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Surface memory effect enhanced by atmospheric pressure plasma jet treatment for liquid crystal alignment

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ABSTRACT

In the present work we tried to study Polyimide (PI) film surface memory effect (SME) enhanced by atmospheric pressure plasma jet (APPJ) treatment for liquid crystal (LC) alignment. To evaluate and describe structural changes on the PI film surface, contact angle measurements and Fourier Transformed Infrared (FTIR) Spectroscopy methods were used. After each treatment cycle, the water drop contact angle to the treated surface decreases and FTIR spectra show an increase of C – O bonds. When LCs in mesophase are injected into a cell flow alignment occurs, and SME imprints the LC flow alignment pattern onto the surface. Some materials like glass and PI films naturally have SME to some degree; however, in our work we show that treatment by APPJ leads to the enhancement of this effect. Kinetics of the alignment pattern imprinting process was investigated by varying the incubation duration, and at room temperature the minimum required time for the imprinting alignment pattern was found to be 20 min. It was shown that the imprinted alignment of LCs on APPJ treated PI films has excellent heat resistance up to 150 °C.

1. Introduction

Polyimide (PI) film is the conventional material for alignment layer used in liquid crystal displays (LCD) [1,2]. The mechanical rubbing technique is used to impart alignment properties to the surface of PI film, but as a contact method it introduces debris into the film and can generate electrostatic discharge during the treatment [3–5]. To improve and overcome these disadvantages several non-contact techniques were developed, like UV photoalignment [6–12], Kaufman ion beam alignment [13,14], low pressure plasma beam treatment [15–19], and atmospheric pressure plasma jet treatment (APPJ) [20–23]. Additionally, a combination of the conventional method with APPJ assistance was used to be able to control not only LC alignment direction but also LC anchoring energy [24]. The alignment mechanisms of alternative techniques tend to be different from the conventionally used mechanical rubbing technique and are still under intense discussion [18,25]. Treatment of the alignment layer at atmospheric pressure represents a method which could be cheap and easily introduced into production lines compared to other alternative methods. Therefore, it brought our attention to investigate the APPJ method in more detail.

The interaction of a plasma jet with PI film surface is a rather difficult and complex problem. We can include here processes like etching of the PI film surface, generation of dangling bond and reactive species, interaction with the active species in the plasma jet, passivation with ambient air after treatment, UV irradiation from plasma, induction of LC alignment properties, and surface memory effect (SME) enhancement. As the APPJ treatment alters surface properties in many ways simultaneously, it is difficult to say which of these processes are crucial and vital for the alignment of LC on the surface. In the present work we tried to separate some of the processes and carry out analyses of the influence of SME and UV irradiation on LC alignment properties.

Surface memory effect is the preferential orientation of LCs at the surface interface that depends on the previous history of the LC orientation [26–30]. PI films and glass substrates exhibit SME [30] and make possible the alignment of LCs without the conventional mechanical rubbing method. Moreover, understanding the SME can help us to understand the interaction mechanism between LC and alignment layer surface. In the present work we tried to analyze and describe in more detail the influence of APPJ treatment on surface properties of PI film.

2. Experimental details

Borosilicate glass substrates (2×2 cm^2 and 1 mm thick) were coated with PI film using the spin-coating method. SE7492 Polyimide film (supplied by Nissan Chemical Industries) was deposited at 2000 rpm for 30 s and then baked at 220 °C for 30 min with 100 nm thick film over all the substrate.

Glass substrates with deposited film were treated by the APPJ scanning system. The schematic of the processing system is shown in Fig. 1. The power electrode was made of 1.5 mm in diameter stainless steel rod, coaxially placed inside of a quartz tube (6 mm outer diameter and 1.5 mm thickness), and was driven by a 10 kV AC generator (20 kHz). 20 mm wide aluminum tape wrapped around a quartz tube played the role of ground electrode. Argon gas was fed into annular space inside of the quartz tube. The ambient atmosphere was air. The input power was equal to 10 W and argon was flown at the rate of 2 slm.

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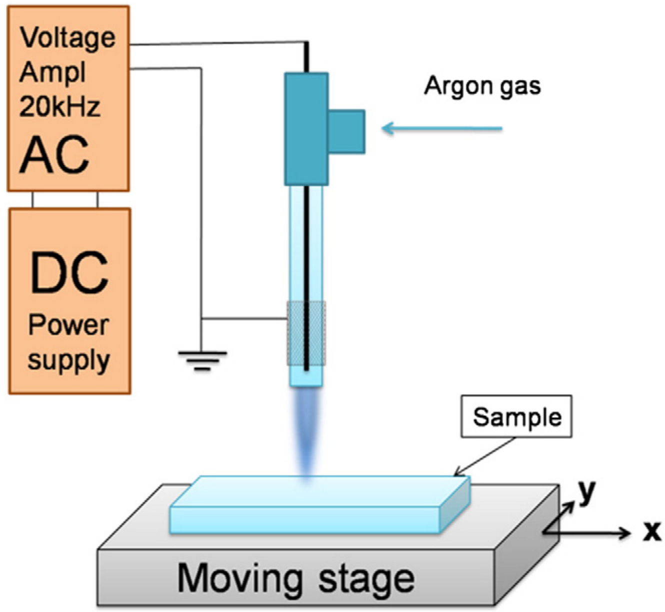

Fig. 1. Atmospheric pressure plasma jet (APPJ) scanning system.

The incident angle of the plasma jet is one of the key parameters to induce directional alignment properties on treated substrates [23]. To investigate SME separately we angled the plasma jet torch normally to the treating surface, thus eliminating the possibility to induce alignment properties on the PI films. To investigate the influence of UV irradiation from the plasma jet, a quartz mask (3×3 cm^2, 0.5 mm thick) was placed between the PI film surface and the plasma jet plum.

The stage on which the substrate was mounted could be moved in both an X and a Y axis by two installed motorized stages (SGSP20-35 controlled by a SHOT-602 Two-Axis Stage Controller). LabVIEW 8.2 was used to compose the controlling program, thus making possible scanning of the substrate and providing directional treatment over the entire substrate. The scanning speed in the X direction was 2 mm/s and steps in the Y direction between each scanning cycle were 0.5 mm.

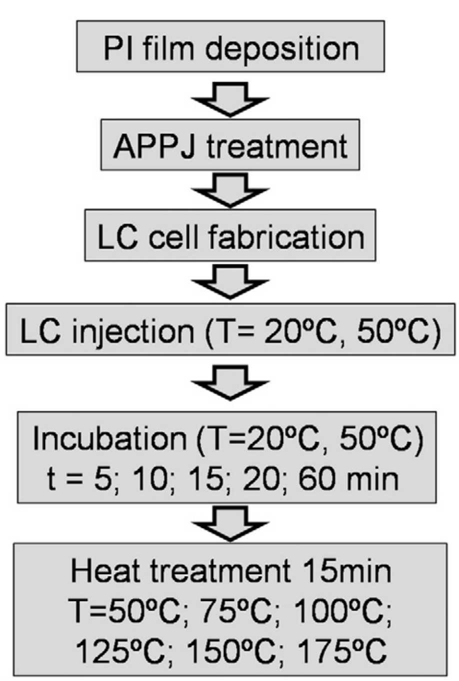

Fig. 2. Procedure of LC cell preparation.

A diagram of the experimental procedure is illustrated in Fig. 2. After treatment, glass substrates with treated PI film were used to fabricate LC cells. The gap between two substrates was 10 μm and was filled with 4-pentyl-4′-cyanobiphenyl (5CB) LC. The melting point and refractive index are equal to 34 °C and 1.53–1.74 for 5CB LC molecules, respectively.

Injection and incubation temperatures, as well as duration, were precisely controlled to characterize SME on APPJ treated PI films. The incubation duration at room temperature was varied to investigate the kinetics of flow alignment stabilization by SME. Heat treatments at different temperatures were carried out to investigate the heat resistance of APPJ enhanced SME.

A Yashima TBR-1 Optical Microscope with installed polarizer filters was used to analyze alignment patterns of the assembled LC cell. Si wafers were used as substrates instead of borosilicate glasses for Fourier Transformed Infrared (FTIR) analysis of treated and as-deposited PI films.

3. Results and discussion

3.1. Plasma jet treatment of Polyimide film

APPJ treatment activates the surface by generating active species and dangling bonds on the surface, as well as increasing surface energy and making the surface more hydrophilic. Water drop contact angle measurements were carried out before and after APPJ treatment cycles and are presented in Fig. 3. The results show the same tendency of water contact angle change as in the work of Yaroshchuk et al. [24].

To investigate structural changes, FTIR spectra were taken from untreated and treated PI films on Si substrates (Fig. 4). Treatment by the APPJ system etches the Polyimide film (this was confirmed by Scanning Electron Microscope (SEM) observation). Therefore, all the peaks on the FTIR spectra decreased and made it difficult to see structural changes. To highlight changes in the film after treatment, we normalized (corresponding to the thickness measured from SEM pictures) both the as-deposited and treated film spectra and analyzed the difference (Fig. 4b).

It is clear from the composition of the PI film before and after treatment, that C–O bonds are the most influenced. The increase in C–O bonds could be explained by the passivation of dangling bonds on the surface by oxygen from the environment during its exposure to the ambient air. The increase of C–O bonds on the surface was also confirmed by X-ray photoelectron spectroscopy measurements in the work of Wu et al. [18,19], where substrates were treated by low pressure plasma treatment systems.

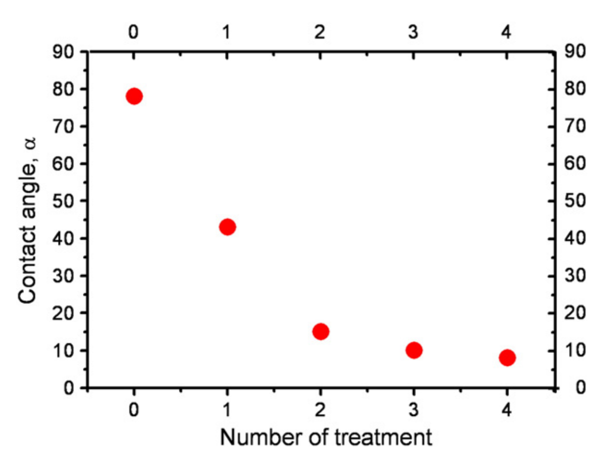

Fig. 3. Water drop contact angle measurements carried out for the SE7492 homeotropic PI film.