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Plasma Beam Equipment and Processes for Liquid Crystal Alignment on the Large-Area Substrates

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Abstract: This paper surveys plasma beam processes of LC alignment recently developed to overcome shortcomings of rubbing technique. The ion beam etching, ion beam sputtering deposition and their combinations are considered. The alignment modes, alignment parameters in these modes, alignment uniformity and stability issues are discussed. The focus is made on the equipment and process for the large area substrates, including fabs of modern generations. It is shown that the processing equipment based on the linear sources with a closed electron drift suits very well for the alignment treatment of large area substrates. There is concluded that sources of etching type are most effective for the uniform planar and low-pretilt alignment used in IPS and TN LCD, while sputtering sources are of the best promise for the high pretilt alignment employed in VAN LCD.

Key Words: Liquid Crystal Alignment, Particle Beam Alignment, Ion Beam Alignment, Sputtering.

1 Introduction

Advance of LCD technology towards display perfection and lowering of manufacturing costs set strong demands to liquid crystal (LC) alignment. There is requested highly uniform alignment on the large-area substrates (1870x2200 mm^2 for the fabs of 7th generation and considerably bigger for the fabs of next generations planned). On the other hand, advance of projection display, stimulated by LCOS technologies, requires LC alignment of high uniformity on microscopic level, also high photo- and thermal stability, Traditional alignment procedure dealing with rubbing of organic films in not able to solve satisfactorily the aforementioned problems. Beside alignment uniformity, it suffers from a number of other drawbacks mainly associated with a mechanical nature of rubbing. These disadvantages are well known for LCD specialists [1].

In this situation, a real technological breakthrough might realize new alignment procedures not suffering from drawbacks of rubbing. Among the alignment processes recently developed the so-called “particle beam” alignment processes are of the best promise. This is a collective term for methods operating with the beams of different particles (ions best, neutrals, electrons and mixtures thereof). To generate in-plane anisotropy of the aligning surface, as a condition of planar/tilted LC alignment, these particles impinge upon substrate obliquely.

The particle beam alignment methods can be divided in two groups. The particle beams of the first group, usually beams of accelerated ions, cause modification of alignment films (etching, molecular bond breaking, etc.). A strong interest to this method, primordially proposed by Little [2], is recently excited by works of IMB group [3,4]. The key point of IBM approach is minimization of surface deterioration by lowering ion energy (E=100-300 eV, only very top layer of the alignment film is affected). Subsequently, alignment properties in case of different feed gases and alignment materials were investigated [5,6].

The beams of the second group deposit particles on the substrate, forming alignment layers. Compared with the etching process, particle energy in this process should be lower (E<50 eV) to cause deposition instead of bombardment. This principle was suggested by Janning in 1972 [7]. He observed LC alignment on SiO_x films formed by oblique vapor deposition. This method yields several alignment modes different for LC with positive and negative dielectric anisotropy [8,9]. In addition to vapor deposition, Motohiro and Taga [10] observed uniform LC alignment on SiO_x layers obliquely deposited by the ion beam sputtering. The latter technique, however, is surprisingly poorly elucidated in literature.

In the present paper we analyze alignment obtained by particle beam etching and sputtering deposition processes and consider potential of these methods for the alignment processing of large area substrates used in modern LCD industry. For this purpose we employ *linear* sources much better adapted for the alignment treatment of large area substrates. We compare alignment obtained by these two methods. The alignment modes, stability and uniformity of LC alignment are considered. Some attention is paid to alignment of LC materials used for non-electrooptic applications. Finally, we draw conclusions about the most effective applications of each alignment procedure.

2 Particle Beam Source and Processing Setup

Result of particle beam treatment depends on the particles’ energy, which, in turn, is determined by operation regime of particle source. The source used in IBM experiments [3,4] and in subsequent studies was electrostatic Kaufman source. This is a tubular source, which contains system of grids served to extract and accelerate ions from a glow discharge generated in the tube. This source necessarily contains source of electrons (electron gun or filament) served to enrich ion beam with electrons. Besides, cathode of this source is usually heated to initiate sufficient amount of free electrons capable to maintain glow discharge. A presence of hot units with a limited lifetime complicates maintenance of Kaufman source.

In contrast to other groups we employed anode layer source (ALS) from Hall family of electrodynamic sources with a “race track” geometry of glow discharge (linear source) [11]. It has extremely simple construction presented in Fig. 1a. The working principle is the following. The electrons circulating in the crossed electric and magnetic fields in a slot formed by inner and outer cathodes and anode ionize the feed gas atoms

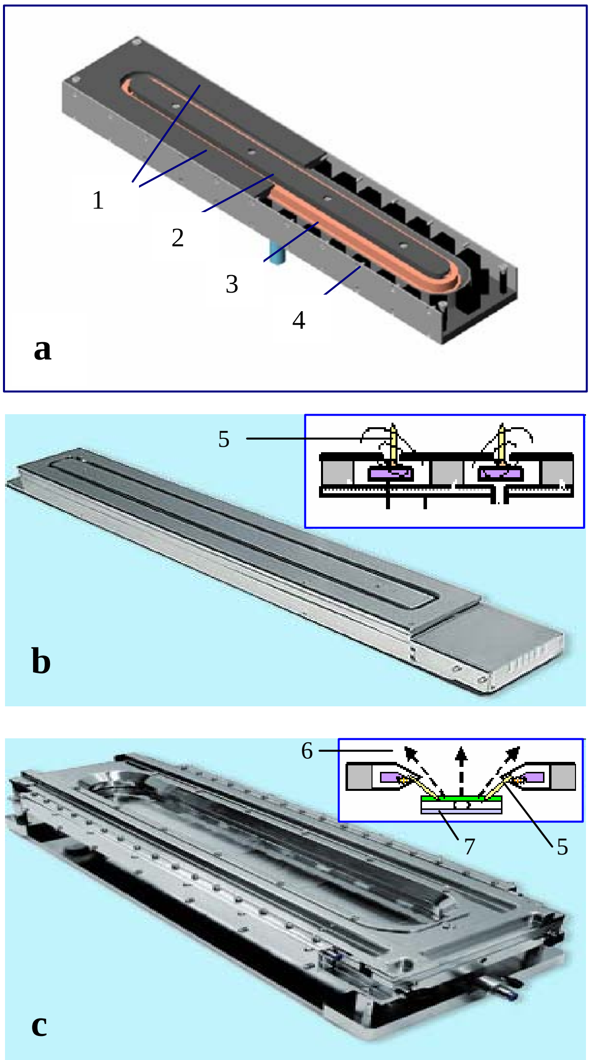

Figure 1. (a) general construction of anode layer source; 1 – outer cathode, 2 – inner cathode, 3 – anode, 4 – permanent magnets; (b) and (c) photographs of etching and sputtering type ALS, respectively. Insets in (b) and (c) schematically explain working principle of sources. 5 – beam of accelerated plasma (primary beam), 6 – beam of particles extracted from target (secondary beam, 7 – target plate.

(usually, argon). The ions are thrown out of the slot due to high positive potential of anode. The ions attract electrons and so beam formed is naturally compensated. In contrast to Kaufman source, the glow discharge and the generated beam are not spatially separated. In fact, the beam is accelerated part of plasma formed in the discharge area. In case of "race track" geometry of slot (Fig. 1a,b), the source generates two "sheets" of accelerated plasma.

The sputtering modification of ALS (Fig. 1c) was designed by Izovac Ltd. [12]. A fused silica target was used to produce SiO_x layers for LC alignment.

The processing scheme is presented in Fig. 2. The substrates were set obliquely with respect to flux of ions or sputtered particles. The incidence angle typically used was about 70^o. The substrates were treated in a cycling (there and back) translation regime or in a roll-to-roll translation manner by mounting corresponding moving system in a vacuum chamber. The translation speed was 2 mm/s. The substrates were treated entirely or partially. In the latter case, the masks of different configuration were employed.

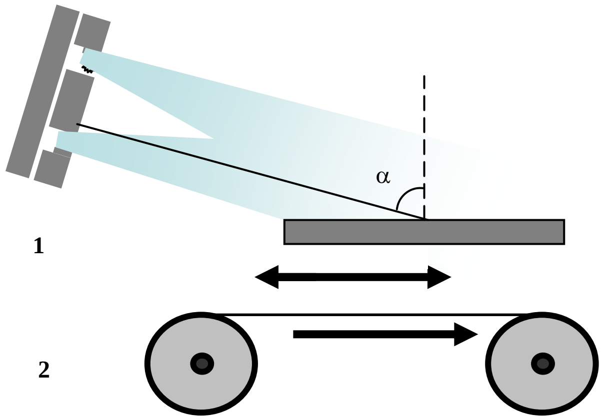

Figure 2. Plasma beam exposure geometry. 1 – cycling translation regime (mainly used for rigid substrates); 2 – roll-to-roll translation regime (used for flexible plastic strips).

Finally note that use of linear source substantially simplifies processing of large area substrates. In this case substrate or source should be moved in only one direction, in contrast to Kaufman source, when two-coordinate movement is needed (Fig. 3).

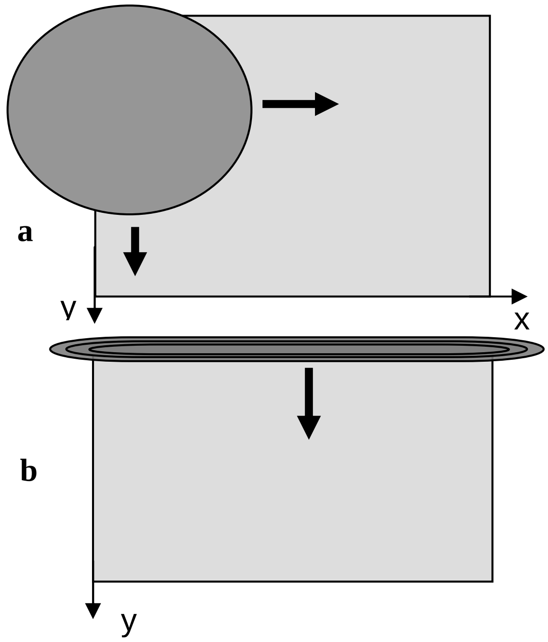

Figure 3. Processing of large area substrates by Kaufman source (two-coordinate translation) and linear ALS (one-coordinate translation or plastic strip rewinding)

3 Alignment properties

Below we consider alignment peculiarities of conventional LCs aligned by the aforementioned processes. After that another application fields of these methods are discussed.

3.1 Plasma beam etching alignment procedure

The types of LC alignment (alignment modes) realized for this process depended on processing conditions and LC properties as well [13,14]. For LC with Δε>0 used in TN, STN and IPS LCD, two modes of uniform LC alignment with different easy axis orientation were observed. In the 1st mode, easy axis is aligned in the incident plane of plasma beam so that LC tilts towards incidence direction of the beam (Fig. 3a). The pretilt angle θ is usually in the range 0^o-8^o and can be easily varied by the incidence angle of the beam, ion energy and expose time. In the 2nd mode, observed only in experiments with ALS beam, easy axis is perpendicular to the plane of incidence (Fig. 3b). Obviously, pretilt angle is zero in this mode, independently on expose parameters. The alignment mode is determined by the exposure dose, which us a product of current density and exposure time. The transition from the 1st to the 2nd mode occurs with the increase of irradiation dose. Fig. 4 demonstrates high alignment quality in case of both types of LC alignment.

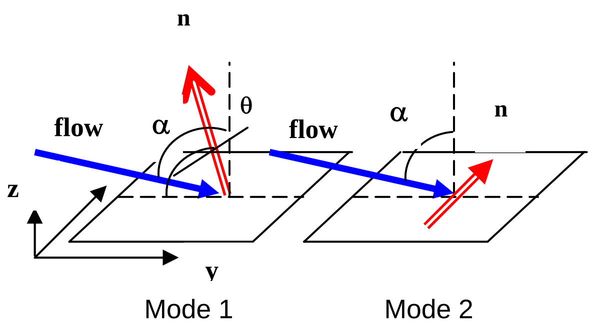

Figure 3. Irradiation geometry and LC alignment in the 1st (a) and the 2nd (b) modes.

LCs with Δε<0, commonly used for VA, align in the 1st mode. The pretilt angle is 20^0<θ<45^0. However, on some hydrophobic alignment layers, at very low irradiation dose (j≤0.5 μA/cm^2, E= (400-600) eV, and τ_{exp}≤1 min), tilted vertical alignment was realized [14].

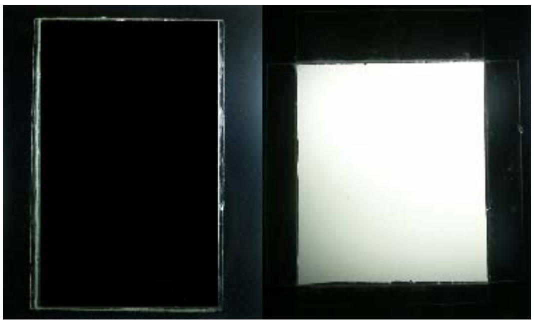

Figure 4. LC cells viewed between a pair of crossed polarizers. The glass substrates 10x13 cm^2 by size are coated by PI and processed by plasma beam (α=700, j=8 μA/cm^2, E=600 V). LC in the cell 1 is aligned in the 1st mode, while in the cell 2 – in the 2nd mode. The cell thickness is 15 μm. LC ZLI2293 (Δε>0).

3.2 Sputtering deposition alignment procedure

The films produced by the oblique ion beam deposition exhibit

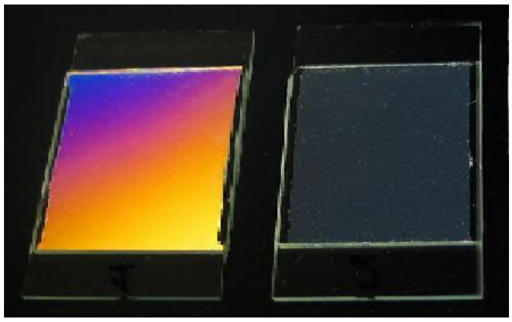

Figure 5. Cells based on 20 nm thick SiO_2 alignment layers obliquely (α=70^o) deposited on ITO coated glass slabs. Crossed polarizers viewing. Cells are filled with LC MLC6608 (Δε<0) (a) and ZLI2293 (Δε<0) (b).

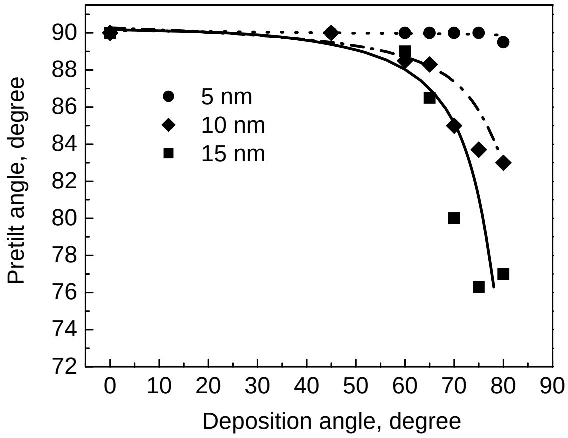

Fig. 6. Pretilt angle vs. deposition angle curves for the SiO_x films of different thickness. Standard values of discharge voltage and discharge current. LC MLC6608.

uniform and stable alignment when the coating thickness exceeded 5 nm. However, the type of alignment depends on the sign of dielectric anisotropy of liquid crystal [15]. For LC with Δε>0 only alignment in the 2nd mode with intrinsically zero pretilt angle is observed (Fig. 3). In turn, LC with Δε<0 aligns in the 1st mode with a tilt towards direction of deposition (Fig. 3).

The typical cells filled with LC (Δε>0) and LC (Δε<0) are shown in Fig. 5. There is evident that LC with Δε<0 demonstrates vertical alignment. The pretilt angle vs. deposition angle curves for this LC are presented in Fig. 6. One can observe pretilt angle decay with the increase of the angle of deposition. The pretilt angle also shows monotonic decay with the thickness of the deposited film in case of large deposition angle (α>75^o). These results give us the way to control pretilt angle to bring it in a range needed for specific application. The other way to control pretilt is based on the use of gaseous feed containing hydrocarbon gas like methane; with the increase of the portion of this gas in the Ar/hydrocarbon gas feed mixture the pretilt angle decreases. We observed excellent electrooptic performance in the VA cells based on the developed SiO_x coatings [15].

The tilted alignment of LCs with Δε>0 was achieved by combination of two sputtering processes. After oblique (α=70^o) deposition of basic d_1=20 nm film, second deposition was provided perpendicularly to the fist one. The deposited film was extremely low (d_2<3 nm). This was sufficient to induce asymmetry of basic film without screening its in-plane alignment direction. When d_2>5 nm, alignment force of the first layer was completely screened.

3.3 Combination of sputtering and etching processes

Normally sputtered inorganic films (SiO_2, Ta_2O_5, TiO_2 and the like) were routinely used as layers for plasma beam alignment processing. Such films influence alignment of LCs with $\Delta\varepsilon>0$ in the 1st and in the 2nd alignment mode. The azimuthal anchoring provided by plasma beam process can be strengthened by using obliquely sputtered films; in case the alignment axis induced by plasma beam coincides with the axis induced by sputtering, the alignment force enhances. The LCs with $\Delta\varepsilon<0$ always align in the 1st mode on the plasma beam processed inorganic substrates. At that alignment the pretilt angle is surprisingly low ($\theta<60^o$) compared with the unprocessed sputtered substrates ($\theta=88^o$-90^o). Apparently, alignment of LCs with $\Delta\varepsilon<0$ is rather sensitive to chemical structure of inorganic surface, which might me strongly modified by plasma processing.

3.4 Alignment stability issue

LC alignment on SiO_x sputtered layers is rather stable. The problem might only be observed for LCs with $\Delta\varepsilon<0$ if glue is not properly selected or cured [16]. In case of etching process the problem is deeper, because alignment instabilities frequently observed are caused by nature of plasma beam modification. Bombarding alignment surface, plasma particles cause bond scission and so generation of highly reactive free radicals and low molecular fraction of alignment material with reduced viscosity. This might cause change of boundary conditions in LC cells and so alignment degradation (aging). These processes are usually slow (months), but can not be ignored. As shown in [17, 18], alignment aging can be inhibited by passivation of the alignment substrate with atomic hydrogen. Besides, this process can be suppressed by proper selection of LCs and alignment materials (highly crosslinked plasma coatings show the best promise) [19]. So, alignment aging in case of plasma etching process can be eliminated, but it requires special care.

3.4 Alignment of “passive” liquid crystals

Particle beam processes can be successfully used to align non-standard LCs, i.e. liquid crystals for non-electrooptic applications. In contrast to common case, director of these LC is not driven by electric field. Because of this the aforementioned LCs we call “passive” LCs. One class of these materials is formed by reactive mesogenes (RM). The RM layers can be solidified by illumination or heating, due to polymerization of reactive molecular groups [17]. The RM layers aligned and subsequently solidified are used as passive optical films and elements of surface electronics. The described etching and sputtering processes can be successfully applied to align RM. The positive A, O and C retardation films, including patterned one, were obtained by these processes. They were deposited on a big variety of substrates, such as bare glass, color filters and color filter arrays, flexible plastic strips [18]. Besides imparting alignment ability, plasma processing of these substrates improved adhesion of RM layers and their uniformity.

The other class of “passive” LCs includes materials, which are in crystalline or glassy state at ambient temperatures, but undergo to LC mesophases at elevated temperatures. Recently we succeeded in alignment of some semiconducting LCs from this class.

4 Conclusions

In summary, etching and sputtering processing by particle beams opens new horizons for LCD technology. The etching process is the most effective one for low-pretilt alignment, while the sputtering deposition process excels for high-pretilt or vertical alignment. The use of linear sources allows one to extend these processes for the alignment treatment of large area substrates (modern LCD fabs). Additionally, they can be effectively used to align nonstandard LCs, such as reactive mesogenes and LCs being in a “frozen” state at ambient temperatures.

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