure method, we have proposed the "photo-rubbing" technology[11,12]. It is a universal single-exposure method that can efficiently induce the required pretilt angle on the aligning photopolymer film even under a normal incidence. In this paper, we demonstrate the performance of photo-rubbing as an emerging technology to open up a novel ap-

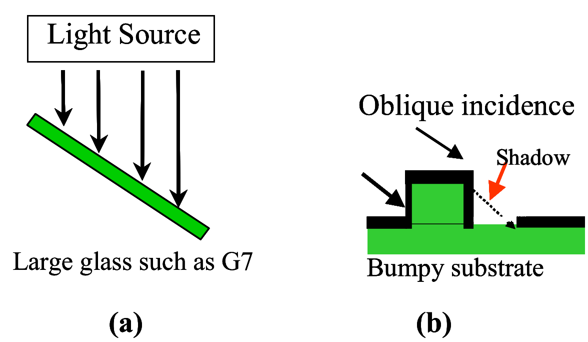

Fig. 1. Disadvantages of the conventional oblique incidence technique (a) Difficulty of design of instrument and uniform exposure in the oblique incidence to the large-size glass (b) Shadow formed by oblique incidence to the bumpy substrate

proach toward devising and manufacturing high-performance LCDs.

2. Practical solution for photo-alignment: Photo-rubbing

Figure 2 shows the setup for the photo-rubbing process. The intensity of the actinic linearly-polarized near-ultraviolet (LPNUV) light is periodically modulated on the photo-alignment films and is scanned in one direction at a constant speed. Similar to the conventional cloth rubbing, the present *photo-rubbing* scheme, albeit in non-contact fashion, produces a highly stable pretilt angle with the uplift of the nematic director towards the scan direction. It allows an accurate control of the pretilt angle values in terms of the scan speed and the light intensity.

The experimental system that we used (Fig. 2) consists of a LPNUV light source, a slit photo-mask set in proximity to the substrate, and a substrate translation stage. The incoming LPNUV light is periodically modulated after passing through the proximity photo-mask with a periodic slit. In the present experiments, the average intensity of the modulated light at the wavelength of 365nm was 2.4mW/cm^2. The polarization axis of LPNUV light is set parallel or perpendicular to the scanning direction according to whether the photo-alignment material used is of parallel-type or perpendicular-type, respectively. As the slit photo-mask, we used a 14µm-pitch slit made by vacuum deposited aluminum grating on a glass slide. The periodically modulated LPNUV light is scanned at a constant speed. In reality, the substrate has instead been translated under a fixed illumination.

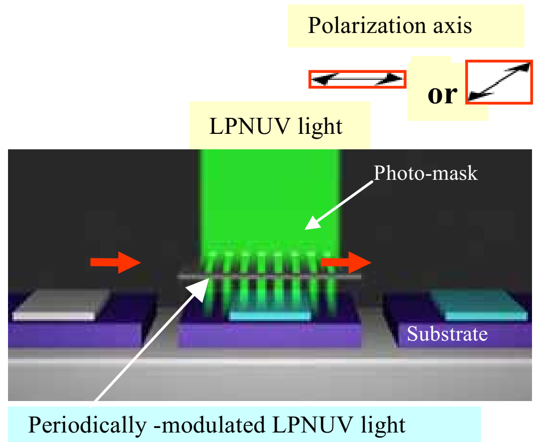

Fig. 2. Schematic diagram of Photo-rubbing method

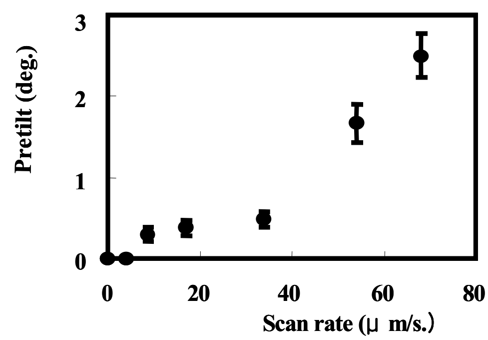

Fig.3 Pretilt angle of 5CB on photo-rubbed PMI-15 films as a function of the scan rate.

We studied the generation of pretilt angle with a photo-alignment material containing w-4(-chalconyloxy) alkyl group (PMI-15). We fabricated 18µm-thick anti-parallel alignment cells, filled with 4-n-pentyl-4'-cyanobiphenyl (5CB), and measured pretilt angle using the crystal rotation method. As PMI-15 belongs to the parallel-type photo-alignment material, the polarization axis of the periodically modulated LPNUV light was set parallel to scanning direction. Figure 3 shows the generated pretilt angle as a function of the scan rate of the periodically modulated light: Regardless of the scan rate, the total UV dose was always taken over 1J/ cm^2, where the alignment became practically saturated When the scan rate was within a range from about 10µm/sec to 40µm/sec, the pretilt angle remains constant at approximately 0.4 degree. At the scan rate above 50µm/sec, however, the pretilt angle increased, reaching 2.5 degree at 70µm/sec. On the other hand, the reproducibility of the generation of pretilt angle above 2 degree is at the same level as that achieved by the proposed single-exposure method.

3. Application to multi-domain LC devices

One of the key issues in the growing LCD-TVs market is to enhance the displayed image qualities, both static and dynamic, to compete with those of CRTs. Among others, improvement of the viewing angle characteristics is always atop the priority list. In order achieve wider viewing angle characteristics, the multi-domain division of a LCD pixel has been proposed many years ago, and is implemented in one way or another in today's high-performance LCDs. An obvious advantage of the photo-alignment technology is its natural ease of domain division. To fabricate, say, a four-domain LCDs as shown in Fig.4, the photo-rubbing allows us to sequentially produce four photo-aligned domains with the use of appropriate photo-mask.(Fig.5). We used PMI-15, and carried out the required photo-rubbing on each sub-pixel by synchronously rotating and scan direction while selecting the sub-pixel by the photo-mask as schematically shown in Fig.5. The alignment pattern is dictated by the

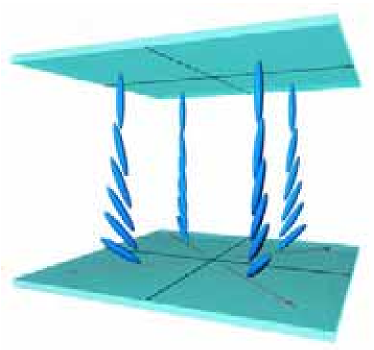

Fig. 4. Four-domain LCD.

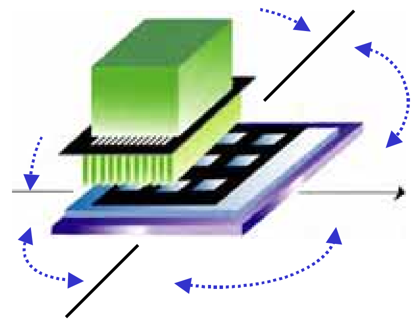

Fig. 5. Scheme to fabricate four-domain pixel by photo-rubbing.

open areas of the mask. The periodically modulated LPNUV light is scanned on the surface of the patterned mask at the constant speed of 40µm. In the real operation, the substrate and the patterned photo-mask -mask have been translated and rotated under a fixed illumination. The individual domain was fabricated by 4 steps of photo-rubbing. The pretilt angle is obtained along the scan direction on each sub-pixel, thereby creating the structure depicted in Fig.4.

We then fabricated a 5µm-thick hybrid cell consisting of the PMI-15-photo-rubbed substrate and a counter substrate on which a homeotropic alignment was enforced by a layer of commercial aligning agent JALS-204(JSR Corp.). We measured the pretilt angle using the crystal rotation method with anti-parallel alignment cells and then cell were filled with 4-n-pentyl-4'-cyanobiphenyl (5CB). Figure 6 shows a micrograph of the LC alignment in the hybrid cell with 4-D structure (under crossed Nichols). The defect-free LC alignment with the pretilt angle of 1.0 degree was observed in each sub-domain. Nematic director is lifted up in the scan direction as indicated by solids allow on each sub-pixel. This 4-D structure is also confirmed by the iso-transmisson image.

Figure 7(a) shows the iso-transmission curve of the 4-D hybrid cell under crossed polarizers. The applied voltage is 2.5V. For comparison, Figure 7(b) shows the iso-transmission curve of the mono-domain cell prepared under the same condition. The four-domain device shows a nicely symmetrical characteristics with a much wider viewing angle compared to that of the mono-domain cell.

4. Conclusion

We demonstrated the generation of pretilt angle using the photo-rubbing method that is based on the unidirectional scanning of periodically intensity-modulated LPNUV light, and showed the possibility of a fairly accurate control of pretilt angle by way of the scan speed. Next, we showed that the photo-rubbing is useful for muliti-domain processing. These results demonstrate that the photo-rubbing technology is a practical non-contact alignment method for manufacturing of large LCD-TVs with wide viewing angle characteristics.

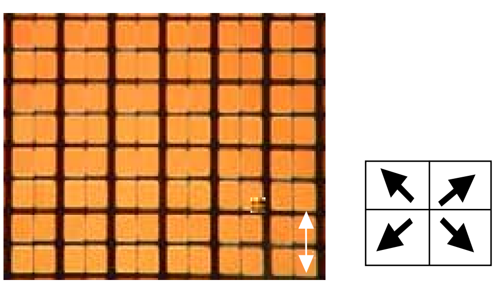

Fig.6 Polarizing micrograph of four-domain pixels with the pretilt angle of 1 degree fabricated by the photo-rubbing.

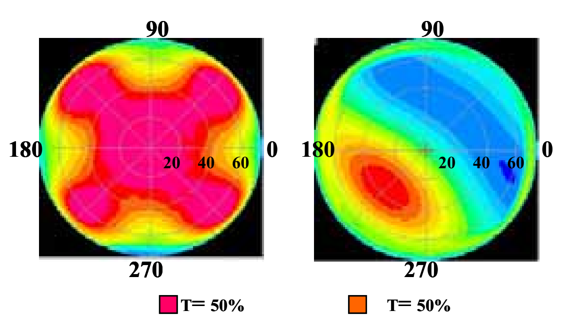

Fig. 7. Iso-transmission curve of photo-rubbed LC cell with crossed polarizer. (a) the iso-transmission curve of the 4-D hybrid cell, (b) shows the iso-transmission curve of the mono-domain cell.

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