Atmospheric Plasma Tool and Process for Liquid Crystal Alignment

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ABSTRACT

The method of liquid crystal alignment is developed based on combination of atmospheric plasma and rubbing processing of aligning layers. In this tandem, rubbing procedure insures uniformity, while plasma process provides tuning of pretilt angle and anchoring energy. High-quality tilted alignment is realized with a pretilt angle controlled in the range 0^o-90^o. The corresponding cells show excellent electro-optic performance.

1. INTRODUCTION

The ion and plasma beam alignment procedures currently attract high interests as alternative to rubbing alignment procedures for liquid crystals [1,2]. They are effective for various classes of LCs, provide very high alignment uniformity, full range control of pretilt angle, and easy way for alignment pattering. Wide practical application of these processes is mainly hindered by a high vacuum (10^{-6}-10^{-5} Torr) operation. To realize this regime, expensive vacuum equipment is necessary. Besides, this process consumes essential time, first of all, because of partial or full depressurization of working area required for reloading of aligning substrates. These difficulties can be circumvented by transferring the process to the range of atmospheric pressures.

The first attempts in this direction were recently made. LC alignment of rather good microscopic uniformity with controllable pretilt angle was realized by processing the aligning substrates with a stream of atmospheric plasma (AP) from barrier [3] and jet [4, 5] discharges. The uniformity of this alignment on microscopic scale was rather high. The uniformity on macroscopic level was however not discussed.

The goal of the present paper is to make a deeper insight into the AP process for LC alignment and bring it closer to industrial applications. It is demonstrated that the alignment capability of this process is dramatically improved when one combines it with a conventional rubbing providing sufficient alignment uniformity in plane of LC cells. The effect of atmospheric plasma on the aligning layers and thereby LC alignment has been also investigated.

2. EXPERIMENTAL

Similarly to [3], the plasma processing setup developed in our lab is based on the barrier discharge principle. A schematic diagram of this setup is presented in Fig. 1. The active particles 2 generated in barrier discharge 1 are extracted from the discharge area by a gas expulsion with a speed of 1 m/s. The gas stream with the involved active particles is directed to the substrate 3 containing polyimide coating on the top. The distance between the plasma jet and the substrate was about 3 mm and the angle between the substrate's normal and the stream direction was about 60^0. The gas feed system 5 varied volume velocity of the gas supplied from the gas cylinder 6 in the range 0.1–10 l/min. As the feed gas argon was utilized. The power supply 8 (0–15 kV, 400 Hz) was used to power the gas discharge. The measuring device 7 allowed to measure a discharge voltage and to estimate a discharge power. The substrate 3 together with a moving platform 4 was translated forward and backwards with a speed 2 mm/s under the particle stream 2. The scanning of aligning layers was controlled by PC. In the exposure process the processing dose was varied by changing discharge power, gas stream velocity and number of scans.

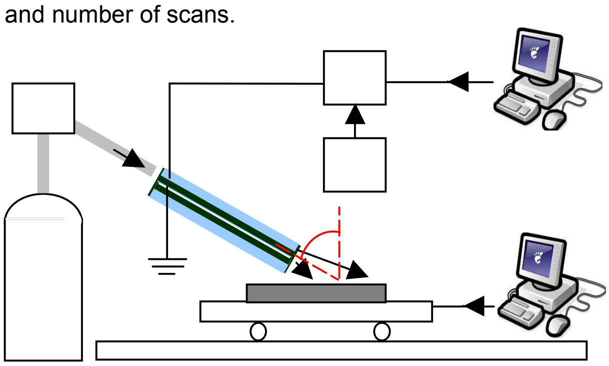

Fig. 1. A diagram of atmospheric plasma processing setup.
1 – barrier discharge block, 2 – flow of active particles, 3 – substrate, 4 – moving system, 5 – gas feed regulation system, 6 – gas cylinder, 7 – gas parameters measuring block, 8 – power supply.

The aligning layers were the films of polyimides AL2021 (JSR, Japan) and SE3510 (Nissan, Japan) designed, correspondingly, for vertical and planar alignment. These films were spin coated on the glass/ITO slides, appropriately backed and subjected to atmospheric plasma treatment.

Two series of cells were investigated. In the first series the substrates of the cells were subjected to only AP treatment. In the second series, the AP processed substrates were additionally subjected to rubbing. The substrates were unidirectionally rubbed with a velvet cloth. The rubbing direction was parallel to the projection of plasma flux on the substrate in a course of treatment.

3. LC ALIGNMENT AND ELECTROOPTICS

3.1 Sole treatment with atmospheric plasma flux

In this series, low dose exposure induces just a slight deviation of LC alignment from the homeotropic state ($90^o > \theta > 88^o$) towards incidence direction of AP stream without noticeable alignment degradation. The further increase of the exposure dose results in transition from the high-pretilt angle to the low-pretilt angle state with insufficient alignment uniformity (cell 4, Fig. 2). Even the cells with better alignment (cells 2 and 3 in Fig. 2) demonstrate non-uniform homeotropic-to-planar reorientation under the applied voltage (Fig. 3 (a)). The LC alignment on the planar polyimide SE3510 was also of rather poor macroscopic uniformity in a broad range of exposure doses.

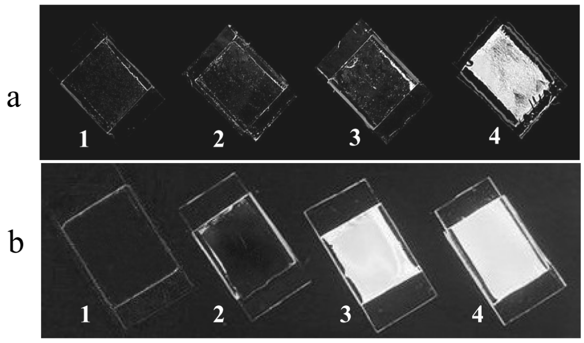

Fig. 2. Photographs of LC cells based on AP processed (a) and AP and rubbing processed aligning layers (b) of polyimide AL2021.
The cells are filled with LC MJ961180 and placed between a pare of crossed polarizers so that the directions of AP/rubbing treatment of the aligning substrates form an angle 45^0 with the directions of the polarizers. In each series, the cells differ in a number of scans of aligning layers, *N*. In (a) series, *N*=0, 2, 4 and 12, while in (b) series *N*=0, 2, 6 and 12, for the cells 1, 2, 3, and 4, respectively. The discharge power is 4 W and the gas stream velocity is 9 l/min.

These results indicate that sole atmospheric plasma treatment does not provide acceptable planar and tilted alignment of LC. To improve alignment parameters, we switched over to the combination of AP processing and conventional rubbing believing that the first action will provide control of pretilt angle and anchoring energy, while the second one will cause alignment uniformity. Similar concept was earlier applied to realize LC alignment on the substrates treated in vacuum plasma discharges [6,7]. Both sequences of AP and rubbing processes have been tested. Below is, however, considered only the order AP - rubbing, which appeared to be much effective for the LC alignment.

3.2 Combination of AP and rubbing treatments

Combining AP and rubbing treatment we realized uniform LC alignment on both homeotropic and planar

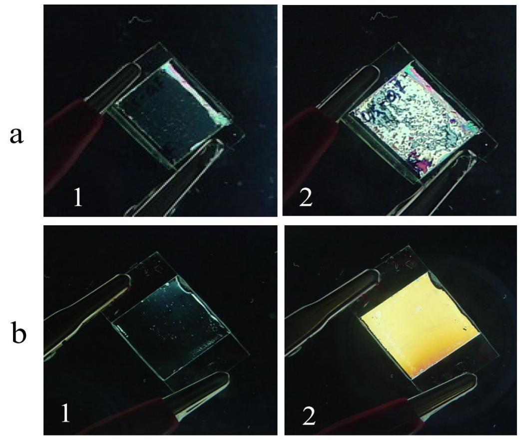

Fig. 3 Photographs of LC cells based on polyimide AL2021 aligning films before (1) and during (2) application of electric field of 6 V.
The polyimide substrates are processed by AP plasma in case (a) and AP and rubbing in case (b). The cells are filled with LC MJ961180 and placed between a pare of crossed polarizers so that the angle between the AP/rubbing treatment direction and the directions of the polarizers is about 45^0. The AP processing parameters are 4 W, 9 l/min, 4 and 2 scans, respectively.

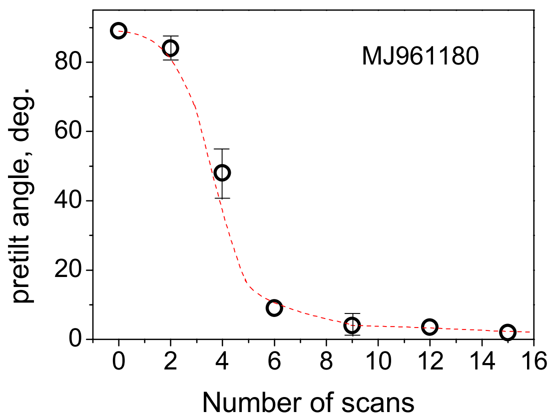

Fig 4 LC pretilt angle as a function of number of scans of the aligning layers of polyimide AL2021 processed by AP stream (4 W, 9 l/min) and subsequently rubbed.

type polyimides. By way of example, Fig. 2 (b) demonstrates set of cells based on AL2021 aligning layers filled with LC MJ961180. There is evident that quality of LC alignment is rather good in a wide range of exposure doses.

For the considered AL2021/MJ961180 couple, pretilt angle θ continuously decreases with a number of scans N running from 90° to about 0° (Fig. 4). In the other series, SE3510/E7, pretilt angle was also continuously tuned in the range 0°-10°. For this series, the dependence of polar anchoring coefficient, W_p, on the AP dose was also found. It was realized that W_p grows with the dose showing tendency of saturation.

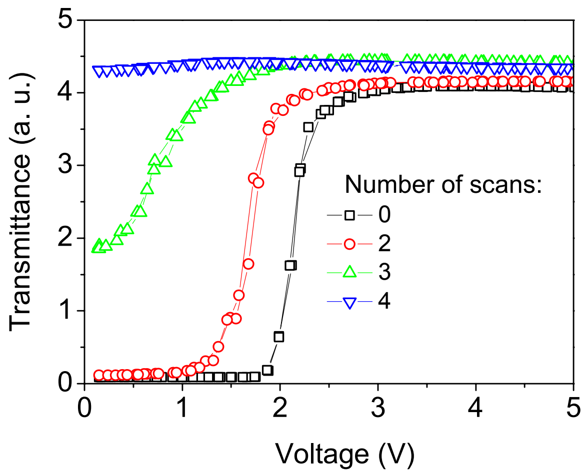

Fig. 5 Transmittance vs. voltage curves for the set of cells based on AP processed and rubbed aligning films of polyimide AL2021.
Plasma processing parameters are 4 W and 9 l/min. The number of scans is varied.

The cells produced by combination of AP processing and rubbing demonstrate good electro-optic performance. Fig. 3 (b) shows AL2021/MJ961180 sample with a vertical alignment in the field off and on states. As is obvious, LC layer uniformly switches in the electric field. The corresponding transmittance T vs voltage U curves are given in Fig. 4. As expected, the pretilt angle decrease results in lowering of electro-optic contrast and, simultaneously, lowering of controlling voltage. Thus, providing continuous control of pretilt angle and anchoring strength, the proposed method enables to optimize the electro-optic performance of LC cells.

5. ALIGNING MECHANISMS

Finally, microscopic mechanisms of pretilt angle variation under the AP treatment have been considered. It was determined that continuous decrease of θ with the exposure dose is caused by destruction of hydrophobic chains on the surface of aligning film. This was confirmed by measuring the contact angle of water on the treated surfaces. According to Fig. 5 (a), the contact angle monotonically decreases with an exposure dose. The weakening of hydrophobicity implies that the treated surface does loses hydrophobic fragments as it happens in vacuum plasma [6,7].

4. CONCLUSIONS

Thus, the alignment effect of atmospheric plasma stream can be dramatically improved by its combination with a conventional rubbing. In this case, the advantages of AP treatment and rubbing are beneficially combined; the plasma process is used to set desirable value of pretilt angle (via destruction of hydrophobic fragments), while the rubbing provides alignment uniformity.

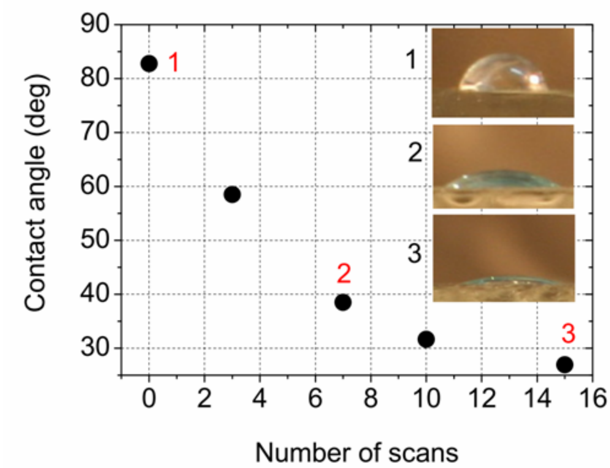

Fig. 6 Contact angle of distilled water on AL2021 film subjected to AP treatment (3 W, 9 l/min) as a function of number of scans. The inset shows the photos of water drops corresponding to several exposure doses.

Combination of these processes yields a wide-range controlling of pretilt angle and anchoring energy without changing of aligning material. The rubbing supplemented AP processing can be quite easily introduced in a manufacturing of LC devices, because it is compatible with the in-line and roll-to-roll modern manufacturing principles and predicts just inessential and cheap modification of the currently used production lines.

Acknowledgement

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