LC ALIGNMENT ON THE NON-ORGANIC SUBSTRATES TREATED WITH DIRECTED PLASMA FLUX

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ABSTRACT

We describe liquid crystal (LC) alignment on the non-organic substrates treated with Ar plasma flux formed by anode layer thruster. The substrates coated by hydrogenated amorphous carbon with small content of nitrogen (a-C:H:N, 2 atomic % of N) as well as the bare glass substrates are used. In the former case, the 10 nm thick a-C:H:N films are coated on the ITO containing glass slides by plasma enhanced chemical vapor deposition. The irradiation parameters are optimized for each kind of substrates. The quality of the obtained homogeneous alignment is similar to that for conventional alignment methods. The LC pretilt angle and the azimuth anchoring energy are measured for various incidence angles of plasma flux. The LC angle on the a-C:H:N coated substrates is detected to be substantially higher then that on the bare glass substrates. Comparing with a treatment by Ar^+ flux generated by Kaufman thruster, our method provides similar values of pretilt angle on the films of hydrogenated carbon, whereas the azimuthal anchoring energy is two orders of magnitude lower. The latter difference may be caused by either various content of fluxes or various flux divergence in case of two kinds of thrusters we compare.

Keywords: liquid crystal alignment, hydrogenated amorphous carbon , anode layer thruster.

INTRODUCTION

Liquid crystal (LC) alignment is a crucial problem of modern LCD technology. Traditional method of LC alignment is associated with the unidirectional rubbing of the aligning substrates. The indisputable advantages of this method are strong azimuthal anchoring, relatively high pretilt angle, high thermal and photo stability, low efficiency of image sticking [1]. However, this method often hinders further technological progress because of a number of principle problems mainly caused by direct mechanical contact with the aligning surface. These problems are surface damage, electrostatic charging, dusting, and non-uniformity of LC alignment. Besides, it is difficult to implement this method to multi-domain and wide viewing angle technology.

This altogether stimulated a number of non-contact methods of surface treatment, main of which are photoalignment [2, 3] and ion beam alignment [4-7]. Both of them are compatible with the wide viewing angle technology. However, only the second method provides alignment parameters similar to those for the rubbed substrates. Moreover, ion beam treatment provides LC alignment with enhanced pretilt angle, which can be quite easily controlled. Recently, we suggested to use plasma fluxes instead of ion fluxes for LC alignment. For this purpose we adapted anode layer thruster (ALT) producing weekly divergent flux of Ar plasma. We showed that this technique provides uniform LC alignment on various organic substrates with a quality comparable with conventional rubbing method [8-10].

In the present study we apply plasma alignment method to prepare *non-organic* aligning coatings for LC cells. We employ hydrogenated amorphous carbon, a-C:H, as the material most widely used for this purpose. In the studies [11-13] Ar^+ ion flux of Kaufman thruster have been used to treat a-C:H films. We compare LC alignment characteristics for the substrates treated by the fluxes of Kaufman thruster and ion layer thruster. Besides, we apply our method to induce LC alignment on the bare glass substrates. The corresponding alignment characteristics are investigated.

EXPERIMENTAL

1. Substrates

As basic non-organic layers, we used the films of hydrogenated carbon containing small amount (2 atomic %) of nitrogen. The films were doped with nitrogen to moderate internal strains and to improve adhesion properties [14]. The a-C:H:N films were deposited on ITO coated glass substrates by r.f. glow capacitively coupled discharge in a parallel plate reactor (Fig. 1).

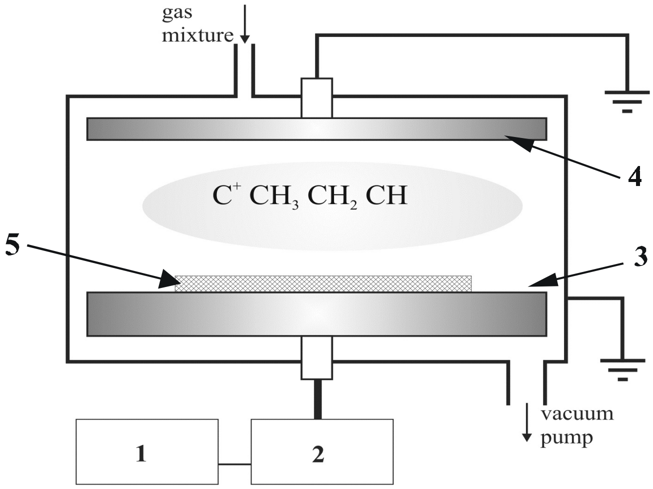


Figure 1. Schematic of the reactor used for deposition of a-C:H films.
1-rf generator unit (13.56MHz); 2-transmatch unit; 3-water cooled cathode; 4-anode; 5-treated substrate.

The r.f. power (13.56 MHz) was applied to the lower electrode, the upper electrode was grounded. The gas mixture (CH_4, H_2 and N_2) was introduced through the upper electrode in a shower head flow configuration. The substrates for coating were put directly on the lower, water-cooled electrode. The stainless steel chamber was evacuated to a base vacuum of about 10^{-4} Torr before each deposition run. Prior to deposition the substrates were pre-cleaned by hydrogen plasma during 3 min at gas pressure and discharge power 0.2 Torr and 250 W, correspondingly. As we checked, this pre-cleaning treatment did not affect ITO coatings noticeably.

The deposition was performed at different values of the total pressure P in the reaction chamber; P was varied from 0.8 to 0.2 Torr. The purpose of P variation was to obtain films with different hardness. The nitrogen content in the gas mixture, P_{N2}, was fixed and equal to 20%. The discharge power during film deposition was equal to 175 W. The deposition time was varied in the range 30-60 s to obtained a-C:H:N films with a thickness of 10 nm. This is a typical thickness for the studies of LC alignment on a-C:H films.

The thickness of the coated films has been estimated by laser ellipsometry at a wavelength of 632.8 nm. The nitrogen content in the films has been measures by Auger electron spectroscopy. The concentration of N in the films was close to 2 atomic %.

Also, bare glass slides (microscope slides from Fisher Scientific) were used for the plasma induced LC alignment.

2. Irradiation source and irradiation procedure

Our irradiation set up is based on anode layer thruster specially designed to produce collimated flux of ions from practically any gaseous feed [15]. The ALT belongs to the class of closed drift thrusters (CDT) that have been optimized in former SU for high thrust efficiency (>50%). The name "closed drift" refers to the drift of electrons along the closed discharging channel that is common to all variants of such thrusters. Comparing with electrostatic ion thrusters, the CDT have simplified construction. They do not require filaments or secondary electron sources to initiate discharge current or to neutralize the beam. Since ions in CDT are accelerated electrodynamically, the grids to extract and accelerate ions are not needed. Comparing with the ion thrusters the CDT possess longer lifetime, higher efficiency and thrust density (they are not space charge limited like ion thrusters). Also, more compact power processing unit are thought to enhance the competetiveness of these thrusters. The closed drift thrusters are routinely used on the Russian satellites for the near-term propulsion. Based on this type of sources various equipment for plasma etching and plasma deposition is developed.

A schematic of the anode layer thruster is shown in Fig. 2. The source contains permanent magnets on the inner and outer cathodes. The anode is above the inner and outer cathodes. Together these electrodes define the size and the shape of the discharge channel. Briefly, the working principle is as follows. The electrons from cathodes drift along the discharge channel as a result of the crossed (mainly radial) magnetic and axial electric fields.

The electrons in the closed drift undergo ionizing collisions with the neutrals injected in to the chamber. The magnetic field is strong enough to lock electrons in a drift within a closed discharge channel, while it is not strong enough to affect the trajectory of the ions which are essentially accelerated by the axial electric field. A number of electrons equal to that of the produced ions reaches the anode due to cross-field mobility and the same number of electrons is thus available at the cathodes to neutralize the exhausted ions. Quasineutrality is therefore maintained and, consequently, no space charge limitation is imposed on the acceleration resulting in relatively high thrust densities (especially compared to electrostatic ion propulsion).

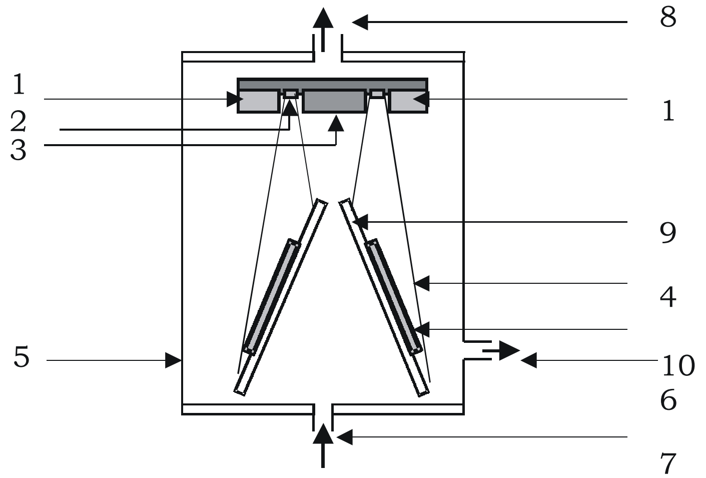


Figure 2. Schematic of anode layer thruster and irradiation method.
1-outher cathode and N pole; 2 - anode; 3 - inner cathode and S pole; 4 - plasma flux; 5 - body of vacuum chamber; 6-8 – gas valves; 9 – substrate holder; 10 – substrate.

The parameters of the fluxes generated by ALT are quite different from those for electrostatic thrusters. In case of ALT, the exhausted ions involve neutrals and electrons. In fact, the formed flux is a part of d.c. plasma generated in the discharge area. The ALT fluxes have hollow cylinder or sheet shape. The latter one is suitable to treat large-scale surfaces (by inclination or translation of the sample).

We used ALT with the race track shape of the discharge channel and argon as a working gas. The pressure P in the source chamber was (2-10) 10^{-4} Torr. The pressure of Ar determined current density j of the plasma ions. The ion energy was determined by anode potential U. It was varied within 200-1000 eV. So, in our experiments three parameters of plasma irradiation can be independently varied; 1) irradiation time τ_{exp}; 2) current density j; 3) ion energy E.

The substrate holder was mounted in a vacuum chamber just under the discharge channel (Fig. 1). A distance between plasma outlet and irradiated substrate was about 8 cm. To generate azimuthal alignment of LC, the substrates where irradiated slantwise. The plasma beam incidence angle α was varied within 0^0 and 80^0. To irradiate only part of the aligning substrate, the masks made from paper or plastic have been used.

3. LC cells and LC alignment characterization methods

Two kinds of LC cells were prepared: 1) the cells in which first substrate is irradiated by plasma beam, while the second one is a rubbed polyimide layer (combined cells); and 2) the cells with both substrates irradiated by plasma beam (symmetrical cells). The cells were assembled to obtain either parallel or 90° twist orientation of LC. To provide antiparallel director configuration in symmetrical cells, the irradiation directions were antiparallel. The cell gap was maintained with spacers of 20 μm in diameter. Independently, the cell gap was checked by the interference method. The cells have been filled with nematic LC K15 (5CB) by Merck.

The quality of LC alignment has been estimated visually, by setting the sample between crossed polarizers or in polarizing microscope. The pretilt angle of LC alignment has been measured in symmetric cells with the crystal rotation technique. The azimuthal anchoring energy was determined from the experimentally measured twist angle in the combined cells assuming infinite anchoring on the rubbed substrate [16].

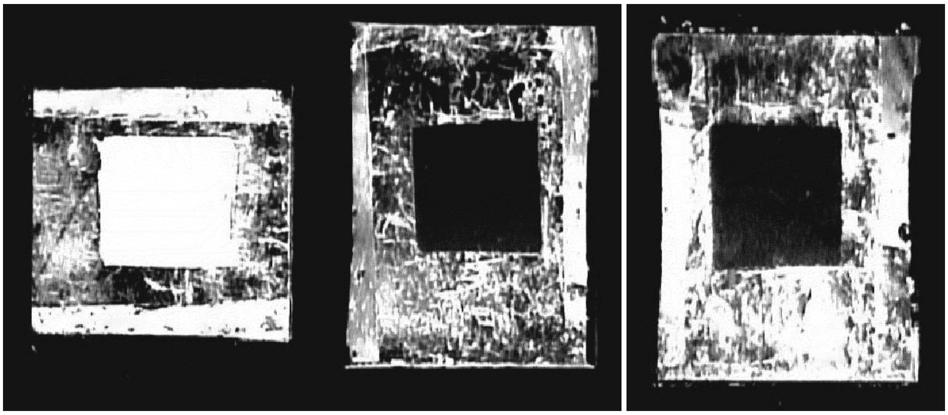
RESULTS AND DISCUSSION

The homogeneous LC alignment on the plasma treated substrates is observed at wide variation of irradiation parameters; j= (0.5-10) μA/cm^2, E= (200-1000) eV, τ_{exp}= 0.5 – 5 min. However, quality of alignment substantially depends on the irradiation conditions.

The irradiation parameters were thoroughly optimized for each kind of substrates. The best results are obtained for the following parameter ranges; j= (0.5-8) μA/cm^2, E= (400-600) eV, τ_{exp}= 2 – 3 min (a-C:H:N films) and j= =(0.5-3) μA/cm^2, E= (400-500) eV, τ_{exp}= 2 - 3 min (bare glass). In the former case, the parameters relate to all a-C:H:N films, i.e. to the films with different hardness.

Besides, incidence angle of plasma flux, α, is important factor of LC alignment. The best quality alignment is observed for the substrates irradiated at 50°-70°, the alignment effect is poor for the incidence angle less then 20°, and it is absolutely absent at α =0°. In the small domains (7×7 mm and less) selected by mask we achieved highly uniform alignment comparable with the alignment on the rubbed polyimide films. In the larger domains the uniformity was poorer, presumably because of plasma flux divergence.

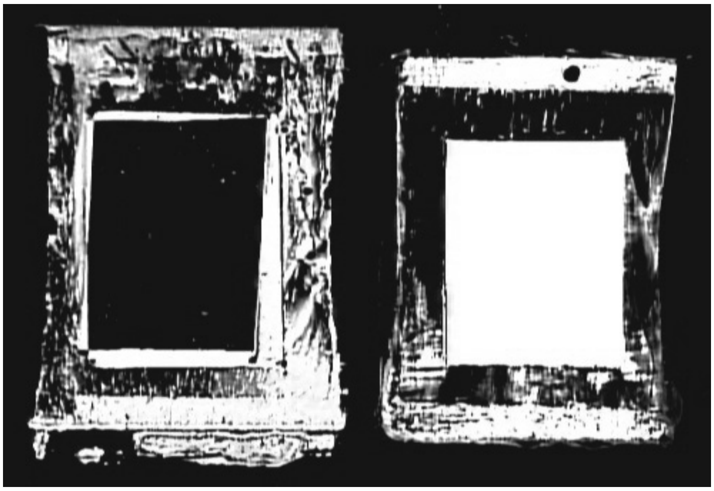
The examples of samples based on hydrogenated carbon and glass aligning films are depicted in Fig. 3 and Fig. 4, respectively. The pictures show high quality alignment in the cells based on both types of non-organic films, in case of both parallel and twist configuration. The alignment is not affected by sample curing at 100 °C over 30 min. Moreover, we did not detect any alignment damage by sample curing with non-polarized UV light (400 mW/cm^2, 1 h). These tests demonstrate high thermal and photo stability of the induced alignment.



a) b) c)

Figure 3. Cells based on plasma treated a-C:H:N aligning layers viewed between a pare of crossed polarizers.

The square like parts of the cells correspond to the plasma treated area. a – combined cell with 90° twist director configuration; b – combined cell with parallel orientation; c – symmetric cell with parallel orientation.



a) b)

Figure 4. Combined cells based on bare glass substrates viewed between a pare of crossed polarizers. The square like parts of the cells correspond to the plasma treated area. a – cell with parallel director configuration; b - cell with 90° twist director configuration.

The results of pretilt angle measurements are presented in Fig. 5. The pretilt angle θ versus incidence angles α curves are non-monotonous. The maximal pretilt angle is obtained for α=60° in contrast to irradiation with a flux from the Kaufman thruster giving maximal pretilt at α=45°. The values of pretilt angle for the hydrogenated carbon films are substantially higher then those for the glass substrates and comparable with the values obtained for the Kaufman source irradiation [11, 12]. Strong difference in the values of LC pretilt angle for a-C:H:N and glass aligning films may be explained by various interaction of these materials with the LC.

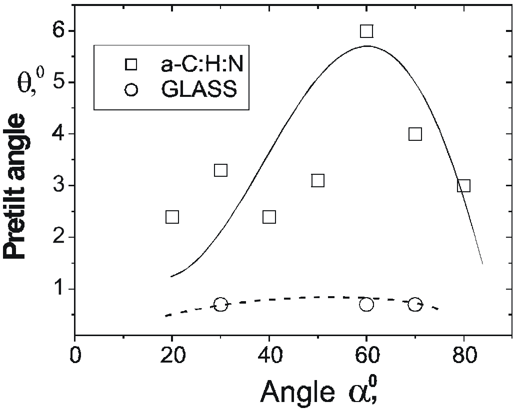


Figure 5. The LC pretilt angle versus plasma incidence angle curves for a-C:H:N and glass aligning layers.

The irradiation parameters for a-C:H:N and glass substrates are j=3 μA/cm^2, E=500 eV, τ_{exp}=2.5 min and j= 0.5 μA/cm^2, E=400 eV, τ_{exp}=2.5 min respectively. The cells gap is 20 μm.

The value of the azimuthal anchoring energy W_a on the hydrogenated carbon films was estimated to be in the range of (2-7) 10^{-3} erg/cm^2. The W_a versus a curve behaves similar to θ versus α curve. Dependence of W_a on the current density and the ion energy was also noticed. In all of these cases W_a was varied in the range mentioned above. The anchoring energy of the order of 10^{-3} erg/cm^2 was detected on the a-C:H:N films of various hardness. The anchoring energy on the glass substrates was of the same order of magnitude. The value 10^{-3} erg/cm^2 corresponds to the case of week azimuthal anchoring. Our estimate strongly differs from the result obtained in [11,12]. The authors of these papers report value 10^{-1}-1.0 erg/cm^2. This is more then two orders of magnitude higher then in our case.

We observed at least two discrepancies with the results obtained in [11,12]; 1) pretilt angle versus plasma incidence angle curve reaches maximum at somewhat higher value of incidence angle; 2) azimuthal anchoring energy is two order of magnitude lower. To our point, this difference may be caused by two reasons:

1)different content of fluxes generated by anode layer thruster and Kaufman thruster.

Anode layer thruster works in plasma generation regime, in contrast to Kaufman thruster producing ion flux. In addition to ions, plasma contains neutral atoms, electrons and deep UV irradiation. Combination of these factors can give aligning effect different from the effect of only ions.

2) different beam divergence in case of the mentioned sources.

The beam divergence of ALT seems to be higher compared with that of the Kaufman source. To clear the question, the comparative measurements of the beam divergence should be carried out. The divergence should be measured in the sample position, since it depends on the distance from the discharge area.

Thus, thorough measurement of the parameters of the generated fluxes is needed to explain difference in the aligning results. These studies are underway.

CONCLUSIONS

Our results show that the plasma treatment method based on the anode layer thruster can be effectively used to induce LC alignment on the non-organic substrates. On the substrates of hydrogenated amorphous carbon the method provides high LC pretilt angle comparable with the angle obtained by ion beam method based on the Kaufman source. At the same time, in our experiments the azimuthal anchoring is two orders of magnitude weaker. The latter result seems to be caused by either different action of plasma and ion fluxes on the substrate, or difference in geometrical parameters of the fluxes. The most important reason will be cleared in our further studies. It is also show that plasma method can be effectively used to generate LC alignment on the glass surfaces. This makes the method extremely useful for some specific applications (integrated optics, etc.), which require contact of LC with the equipment parts made of glass or other non-organic materials.

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