TREATMENT OF POLYIMIDE FILMS BY AN ATMOSPHERIC PRESSURE PLASMA OF CAPACITIVE RF DISCHARGE FOR LIQUID CRYSTAL ALIGNMENT

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Uniform planar alignment of liquid crystals is obtained by polyimide films obliquely treated by a stream of argon plasma from capacitive RF discharge at atmospheric pressure. Two liquid crystal alignment modes are discovered differing by their longitudinal or transverse orientation with respect to treatment direction. Optimum parameters of the treatment for obtaining these orientation modes are determined.

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INTRODUCTION

Alignment of liquid crystal (LC) layers is among key processes of the technology of LC devices. Perfection of these devices strengthens demands to the LC alignment. They require alignment of high macroscopic and microscopic uniformity with precisely adjustable parameters. The alignment technology presently used in manufacturing is associated with rubbing of polyimide (PI) layers. Due to a number of shortcomings, it less and less satisfies the abovementioned demands.

Limitations of rubbing led to development of alternative methods of LC alignment. The most famous of them are photoalignment and series of vacuum methods, such as vapor and ion/plasma beam scattering deposition, and ion/plasma beam etching process. The latter process caused a great wave of interest in the past decade as it provides alignment of very high microscopic uniformity, sufficiently strong anchoring and wide-range controlling of alignment parameters. But for industrial applications it appeared to be too complicated and much more expensive than the rubbing method.

A clear trend of the recent years has been in the transfer of the ion/plasma beam etching process from the high vacuum range in the field of atmospheric pressure. LC alignment of rather good *microscopic* uniformity was achieved by processing aligning substrates with a stream of atmospheric plasma extracted from barrier [1] and jet [2] discharges. At the same time, obtaining a uniform alignment of the LCs over macroscopic areas (>0.5 cm^2) remains problematic. In a previous work, we proposed combining plasma treatment with rubbing for achieving uniform alignment with variable pretilt [3]. In this paper, we set an ambitious goal - to achieve a uniform LC alignment of the *macroscopic* scale using only the flow of active particles extracted from gas discharge.

1. EXPERIMENTAL SETUP

Block diagram of the experimental setup is presented in Fig. 1. The setup was based on three-electrode discharge device composed of two flat copper electrodes 1, each having 50x41x0.1 mm dimensions, deposited onto polycore (Al_2O_3) isolators 2 (60x48x1 mm), and grounded electrode 3 having a shape of rod with rectangular cross section. Gas-filled gap for the discharge between isolated electrodes 1 had 1 mm thickness. Angle α between the plane of moving system with substrate (glass plates) 4 and the plane of electrodes 1 could be varied in a range of 30…90^0. (electrodes 1 were oriented by their wide sides towards treated substrate). Electrode 3 was located under the moving system parallel to the edge of bottom isolator 2 at a distance of ≈ 5…8 mm from the isolator edge.

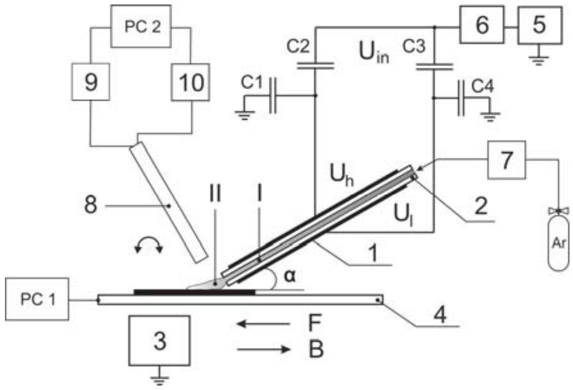

Fig. 1. Scheme of experimental setup.
1, 3 – the discharge electrodes, 2 – isolators, 4 – substrate moving system, 5 – RF generator, 6 – impedance matching unit, 7 - gas feed regulation system, 8 – optical unit, 9 – spectrometer, 10 -oscilloscope. F and B mark forward and backward directions of sample translation

For powering the discharge device, RF (13.56 MHz) generator 5 (MV-1.5, JSC "Selmi", Sumy) was used with impedance matching unit 6. Voltage RMS value after the matching unit could be varied in a range of 0…1600 V. The power was supplied to the electrodes 1 via capacitive dividers (C1-C2, C3-C4) for setting desired ratio of RF voltage values between the electrodes 1 and between these electrodes and grounded electrode 3. Volumetric rate of argon feed was set in a range of 0.5…18 l/min by means of gas feed regulation system 7.

The substrate with aligning layer was placed on moving system 4, which was stepwise translated in forward or backward direction under the plasma stream.

Mean translation velocity was set in a range of 0.05…0.3 mm/s with the use of stepping motor drive controlled by a software from computer PC1. The films were treated in oblique geometry so that the angle α between the plane of electrodes 1 and moving platform 4 was 30^o (Fig. 1).

Electrical characteristics of the discharge were determined by calculations on a basis of known capacity values of power supply dividers and measured amplitudes and phases of the voltages at the input of the dividers U_{in}, and at the top and the bottom electrodes (U_h and U_l respectively). For taking into account RF displacement currents via the surrounding space, calibration of the measuring system was performed by the supply of RF power without the discharge ignition (system of the electrodes represented pure reactive load). Measurements of active and reactive components of the load with the discharge glow allowed obtaining values of voltage applied to the discharge gap U_{disch} and active discharge current I_{disch}.

Measurements of kinetics of the plasma glow in visible spectrum range were performed by means of specially designed unit 8 using FEU-115 photomultiplier. For the studies of plasma emission spectra, CCD spectrometer 9 SL40-2-1024USB was used. All electrical signals were digitized by means of oscilloscope Tektronix TDS1012-10 and processed by computer PC2.

2. EXPERIMENTAL RESULTS

2.1. RF DISCHARGE FEATURES

When RF voltage was supplied to the setup, discharge I at first was ignited between flat electrodes 1, and with subsequent voltage increase discharge II occurred between higher-voltage electrode 1 (the top one in Fig. 1) and electrode 3. One can see from Fig. 2 that the discharge volt-ampere characteristics (VAC) for different volumetric rates of argon feed have similar behavior – at first, I_{disch} grows practically linearly with U_{disch} increase, and with subsequent increase of the discharge voltage, the currenrt reaches its quasistationary values. The current saturation occurs when the discharge plasma fills the whole volume of the discharge gap between electrodes 1.

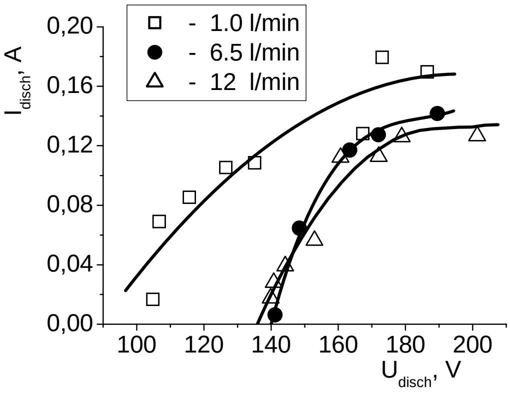

Fig. 2. Volt-ampere characteristics of the RF discharge for different values of volumetric rate of argon feed

At the same time, increase of the feed rate from 1 to 6.5 l/min (residence time for particles in the discharge ≈ 0.5 s and ≈ 0.08 s, respectively) results in both increase of minimum voltage of the discharge glow from ≈ 100V to ≈ 140 V, and decrease of the discharge current at the same values of U_{disch}. From our viewpoint, such VAC transformation with increase of gas feed rate may be due to ejection of charged plasma particles [4] from the discharge gap between flat electrodes 1 which leads to impediment of the discharge I glow. Indirect validation of such assumption is given by fact that discharge II occurs and glows steadily only at higher rates of argon feed, that is at supposed ejection of big enough quantity of charged particles. (At that, discharge II glowed steadily along the slit between electrodes 1, and its transverse dimensions were ≈ 4…5 mm). Threshold voltage of discharge II ignition approximately coincided with a bend at the discharge VAC.

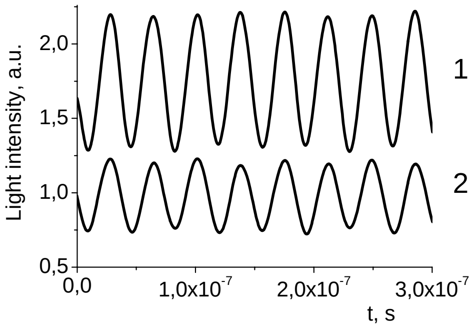

Fig.3. Kinetics of plasma emission intensity for the discharges I –1 and II -2 . Volumetric rate of argon feed was 6.5 l/min

One can also consider peculiarities of RF discharge glow (especially at atmospheric pressure) by study of the discharge emission kinetics which in the first approximation reflects that of the plasma density. For measurements of the discharge I emission, optical axis of unit 8 was set parallel to the plane of electrodes 1, and for study of the discharge II the axis was set perpendicular to the substrate plane, and shifted from the isolator 2 edge by 2 mm. One can see from Fig. 3 that plasma emission intensities for the discharges I and II are modulated with 27.12 MHz frequency which equals doubled value of the supplied voltage frequency. Modulation factor is ≈ 22…25 % and weakly depends on argon feed rate. It should be noted that presence of plasma density modulation of the discharge II means that boundary zones of this discharge perform grazing motion along the substrate surface with 27 MHz frequency

2.2. SUBSTRATE TREATMENT BY RF DISCHARGE PLASMA

The aligning layers were the films of polyimide AL1051 (JSR, Japan) designed for planar alignment. The films were obtained by spin coating the PI solution on the glass slides. Subsequently, the films were baked at 180^{o}C for 1 h and subjected to plasma or rubbing treatment. The width of plasma treated area in our experiments was about 20 mm.

To determine alignment direction on the plasma treated substrate, this substrate was combined with a rubbed one (reference substrate) by making capillary LC cells. The plasma and rubbing treated substrates were combined in such a way that their rubbing and plasma processing directions either were antiparallel, or formed 90° angle. 18 nm spacers maintained a cell gap. The cells were filled with nematic LC ZLI4801 from Merck Japan. The quality of LC alignment was monitored by observation of the cell placed between two crossed polarizers, both by naked eye and with an optical polarizing microscope.

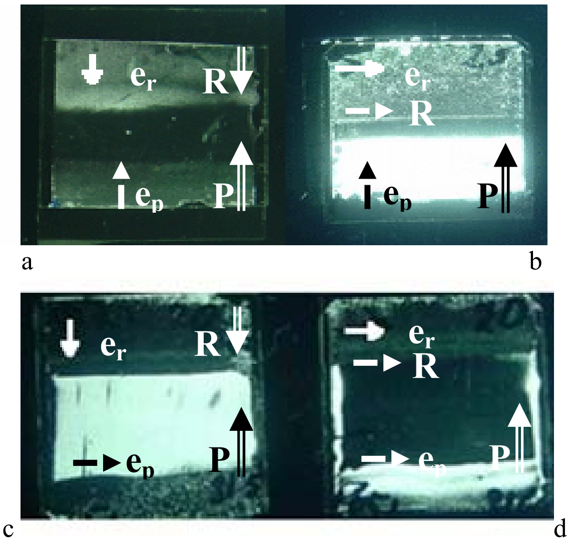

Fig. 4. Photographs of LC cells made of the rubbed and plasma processed substrate viewed between a pair of crossed polarizers demonstrating the first (a, b) and the second (c, d) alignment modes (parallel and perpendicular to the direction of plasma processing). The arrows R and P show rubbing and plasma processing direction, while the arrows e_r,and e_p the corresponding directions of LC alignment. Ar flow rate 6.5 l/min and the speed of substrate translation 0.11 mm/s (a, b) or 0.014 mm/s (c, d)

The experiments have shown that the alignment of LC depends essentially on the gas flow rate, discharge power, the velocity and direction of substrate motion, the substrate's temperature during treatment. Depending on the treatment conditions, as in the case of high-vacuum plasma, we observed two types of LC alignment with the easy axis directed along the treatment direction and perpendicularly to this direction, respectively. As an example, Fig. 4 presents pictures of LC cells in which one aligning substrate is processed by the plasma for different time. The processing time depends on the average translation velocity of the aligning substrate, which is equal to 0.11 mm/s and 0.014 mm/s in cases (a), (b) and (c), (d), respectively. The angle between the plasma processing direction of the tested substrate and the rubbing direction of the reference substrate was 0° in cases (a) and (c), and 90° in cases (b) and (d). The cells were filled in isotropic phase. The dark/bright strip in the cell corresponds to the area of tested substrate processed by plasma flow. The bright state of the cells (b) and (c) suggests that the LC alignment on the tested substrate is set by the plasma process. In other words, the anchoring induced by the plasma processing is sufficiently strong so that the corresponding alignment is not overcome by the opposite rubbed surface.

It turned out that the quality of the LC alignment is much higher in the case of scanning the substrate in the forward direction (see Fig. 1). This might be caused by the asymmetry of the ejected particle flux near the treated substrate. The reason for this, as well as the nature of two alignment modes will be clarified in future studies.

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ОБРАБОТКА ПОЛИИМИДНЫХ ПЛЕНОК ПЛАЗМОЙ ЕМКОСТНОГО ВЧ-РАЗРЯДА АТМОСФЕРНОГО ДАВЛЕНИЯ ДЛЯ ОРИЕНТАЦИИ ЖИДКИХ КРИСТАЛЛОВ

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Получена однородная планарная ориентация жидких кристаллов полиимидными слоями, наклонно обработанными потоком Ar-плазмы емкостного ВЧ-разряда атмосферного давления. Найдено два типа ориентации жидких кристаллов – вдоль и перпендикулярно направлению обработки. Установлены оптимальные параметры обработки для получения этих ориентационных мод.

ОБРОБКА ПОЛІІМІДНИХ ПЛІВОК ПЛАЗМОЮ ЄМНІСНОГО ВЧ-РОЗРЯДУ АТМОСФЕРНОГО ТИСКУ ДЛЯ ОРІЄНТАЦІЇ РІДКИХ КРИСТАЛІВ

В.Ю. Баженов, Р.Ю. Чаплінський, Р.М. Кравчук, А.І. Кузмичов, В.М. Піун, В.В. Ціолко, О.В. Ярощук

Одержана однорідна планарна орієнтація рідких кристалів поліімідними шарами, похило обробленими потоком Ar-плазми ємнісного ВЧ-розряду атмосферного тиску. Знайдено два типи орієнтації рідких кристалів – уздовж та перпендикулярно напрямку обробки. Встановлено оптимальні параметри обробки для одержання цих орієнтаційних мод.