Liquid Crystal Alignment on the Large Area Substrates: Principle and Realization

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ABSTRACT

We developed effective method for the liquid crystal alignment on the large area substrates. This method is based on the oblique treatment of the aligning substrates with a "sheet" of accelerated plasma generated by the anode layer source of "race track" geometry. During this treatment, substrate or source is cyclically translated in the direction perpendicular to plasma "sheet". This method provides controllable alignment parameters, excellent alignment uniformity and reproducibility.

1. INTRODUCTION

The modern LCD technologies set strong demands to the liquid crystal (LC) alignment. It should be highly uniform (even on the microscopic level), stable and posses adjusted alignment parameters, such as pretilt angle and anchoring energy. The electrooptic performance sets additional demands, such as strongly reduced RDC and acceptable VHR, which partially relate to alignment conditions and alignment materials. These requirements should be satisfied for the large area (LA) substrates used in the modern LCD manufacturing. Nowadays, LCD production equipment operates with the substrates of 6th generation with a size of 1500x1600 mm^2. The substrates of 7th generation are planned to be 1870x2200 mm^2 by size.

The traditional rubbing procedure less and less satisfies demands mentioned above. For this reason, development of new alignment processes overcoming intrinsic problems of rubbing alignment is of great actuality. Among the most promising candidates the group of particle beam methods is especially intriguing. In these methods, surface of the alignment substrate is obliquely treated with a flux of particles (atoms, ions, electrons or mixtures thereof), which causes anisotropic deposition or etching of the substrate. In spite of long history of these studies [1,2], especial interest to them arose recently after publications of IBM group [3,4]. The idea of IBM authors is based on the treatment with ions of *low* energy, which modify only very top layer of the aligning film. To realize this regime, the ion beam from Kaufman type ion source was utilized. The high-quality alignment with controllable pretilt angle was achieved for a number of aligning materials.

Earlier, we showed [5,6] that results rather similar to the results of IBM group can be obtained by substitution of ion beam with a beam of accelerated plasma generated by the source known as anode layer thruster (ALT) or a source with closed electron drift. In addition to advantages of IBM method, for LC with $\Delta\varepsilon>0$ we realized two alignment modes; with the easy axis confined to the plane of plasma incidence (mode 1) and perpendicular to this plane (mode 2). In the 1st aligning mode the LC pretilt angle is non-zero and can be controlled with the incidence angle of plasma beam and the irradiation dose. With the increase of irradiation dose, anchoring transition from the 1st to the 2nd mode occurs through the transient two-fold degenerated alignment [7]. Recently, this technique was utilized to realize tilted vertical alignment, which is presently of special interest [8].

One more advantage of ALT set up is good potential for treatment of large area surfaces. The shape of this source is very flexible; it effectively works as long as plasma discharge has a form of loop. The latter condition provides closed drift of electrons supporting plasma discharge. In case of "race track" shaped discharge channel, ALT generates two "sheets" of plasma. By sample translation normally to the plasma sheet one can provide treatment of LA substrates. The width of these substrates is limited with a width of plasma sheets, while the length is limited only with the accessible translation amplitude and chamber size.

In the present research we evaluate the capability of ALT treatment for LC alignment on the large area surfaces. For this purpose, extended ALT and translation irradiation regime are combined. The alignment uniformity on the enlarged substrates is studies. We also consider a sinchronism of LC anchoring transitions in the different points of substrates as an indicator of treatment uniformity. The obtained results allow us to draw very encouraging conclusions regarding application of ALT for the generation of LC alignment on the LA surfaces.

2. EXPERIMENTAL DETAILS

2.1. Plasma irradiation set up

We utilized anode layer thruster with a race track shape of discharge area. General construction of this source is presented in Fig. 1. The source contains inner and outer cathodes and anode, which define the size and the shape of the discharge channel. At the outer cathode, the source contains permanent magnets and so the inner and the outer cathodes serve as magnet poles. Due to this construction, ion flux is formed in crossed electric (**E**) and magnetic (**H**) fields immediately within the discharge channel and thus it is a part of d.c. plasma generated in the discharge area. The details of construction, characteristics and principles of operation of this device can be found elsewhere [9].

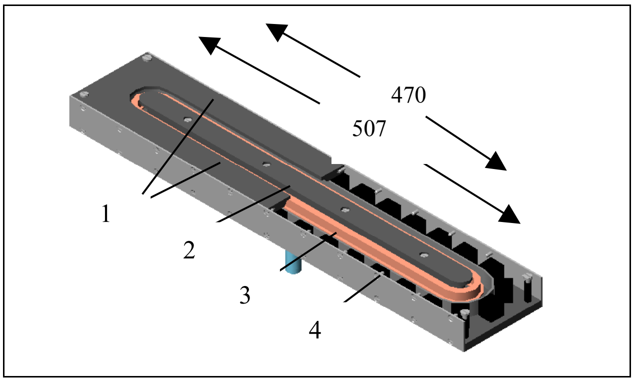

Fig. 1. ALT used in our studies. 1 – outer cathodes; 2 – inner cathode; 3 – anode; 4 – permanent magnets.

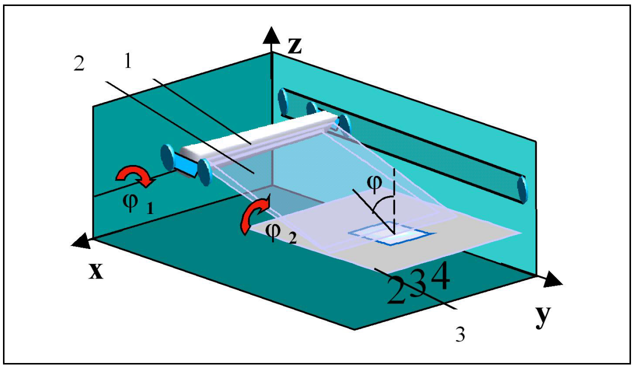

Fig. 2. Scheme of irradiation setup. 1 – ALT; 2 – plasma "sheet"; 3 – substrate's holder. φ1 and φ2 denote rotational degrees of freedom of ALT and holder, which determine incidence angle φ of plasma flux.

The length of "race track" of our source is 508 mm, while the length of linear part is about 470 mm (Fig. 1). The low power of discharge allowed us to refused cooling lines. It lightens the source and let to avoid the use of hoses moving and bending during translation.

The source mounting lets rotation around horizontal x axis and cycling translation across the plasma "sheet" (along y axis, Fig. 2). The holder of substrates had similar degrees of freedom: rotation around x axis and cycling translation along y axis. This flexible construction allowed us to realize two translation regimes: (1) unmoved horizontal position of the aligning substrate and cycling translation of the ALT tilted with respect to the horizontal level; (2) unmoved horizontal position of plasma source and tilted movable position of the substrate. Both methods provide oblique treatment of the aligning substrate in the dynamic regime.

The working gas was argon. It was let directly in a vacuum chamber. The gas pressure p was 3 10^{-4} Torr. The anode potential U was 600 V. At these conditions, ion current density in the sample position was 6-8 μA/cm^2. The angle of plasma beam incidence φ was 60^0-70^0. The time of irradiation was varied within 1 and 10 min. These treatment parameters were earlier optimised for the small area substrates [5-7]. A speed of translation was about 1 cm/s.

2.2. Samples

As aligning substrates we used ITO coated glass slides with the polyimide (PI), polyvinylcynnamate (PVCN) or a-C:H aligning layers. Two sizes of the aligning substrates were chosen. The regular size was 2x3 cm^2. These substrates were placed in different parts of 40x40 cm^2 holder plate. Using this mosaic principle we modeled 40x40 cm^2 substrates and judged about alignment uniformity on the substrates of this scale. We also used 12x15 cm^2 substrates for the cell preparation. Two types of LC cells have been prepared: (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 and assembled in an antiparallel fashion (symmetric cells). 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. The cell gap was kept with spacers of 6 μm and 20 μm in diameter. We used LC with $\Delta\varepsilon>0$ (K 15 and ZLI2293 from Merck) and LC with $\Delta\varepsilon<0$ (MJ961180 from Merck Japan). The in-plane uniformity of LC alignment was tested by sample observation in viewing box or in polarizing microscope. The out-of-plane uniformity was judged from the measurement of LC pre-tilt angle.

3. ALIGNMENT RESULTS

Figure 3 shows a set of asymmetric cells filled with K15 in which the plasma treated substrates (tested substrates) are processed over different time. The tested substrates were placed in the same spot of holder, in order to provide equal irradiation conditions, except irradiation time τ_{exp}. One can see that, with the increase of irradiation time, anchoring transition from the 1st to the 2nd alignment mode occurs. It appears at the same irradiation dose for the substrates located in the different holder's spots during irradiation. This is one of the evidences of treatment uniformity.

By studying the in-pane alignment uniformity we concluded that it realizes at the time of irradiation longer then the time of one translation cycle. At this condition, the substrates placed in different spots of holder show pretty much the same in-pane alignment direction; the deviation of easy axis is within 0.5^0 (it concerns both the 1st and the 2nd mode). The uniformity slightly improves with the number of translation cycles.

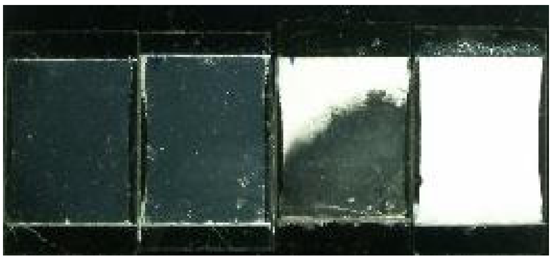

Fig. 3. Set of asymmetric cells viewed in crossed polarizers. The tested PI substrate in these cells is irradiated 1, 3, 5 and 10 min, respectively. Irradiation conditions: a=60^0, j=8 mA/cm^2, E=600 eV. The cells are filled with LC K15.

The in-plane alignment of LC MJ961180 with $\Delta\varepsilon<0$ is also uniform on the large area surfaces subjected to plasma "sheet". However, in contrast to the LC with $\Delta\varepsilon>0$, no transition to the 2nd mode is observed, even at the large irradiation doses (τ_{exp}=30 min).

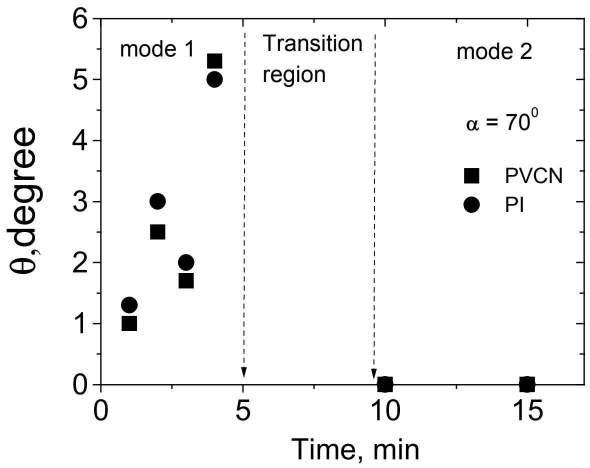

Fig. 4. Pretilt angle vs irradiation time for cycling translation. Irradiation parameters: $\alpha=70^0$, j=8 μA/cm^2, E=600 eV.

The out-of-plane uniformity is also sufficiently good. The deviation of pre-tilt angle in the cells is within 15%. For K15 and ZLI2293 ($\Delta\varepsilon>0$) the value of pre-tilt angle non-monotonously changes with the irradiation dose as it is shown in Fig. 4; it grows with τ_{exp}, reaches maximum and decreases to zero at the transition to the 2nd mode. For MJ961180 with $\Delta\varepsilon<0$ the value of pre-tilt angle is about 25^0 and its dependence on the irradiation time is rather weak.

For fluorinated PI substrates specially designed and extremely low irradiation dose (E=600 V, j=0.5 μA/cm^2, 15 s) we achieved tilted vertical alignment (VA) of MJ961180; the pre-tilt angle was about 88^0-89^0 degree. Testing substrates located in different places of holder we proved high uniformity of VA. The pre-tilt angle deviation was estimated to be less then 0.4%.

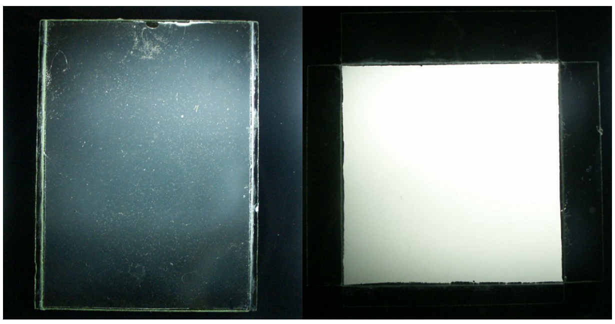

Fig. 5. Photos of 12x15 cm symmetric cells (d= 20 mm) based on plasma treated PI substrates viewed between crossed polarazers. The cells are filled with LC ZLI2293. a – twist angle is zero; b – twist angle is 900. Irradiation conditions: a=700, j=8 mA/cm2, E=600 V).

Two translation cases (source translation and substrate translation) result in very similar alignment, including excellent alignment uniformity. At the same time, we believe that the source scanning method is more suitable for the treatment of large area glass substrates characterized by rather high fragility.

Finally, Figure 5 shows the samples of the increased size (12x15 cm^2) with parallel (a) and 90^0 twist (b) director configuration. These pictures also show good uniformity of LC alignment. The amplitude of pre-tilt angle deviation in sample 1 is less than 15%.

4. CONCLUSIONS

Our results demonstrate high potential of ALT generating sheet like plasma fluxes for the alignment treatment of the large area bounding substrates for LCD. This method provides LC alignment with a high uniformity in the azimuthal (in-plane) and polar (out-of-plane) directions. The method can be effectively used to realize low tilt alignment for TN and IPS modes, and high tilt alignment for VA mode. In spite of studying only alignment on the 40x40 cm^2 surfaces, limited with the length of our ALT source, we can predict similar alignment uniformity for the substrates of substantially bigger size. Indeed, ALT can be easily scaled up and so adapted for the large area treatment. As we believe, these sources will be successfully utilized not only for treatment but also for deposition (oblique deposition by sputtering or direct plasma deposition) of large area films for LC alignment. However, potential of ALT sources for LCD is not limited to alignment films. For instance, they can be effectively used for coating of antiscratching or antireflection layers, especially on the large area LCD plates.

Acknowledgement

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