P-83: Liquid Crystal Alignment on Substrates Treated with the Plasma Flux: Static and Dynamic Regimes of Irradiation

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Abstract
In this paper, we present the new results related to LC alignment on the substrates obliquely treated with a "sheet" of accelerated Ar^+ plasma generated by an anode layers thruster (ALT). The substrates of organic (polymers) and inorganic (glass, DLC, SiO_2, etc.) origin were treated with the plasma flux in static and dynamic regime (unidirectional translation perpendicularly to plasma "sheet"). For LCs with $\Delta\varepsilon>0$, in both regimes, we observed two aligning modes, with the easy axis confined to the plane of plasma incidence (mode 1) or perpendicular to this plane (mode 2). In the 1st aligning mode the LC pretilt angle is not equal to zero and can be varied with the incidence angle of plasma beam and the irradiation dose. The uniformity of pretilt angle is better in the dynamic regime. With the increase of irradiation dose, the alignment transition from the 1st to the 2nd mode occurs. For the LC mixtures with $\Delta\varepsilon<0$, used for VA LCD, only the 1st mode alignment (uniform over the whole substrate) is realized. It occurs at low and even at the relatively high irradiation doses, which cause the 2nd mode alignment for the LCs with $\Delta\varepsilon>0$. The pretilt angle achieves values as high as 30^0 and can be controlled by the irradiation dose and by the incidence angle of plasma beam. The 2nd alignment mode is observed at high irradiation doses and only in the static regime of irradiation. It occurs in the central, most intensive part, of the plasma "sheet", while the periphery part shows the 1st mode. The areas of the 1st and the 2nd mode are separated with the narrow transition area showing multidomain (two-fold degenerate) LC alignment. The easy axis in these domains is turned by about $\pm 45^0$ with respect to the alignment direction in the 1st mode area. The alignment transition 1st mode – two-fold degenerate alignment – 2nd mode observed for LC with $\Delta\varepsilon<0$ is quite similar to the one earlier described for vapor deposition alignment. In the dynamic irradiation regime, for both types of LC, uniform alignment on the substrates as big as 15x15 cm is realized.

1. Introduction
Particle beam processing (PBP) methods are very promising candidates to replace the traditional rubbing procedure for LC alignment in the next generation of LCD. Avoiding mechanical contact with the aligning substrate, PBP methods minimize surface damage and contamination. Simultaneously, they improve alignment uniformity and simplify pattering of LC alignment.

The PBP consists in the oblique treatment of LC aligning substrates with a directed flux of particles (atoms, ions, electrons or mixtures thereof), which deposit on the substrate [1-3] or etch it [4,5]. As the result, the aligning surface becomes anisotropic and capable of LC alignment.

The renewed interest to PBP methods was sparked by the recent publication of the IBM group [6,7]. Their procedure is based on the anisotropic etching with the ion beam. In contrast to the previous studies [4,5], IBM team uses ions of low energy, which modify only the very top layer of the aligning film. This is achieved by the use of the ion source of Kaufman type.

As we showed earlier [8-10], the ion beams can be successfully replaced for the purpose of LC alignment with the beam of accelerated plasma. In contrast to the "cold" r.f. plasma carried to the substrates with the directed gas stream [3], we used the plasma beam that is extracted and accelerated electrostatically. The energy range of accelerated ions was chosen to be comparable with that used in IBM experiments. For this purpose we adapted an anode layer thruster (ALT) generating sheet-like fluxes of Ar plasma [11]. Irradiations is carried out in the static regime (the samples do not move). It was shown that for most LCs with $\Delta\varepsilon>0$, depending on the irradiation dose, there are two alignment modes: (1) one with the easy axis confined to the incident plane formed by the direction of the beam and the normal to the treated substrate; (2) the second mode with an easy axis that is perpendicular to the plane of incidence. By increasing the irradiation dose, one can change the alignment direction from the type (1) towards the type (2). In the mode 1, the value of the pretilt angle can be controlled with the irradiation parameters such as irradiation angle, ion current density, ion energy, etc. The second type of alignment has a zero pretilt.

In the present work, we report on the extension of the original technique to LCs with $\Delta\varepsilon<0$. We also study the alignment features for samples treated dynamically, when the sample moves with respect to the plasma beam. We analyze applicability of the ALT technique to the treatment of large-area aligning substrates.

2. Experimental
2.1 Substrates
As the bounding substrates we used the following:

(1) polymer layers spin coated on glass slides (2x3 cm) from

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the polymer solution and subsequently backed. We used polyvinylcinnamate (PVCN) from Aldrich, polyimide (PI) 2555 from Dupont, polymethylmethacrylate (PMMA) from Aldrich.

(2) bare glass substrates (microscope slides from Fisher Sci.).

(3) plasma coatings of hydrogenated carbon (a-C:H) prepared by plasma enhanced chemical vapor deposition as described in Ref. [12].

2.2 Treatment Procedure

For irradiations, we used the ALT with a race track discharge area. In our case this source worked in the regime of low energies (E=500-800 eV) and currents (j=5-10 μA/cm^2) [10]. The width of generated plasma "sheet" was about 30 cm. The distance between discharge area and treated substrates was 6-10 cm. The substrates were set for oblique irradiation. The substrate holder was mounted on the PC controlled translation system providing translation in the sample plane perpendicularly to the plasma sheet, as shown in Fig.1. The translation amplitude was varied within 3-15 cm depending on the size of treated substrate. Due to the translation, different parts of the sample passed over the plasma beam undergoing the plasma treatment. Several translation regimes were used:

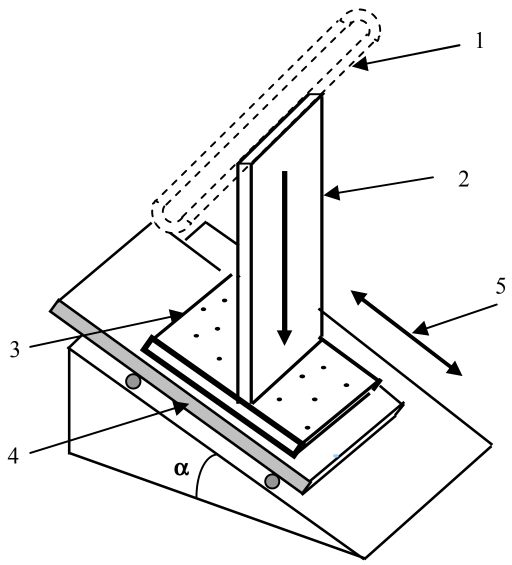


Fig. 1. Sample irradiation geometry. 1-race track shaped discharge area; 2 – plasma flux; 3- substrate; 4- translation system; 5- translation direction.

(1) One-direction translation. In this case, the translation speed was varied to get different exposure doses.

(2) Cyclic translation. In this regime, the translation speed was set at 2-5 mm/s. The irradiation dose was controlled by the number of cycles.

The static irradiation regime was also studied. In this case, the sample was set in such a way that the most intensive part of plasma sheet corresponded to the middle of the treated substrate.

2.3 Cells

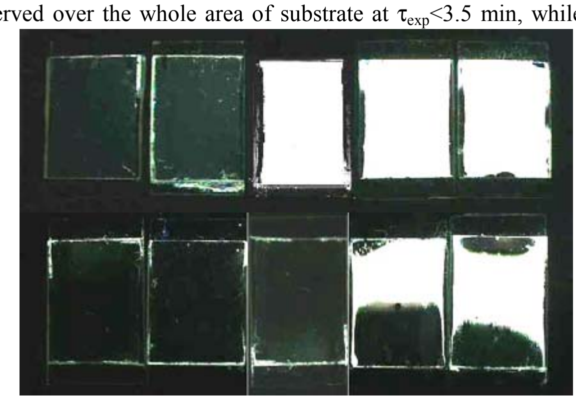
The LC alignment has been studied by preparing two types of LC cells: (1) one substrate is irradiated by plasma beam, while the second substrate has a rubbed polyimide layer (asymmetric cells); and (2) both substrates are irradiated with the plasma beam (symmetric cells). To obtain a uniform director orientation across the LC cell, the cells were assembled in an antiparallel fashion, meaning that the glass plates were set in such a way that the vectors specifying the direction of irradiation were antiparallel to each other. The asymmetric cells were prepared with the aim of determining the direction of LC alignment on the plasma treated substrate. The symmetric cells were used to measure the pretilt angle by crystal rotation method and magnetic null method. The cell gap was kept with spacers of 6 μm and 20 μm in diameter. As LC with Δε>0 we used nematic LC K15 (5CB) and ZLI2293 purchased from Merck. As the LCs with Δε<0 we used the nematic mixtures MJ961180 (Merck Korea) and ZLI4788 (Merck).

3. Experimental Results and Discussion

3.1 Static Regime of Irradiation

We used irradiation conditions optimized for various kinds of substrates [8-10]. Figure 2 shows two sets of asymmetric samples in which the tested PI substrate is treated with the plasma beam (j=8 μA/cm^2, E=600 eV) over various periods of time. In the first series, corresponding to 5CB (Δε>0), the 1st alignment mode is observed over the whole area of substrate at τ_{exp}<3.5 min, while the 2nd mode is observed for τ_{exp}>4 min. The alignment transition from the 1st to the 2nd mode occurs sharply. The alignment characteristics of LC with Δε>0 in the 1st mode are described in details in [8-10].

a



b

Fig. 2. Photos of asymmetric cells (d=20 μm) viewed between a pare of crossed polarizers. The cells are filled with LC 5CB (set a) and MJ961180 (set b). In each set, testing PI substrate is treated with plasma beam over 1, 3, 5, 15, and 30 min in static regime.

In the case of LC MJ961180 (Δε<0), the 1st mode alignment over the whole area is observed even for the irradiation doses well above the transition dose for LCs with Δε>0. In the 1st mode, the alignment characteristics of MJ961180 are similar to those for LC with Δε>0, except the pretilt angle is larger. In Fig. 3 we show the pretilt angle vs. the irradiation angle (measured from the normal to the substrate) for 5CB and MJ961180. As can be seen from Fig. 2, at τ_{exp}>10 min, the 2nd alignment mode appears in the area corresponding to the central, most intensive part of plasma beam. At the same time, the periphery part is still aligned in the 1st mode. The areas of the 1st and the 2nd mode are separated by the narrow transition area showing a multidomain LC alignment. The easy axis in these domains is turned symmetrically by about ±45^0 with respect to the alignment direction in the 1st mode area (two-fold degenerate alignment). The area aligned in the 2nd mode, as well as the areas of two-fold-degenerate alignment, did not extend substantially with the increase of the irradiation time from 10 to 30 min.

The sequence of the alignment transitions 1st mode – two-fold degenerate alignment – 2nd mode was observed for MJ961180 on

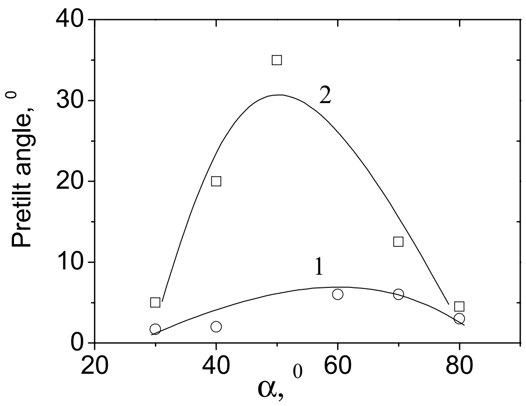


Figure 3. LC pretilt angle at the PI substrate vs incidence angle for static irradiation regime. Curve 1 and curve 2 correspond to LC 5CB and LC MJ961180, respectively. The irradiation parameters for polymer and glass substrates are j=8μA/cm^2, E=600 eV, τ_{exp}=1.5 min and j= 2 μA/cm^2, E=500 eV, τ_{exp}=1.5 min, respectively. The cells gap is 20 μm.

different substrates listed in Section 2.1. In contrast, only the 1st mode – 2nd mode transition is observed for 5CB and ZLI 2293 on these substrates.

The transformation of LC alignment with the increase of irradiation dose is qualitatively similar for different kinds of LCs. Most probably, the two-fold-degenerate alignment is not observed for LC with Δε>0, because of the very sharp transition from the 1st to the 2nd mode when the dose increases. By contrast, a very broad transition for MJ961180 allows one to observe the different stages of transformation.

There is an interesting parallel between the etching and deposition PBP alignment. The transition 1st mode – two-fold degenerate alignment – 2nd mode was earlier described for the LC alignment on the obliquely deposited SiO_x films. This transition occurs with the decrease of the angle of plasma beam incidence (accounted from the substrate normal). The sequence of alignment modes described above was observed for various LCs, although the range of evaporation angles corresponding to different alignment regimes depended on the type of LC. This similarity in LC alignment on the obliquely deposited and obliquely etched substrates might imply some similarity of the alignment mechanisms. Thus the topological factor considered as the major factor of LC alignment on the obliquely deposited films [13] may be also important in the case of LC alignment caused by the anisotropic etching. This suggestion agrees well with our results of AFM studies [10].

3.2 Dynamic Regime of Irradiation

Figure 4 shows a set of asymmetric samples in which the tested PI substrate is treated with the plasma beam (j=8 μA/cm^2, E=600 eV) in dynamic regime over various periods of time. The samples are filled with LC 5CB (Δε>0). As one can see, the alignment

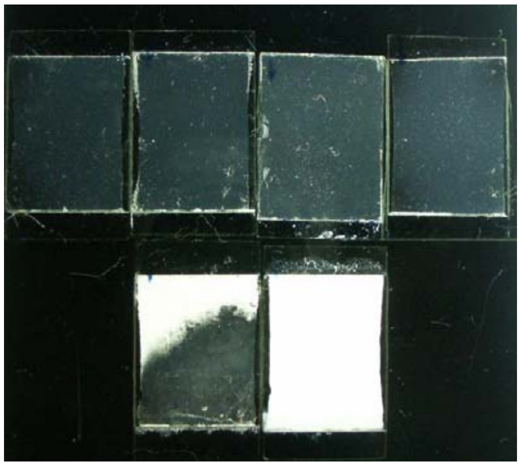


Fig. 4. The set of asymmetric cells viewed between crossed polarizers. The tested PI substrates in the cells have been irradiated during 1, 2, 3, 4, 5 and 10 min, respectively. Irradiation conditions: cycling regime, α=70^0, *j*=8 μA/cm^2, E=600 eV. The cells are filled with 5CB.

transition from the 1st to the 2nd mode occurs at the doses slightly higher then in case of static regime (Fig. 2). Besides, a rather broad range of doses where 1st and 2nd mode coexist is observed (τ_{exp} =5 – 10 min). However, the two-fold degenerate alignment is not observed. Similar results are obtained for LC ZLI 2293. For MJ961180 (Δε<0), only the 1st mode alignment is observed up to τ_{exp} =60 min. The two-fold degenerate alignment and the 2nd mode alignment were not achieved, because of complete etching of PI layers at high irradiation doses.

In the 1st mode, the LC pretilt angle can be controlled by the irradiation angle and the exposure dose. Figure 5 shows the pretilt angle of 5CB as the function of exposure time. The pretilt angles are comparable to those obtained in the static regime. At the same time, the uniformity of pretilt angle over the cell area is substantially better in the case of dynamic regime of irradiation. The translation direction does not affect the direction of LC tilt, which is determined mostly by the direction of plasma beam.

3.3 Treatment of Large Scale Substrates

In the dynamic regime, the ALT allows one to treat large-scale substrates; the width of the treated substrate is limited only by the length of the "race track" of ALT. We prepared samples with area

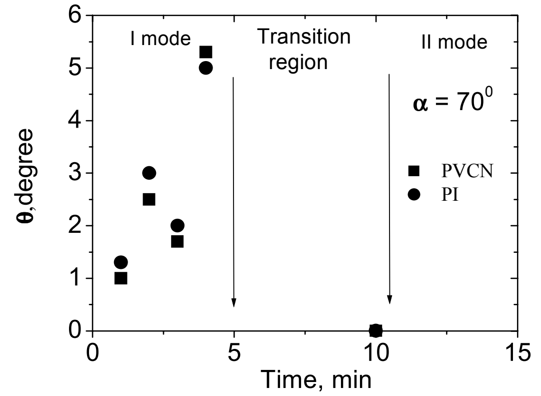


Fig. 5. Pretilt angle of 5CB at PI and PVCN substrates vs irradiation time for cyclic translation. Irradiation parameters: $\alpha=70^0$, j=8 μA/cm^2, E=600 eV.

15x15 cm^2, Fig. 6. The LC alignment in these cells is rather uniform; the LC pretilt angle variations in these cells has been estimated to be insignificant, within 0.3^0.

Figure 6. Photos of 15x15 cm symmetric cells (d= 15 μm) based on plasma treated PI substrates viewed between crossed polarazers. The cells are filled with LC ZLI2293. a – twist angle is zero; b – twist angle is 90^0. Irradiation conditions: $\alpha=70^0$, j=8 μA/cm^2, E=600 V).

4. Conclusions

We describe an alignment technique for various types of LCs (with $\Delta\varepsilon>0$ and $\Delta\varepsilon<0$) in static and dynamic irradiation regimes. It is shown that movement of the aligning substrate under plasma irradiation results in the alignment properties similar to that observed for the static regime. At the same time, the translational movement substantially improves uniformity of LC alignment. Most importantly, it allows one to treat the large-area aligning substrates preserving the quality of uniform alignment. By increasing the size of ALT plasma source, one can extend the process of plasma alignment to the substrates with dimensions of meters and more, as required in modern LCD applications.

5. Acknowledgements

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6. References

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