Atmospheric Plasma as a Tool for Tuning Vertical Liquid Crystal Alignment

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ABSTRACT

A gaseous stream containing active particles of atmospheric plasma generated in a barrier discharge is applied for processing polyimide (PI) layers for vertical alignment of liquid crystals (LC). A continuous change of LC pretilt angle is attained by changing processing dose. This variation is shown to be caused by the destruction of hydrophobic chains presented on PI surface.

INTRODUCTION

LCD development strengthens demands to liquid crystal (LC) alignment. The alignment process should provide very high alignment uniformity (on both macroscopic and microscopic levels), adjustable pretilt angle and anchoring strength, easy pattering procedure, high alignment stability with regard to heat, light and chemical reactivity.

The conventional rubbing technique commonly used in mass production of LC devices frequently does not satisfy these demands. To meet the above mentioned conditions, several new alignment processes are recently proposed [1,2]. They consist in alignment processing of LC boundary substrates with beams of accelerated ions or plasma. The beam of active particles directed obliquely to the treated substrate causes its anisotropic milling or etching. These processes provide very uniform alignment with tunable anchoring and easy axis. By using these techniques, the pretilt angle of LC can be continuously varied in a range 0°– 90° [3]. Moreover, the mentioned processes can be readily applied for the alignment treatment of large area substrates [3] and creation of alignment patterns [2].

The main reason hindering industrial application of the ion/plasma beam alignment technique is a high vacuum; the residual pressure should be of the order of 10^{-5} Torr and the working pressure should be of the order of 10^{-4} Torr. To realize this regime, expensive vacuum equipment is necessary. Because of this there is a strong desire to transfer the developed alignment processes to the range of atmospheric pressures.

The first attempt in this direction was recently made by the group from Seoul National University [4]. The authors used processing set up based on barrier discharge. The stream of Ar gas passed through the discharge area feeding the discharge and blowing active particles out of the discharge in the direction of an alignment substrate. By this way, authors of [4] realized tilted alignment with a tilt angle variation in a 90^0-0^0 range.

Besides, very recently, group from ITRI (Taiwan) joined this research direction and published first results obtained for linear source of atmospheric plasma [5].

Our goal is to make a deeper insight into the atmospheric plasma processing (APP) for LC alignment and approach it to industrial applications. In the present paper we consider influence of atmospheric plasma on vertical alignment of LC.

EXPERIMENTAL

Plasma processing set up

Similarly to [4], 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 substrate 3. The distance between the plasma jet and the substrate was about 3 mm and the angle between the substrate's normal and the stream was about 60^0. The gas feed

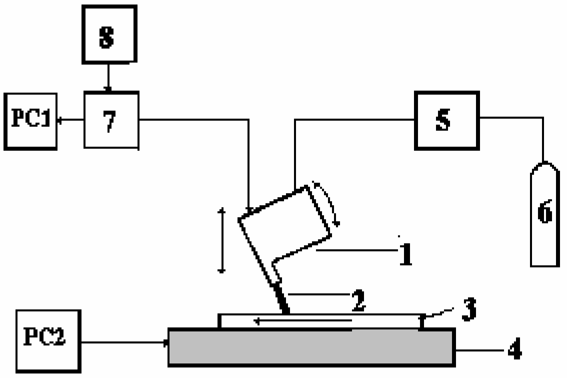

Fig. 1. A schematic diagram of atmospheric plasma processing setup. 1 – barrier discharge block, 2 – flow of active particles, 3 – substrate, 4 – moving system, 5 – gas feed regulation system, 6 – gas cylinder, 7 – gas parameters measuring block, 8 – power supply.

system 5 varied volume velocity of the gas supplied from the gas cylinder 6 from 0.1 to 10 l/min. As the feed gases Ar and O_2 were utilized. The power supply 8 (0–15 kV, 400 Hz) was used to power the gas discharge. The measuring device 7 allowed us to measure a discharge voltage and 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 process was controlled by PC.

Samples

As aligning layers we used the films of polyimide AL2021 (JSR, Japan) designed for homeotropic alignment. The films were coated on the glass/ITO slides. These substrates were treated by particle stream and used to prepare the symmetric antiparallel cells with a cell gap of 18 μm. The cells were filled with VAN LC MJ961180 ($\Delta\varepsilon<0$) from Merck Japan.

RESULTS

Alignment results

It was established that active particles from O_2 plasma are less effective for variation of pretilt angle and more aggressive for LC alignment than those from Ar plasma. Because of this we are focused below on the results for the Ar gaseous feed.

According to Fig. 2 (cells 1-3), APP produces sufficient alignment quality for relatively low exposure doses. The pretilt angle θ in these cells is tuned from 90° to 89° by changing number of scans, discharge power and volume velocity of feed gas (Fig. 3).

Note that increase of the dosage results in deterioration of high-pretilt-angle alignment and transition to a random planar state. This suggests that exposure dose should not exceed some critical value destructive for LC alignment. Before this critical dosage, the atmospheric plasma can be successfully used for the fine tuning of pretilt angle in VAN cells.

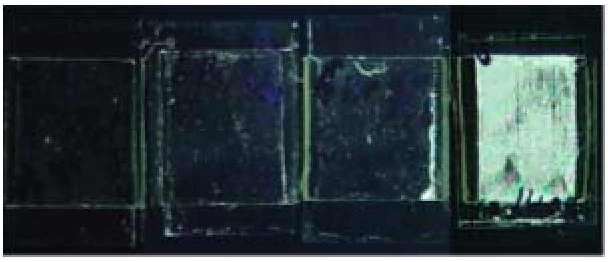

Fig. 2. A series of LC cells viewed between crossed polarizers. The cells differ in number of scans of aligning substrates, N; N=4, 6, 8 and 14 for cells 1, 2, 3, and 4, respectively. The discharge power is 6 W and the stream velocity is 9 l/min.

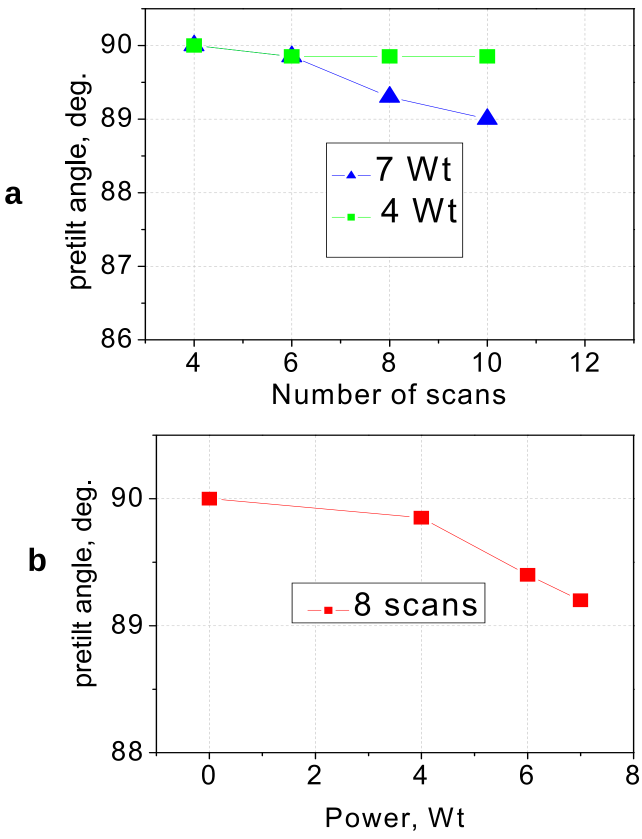

Fig. 3. Pretilt angle as a function of (a) number of scans for discharge powers 4 W and 7 W and (b) discharge power for the fixed number of scans. The stream velocity of Ar particles is 9 l/min.

Electro-optic switching

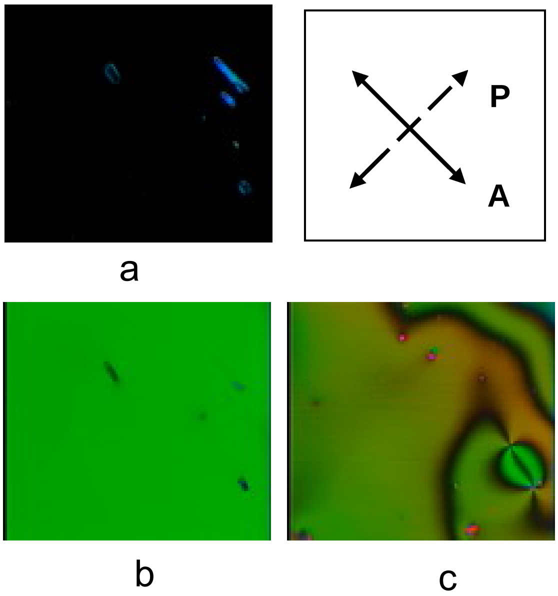

Fig. 4. Microphotographs (X50) of VAN cell viewed between crossed polarizers. (a) initial homeotropic state, (b), (c) field on planar state. U=10 V, 1 kHz.

Under the applied voltage LC in the prepared VAN cells undergoes homeotropic-to-planar reorientation as in conventional rubbed cells. LC reorients in one direction according to the plasma induced direction of tilt. This is supported by absence of reverse tilt domains in the on state. However, macroscopic uniformity of realized planar alignment was somewhat poorer than in the conventional cells. On microscopic level, these cells contain areas with very uniform alignment (Fig. 4, b) as well as areas with schliren textures typical for poor alignment (Fig. 4, c). This means that parameters of plasma stream (divergence, flow intensity, type of particles, etc.) and processing conditions (exposure angle, processing time, etc.) should be further optimized to provide better in-plane anisotropy of treated surfaces.

Mechanism of pretilt angle variation

Our further efforts were aimed on clarification of microscopic mechanisms leading to pretilt angle change under the APP. It was reasonable to check first the mechanism earlier established for pretilt angle tuning by high vacuum plasma. In the latter case, continuous decrease of θ is caused by destruction of hydrophobic chains on the surface of aligning film [3, 6].

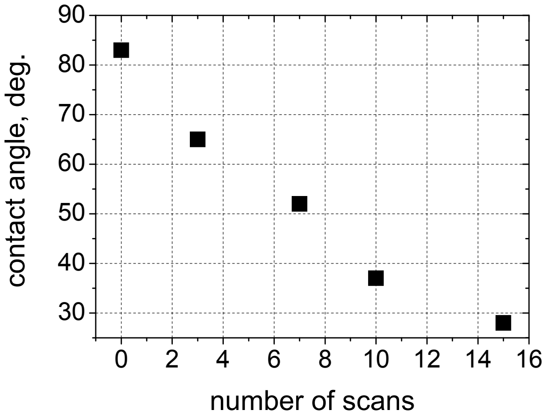

Fig. 5. Contact angle of water on PI film subjected to APP (3 W, 9 l/min) as a function of number of scans.

Fig. 5 demonstrates that water's contact angle used as a measure of surface hydrophoby monotonically decreases with an exposure dose. This implies that treated surface loses hydrophobic fragments.

The other evidence of the destruction of hydrophobic fragments was obtained by AFM measurements. Fig. 6 presents AFM images of polyimide surface before and after processing with atmospheric plasma. The yellow and brown (darker) features correspond to heights which may be assigned to the assembled hydrophobic chains. There is evident that number of these features is considerably reduced after the APP.

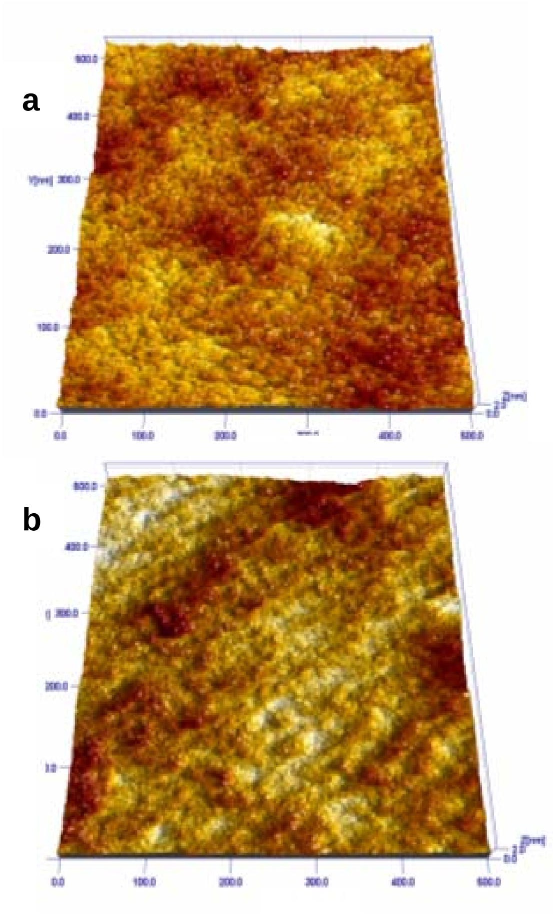

Fig. 5. AFM images of AL2021 polyimide film (a) before and (b) after processing with atmospheric Ar plasma (6 W, 9 l/min, 12 scans).

CONCLUSSIONS

A processing with atmospheric plasma can be successfully used for the fine tuning of pretilt angle in VAN LC cells. The plasma influences pretilt angle via destruction of hydrophobic chains on PI surface.

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