Liquid Crystals Alignment on the Plasma Beam Etched Inorganic Coatings Prepared by Sputtering Deposition

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ABSTRACT

Liquid crystal (LC) alignment on the SiO_2 films anisotropically etched with a plasma flux from the anode layer thruster (ALT) is investigated. Twin magnetron (TM) and anode layer thruster (ALT) sputtering machines were used to deposit isotropic SiO_2 films on glass substrates. Depending on the dose of plasma etching, the ALT coated films show either tilted ($\theta \leq 1^0$) or planar alignment, with the easy axis of LC alignment being in the incidence plane of plasma beam (1st mode) or perpendicular to this plane (2nd mode). Plasma etching of the TM coated films results only in the 2nd mode alignment. The difference in LC alignment on the ALT and TM coated films is explained by different film density determined by the sputtering conditions.

Keywords: ion beam alignment; inorganic coating; anode layer thruster.

INTRODUCTION

Proper alignment of LC layers is a key issue in LCD technologies. In general, it is achieved by a specific treatment that generates surface anisotropy on aligning substrates. The treatment procedure widely used in the LCD technologies is unidirectional rubbing. However, because of the mechanical contact with the aligning substrate, this procedure suffers from serious drawbacks, which often hinder the further progress of LCD technologies. This stimulates development of alternative methods capable to replace the rubbing procedure in the next generations of LCD. The most promising of them are the methods dealing with particle beams. The particles might be ions, neutral particles, electrons and mixtures thereof. With respect to the treatment effect, two types of particle beam alignment methods can be distinguished. In the first type, the particles are deposited on the substrate, forming the alignment coating. The deposition might be direct (thermal deposition [1], etc.) or indirect (ion beam sputtering [2], etc.). In the second type of treatment, the particle beam is used to etch the aligning layer that was deposited prior to irradiation. First M.J. Little et al. [3] suggested oblique irradiation of the aligning films with ion fluxes of high energy (1-3 keV). Recently, IBM modified this procedure reducing the energy of ions to 50-300 eV [4,5], to minimize destruction of the aligning layer. Using a source, known as an anode layer thruster (ALT), we utilized a flux of weakly accelerated ions for soft treatment of the aligning films [6-8]. Because the particle beam is generated immediately in the discharge area of ALT, it is more correctly to consider it as a flux of accelerated plasma. The ion energy in our experiments was similar to that in the experiments of IBM. The main advantages of our system are simple construction and the easiness of scaling. This allows us to apply ALT for the treatment of large-scale substrates, including the substrates of last generations.

Some modern applications require stable work of LCD at critical conditions. For instance, LCD cells used in projection displays should endure very intensive luminous fluxes. This sets very strong demands to the photostability of LC and aligning substrates. The inorganic transparent substrates prepared by the methods of particle beam alignment are among the most promising candidates for this purpose. The first attempt was made in Ref. [9] by using obliquely deposited SiO_2 layers. However, this procedure yields only high pretilt angles needed for VA model. The generation of low-tilt alignment ($\theta=3^0$-5^0), utilized in the TN, STN, IPS modes, is a big challenge for this method. As we believe, the low-tilt alignment can be realized by using etching alignment technique. In the present work we elucidate the efficacy of the ALT etching procedure for LC alignment on inorganic substrates. We involve SiO_2 aligning layers deposited by the sputtering method using two different sputtering machines, providing films of different density. It is shown that the last parameter substantially influences LC alignment.

EXPERIMENTAL

<u>Film deposition procedure</u>

The SiO_2 coating on glass/ITO substrates was formed by the sputtering method using two kinds of sputtering machines. In both cases, a vitreous silica target was sputtered by Ar^+ ions and deposited on the glass/ITO slides in a scanning regime at approximately normal incidence. The first coating procedure was based on the conventional twin magnetron (TM) sputtering. The working pressure and voltage were 8.5 10^{-2} Pa and 3.5 kV, respectively. In the other coating procedure we used a unique sputtering device based on the ALT source designed by Izovac [10]. The operation pressure and voltage were 4.5 10^{-2} Pa and 3.5 kV. The TM sputtering machine provided three times higher sputtering rate than the ALT machine. The thickness of all films was about 30 nm. Before sputtering deposition, the glass/ITO plates were pre-cleaned by Ar^+ ions, generated by the etching type ALT or TM working in a low-power regime.

<u>Etching procedure</u>

The coatings were anisotropically etched by an obliquely incident flux of accelerated plasma from the ALT of etching type (Fig. 1). In the Institute of Physics, at the NAS of Ukraine this procedure was optimized for the alignment treatment of organic substrates [6-8] and some inorganic substrates, such as bare glass and a-C:H coatings [11]. It was shown that, depending on irradiation dose, two modes of planar/tilted LC alignment can be observed. In case of low dose, the easy axis of LC alignment lies in the plane of plasma beam incidence and is directed towards

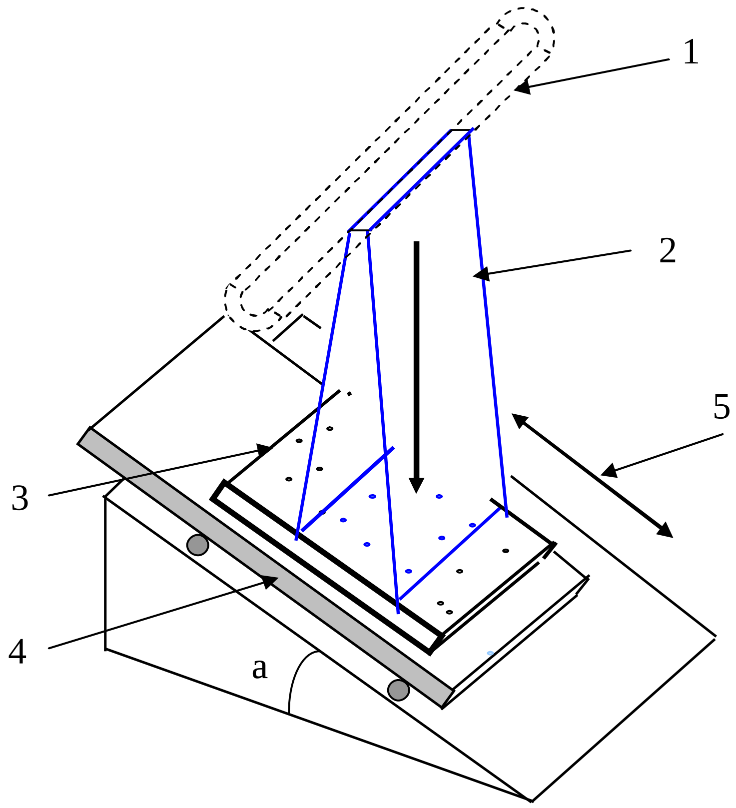

Figure 1. Sample irradiation scheme. 1-race track shaped discharge area; 2 – plasma flux; 3- substrate; 4- translation system; 5- translation direction.

the direction of plasma flux (1st alignment mode). The 1st mode is characterized by the non-zero pre-tilt angle, which can be varied by varying the parameters of irradiation. At high irradiation dose the easy axis is aligned perpendicularly to the plane of plasma beam incidence, with zero pre-tilt angle. An increase of irradiation dose leads to the anchoring transition from the 1st mode to the 2nd mode with the transient alignment characterized by the two-fold degenerated easy axis in the azimuthal plane. In Ref. [8] the observed multimode alignment is explained by the divergence of plasma flux. In frame of this concept, the 1st alignment mode is determined by inclination of the aligning film during irradiation that causes oblique incidence of the non-divergent part of the ions. In turn, the 2nd mode is a result of the oblique ion incidence due to the beam divergence. The symmetry of the ion divergence in the plane perpendicular to the incidence plane of plasma flux may explain zero pre-tilt angle alignment in the 2nd alignment mode.

Since tilted LC alignment is mainly required, we concentrated on the 1st alignment mode, studying the parameter range that yielded this kind of alignment. In the present experiments the

Ar^+ ion energy and the current density were, respectively, about 600 V and 6 $\mu A/cm^2$, and the incidence angle of ions was about 70^0. The exposure time was varied from 0 to 20 min. The irradiation was carried out in a static irradiation regime.

<u>Cells and Alignment tests</u>

The LC alignment was studied by preparing two types of LC cells: (1) asymmetric cells in which one substrate was treated with the plasma beam, while the second substrate had a rubbed polyimide layer; and (2) symmetric cells, in which both substrates were irradiated with the plasma beam and the directions of plasma beams treatment of these plates were antiparallel to each other. For cell making spacers of 20 um were used, yielding a cell gap of around 20 um. The cells were filled with the nematic LC ZLI 2293 ($\Delta\varepsilon>0$) and MJ961180 (($\Delta\varepsilon>0$) purchased from Merck. The symmetric cells were used to measure the pre-tilt angle by the crystal rotation method. The asymmetric cells were prepared to determine the direction of LC alignment in the plane of the plasma treated substrate.

RESULTS AND DISCUSSION

Figure 2 shows two sets of asymmetric LC cells, consisting of a rubbed PI substrate and sputtered SiO_2 substrate, filled with LC ZLI 2293. The first set (above) corresponds to the ALT sputtering, while the second one (below) to the TM sputtering procedure. In each set, the first cell contains a non-treated SiO_2 substrate, the second and the third sample contain a substrate treated 2 and 10 min, respectively. One can clearly see that the ALT sputtered films are capable to align LC ZLI 2293 in the 1^{st} and in the 2^{nd} alignment mode depending on the plasma etching time. In contrast to this, the magnetron sputtered coatings cause only 2^{nd} mode alignment due to the procedure of anisotropic etching.

One can also observe the intermediate modes between the 1^{st} and the 2^{nd} mode. A full sequence of the alignment modes reflects Figure 3. It shows azimuthal angle ϕ of the LC easy axis (the angle between the projections of plasma beam and easy axis on the alignment substrate) as a function of plasma irradiation time. The ϕ values equal to 0^0 and 90^0 correspond to LC alignment in the 1^{st} and in the 2^{nd} alignment modes. The intermediate values correspond to the two-fold degenerated alignment that defines the multidomain alignment with the azimuthal angle of easy axis equal to $\pm\,\phi$. A sequence of the alignment modes 1^{st} mode – two-fold degenerated alignment – 2^{nd} mode, observed for the ALT-sputtering series, was earlier observed for a number of organic aligning films [12]. At the same time, the appearance of only the 2^{nd} mode in case of magnetron sputtering is a very interesting exception from the normally observed behavior. The difference in the LC alignment on ALT and magnetron sputtered SiO_2 films might be explained by taking into account the various deposition conditions. The low gas pressure and the slow deposition in case of ALT sputtering process results in the dense and rigid films. In contrast, the fast deposition and increased pressure in case of magnetron sputtering creates porous and fragile films more liable to plasma modification. In the latter case, the 1^{st} mode can be observed in a very narrow range of exposure doses or even can be completely suppressed.

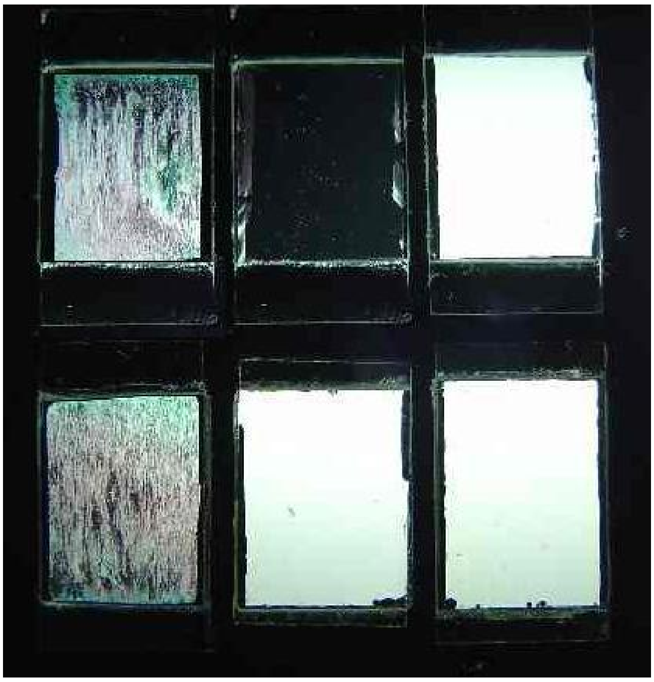

Figure 2. The sets of asymmetric cells filled with LC ZLI 2293 viewed between two crossed polarizers. The upper and lower set corresponds to the cells containing ALT and TM sputtered SiO_2 substrate, respectively. In each set, first cell contains non-treated SiO_2 substrate. In the second and the third cell the SiO_2 substrate is anisotropically etched with plasma beam, 2 and 10 min, respectively. Irradiation conditions: static regime, $\alpha=70^0$, j=8 $\mu A/cm^2$, E=600 eV.

The 1^{st} mode alignment on the ALT sputtered substrates is characterized by non-zero pretilt angle. For LC ZLI 2293, $\theta \leq 1^0$. The value of θ nonmonotonously depends on the time of plasma treatment; θ approaches zero at small irradiation doses and at the doses close to the alignment transition to the 2^{nd} mode. Unfortunately, the value $\theta \leq 1^0$ is lower than the value range requested by the conventional LCD modes. But we believe that it can be optimized by the modification of etching procedure (reactive etching caused hydrophobization) or by the passivation of SiO_2 films with organic monolayers reducing their surface energy [9]. The important advantage of the plasma etched SiO_2 aligning films is good alignment stability. At room conditions, the pretilt angle induced on SiO_2 substrates is stable over 3 months of our monitoring.

Interestingly to note that 2nd mode alignment on the SiO_2 substrates was never observed for LC MJ961180 with negative dielectric anisotropy. This LC always aligns in the 1st mode with the high pretilt angle (θ>20^0). The alignment tendency of LC MJ961180 on the SiO_2 films anisotropically etched is quite similar to that of other LC ($\Delta\varepsilon$<0) on the obliquely sputtered SiO_2 films [12]. This may imply that major alignment mechanisms are same in case of anisotropic deposition and anisotropic etching.

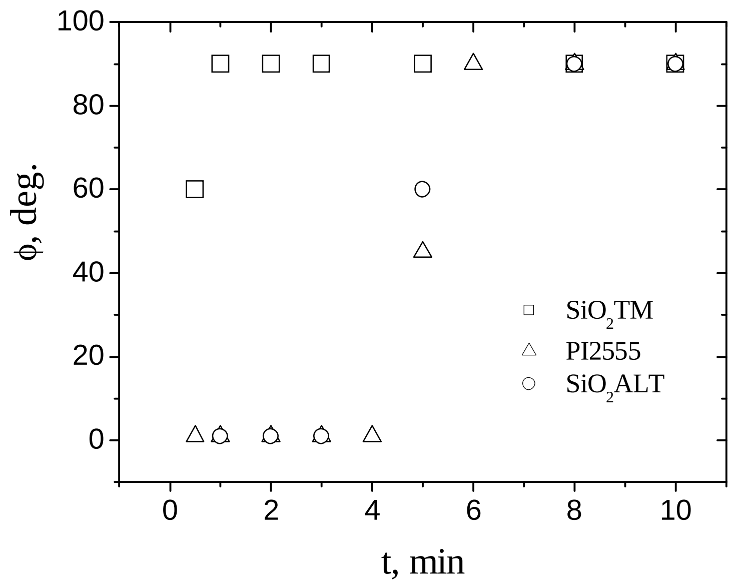

Figure 3. The azimuthal angle of the LC easy axis as a function of plasma treatment time for the TM and ALT sputtered SiO_2 films. For comparison we also present plot for the conventional PI substrates.

CONCLUSION

Using SiO_2 sputtered films we demonstrated that plasma beam alignment method can be successfully applied to generate tilted/planar LC alignment on inorganic layers. Similarly to polymer substrates, the ALT anisotropic etching of SiO_2 layers may result in two LC alignment modes with tilted (mode 1) and planar (mode 2) uniform alignment. It is established that realization of these modes depends on the density of the sputtered films determined by the sputtering conditions (sputtering rate, gas pressure, etc.). In dense films both modes can be induced, while in low density films only the 2nd alignment mode is detectable. The LC mixture with negative dielectric anisotropy aligns only in the 1st mode, independent on the parameters of sputtering deposition and post-deposition etching.

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