P-45: Ion Beam Processes for Liquid Crystal Alignment on the Large-Area Substrates

Oleg Yaroshchuk[1], Ruslan Kravchuk[1], Leonid Dolgov[1], Andriy Dobrovolskyy[1], Alexandr Khokhlov[2], Eugene Khokhlov[2], Eugene Telesh[2], & Oleg Lavrentovich[3]

[1]Institute of Physics, NASU, Prospect Nauki 46, Kyiv, Ukraine, 03028;
[2]Izovac Ltd., Bogdanovicha St., 155-907, Minsk, Belarus, 220040;
[3]Liquid Crystal Institute & Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA, 44242

Abstract: *The alignment of liquid crystals (LC) through anisotropic etching of the alignment substrate by ion or plasma beam is among the most promising methods to replace traditional rubbing process in a new generation of LC devices. By the use of extended sources with a closed electron drift we realized etching treatment of the large-area alignment surfaces (40x40 cm^2) with a good LC alignment uniformity. Besides, modified sources from the same class equipped with a silica target were used to realize an oblique sputtering of the aligning SiO_x films. The characteristics of LC alignment at different sputtering conditions (deposition angle, feed gas, film thickness, etc.) are investigated. The alignment peculiarities for the etching and sputtering alignment processes are compared. We conclude that etching process is more effective for LC with positive dielectric anisotropy $\Delta\varepsilon$ used in IPS, TN and STN LCD, while sputtering process is more suitable for LC with $\Delta\varepsilon<0$ used in VA LCD. Both of these processes on the base of linear sources with closed electron drift can be easily adapted for the alignment treatment of large-area substrates used in the modern LCD manufacturing.*

Keywords: liquid crystal alignment; plasma beam alignment; ion bean sputtering alignment.

Introduction

The urge towards perfection of LCD and the extension of the field of their application set strong demands to liquid crystal (LC) alignment. The modern LCD technologies request alignment treatment on the large-area substrates (1870x2200 mm^2 in the planned 7th generation fabs). The development of projection display, stimulated by LCOS technologies, requires LC alignment of high photo- and thermal stability, high uniformity on microscopic level. The image sticking becomes critical issue in TV LCD. The traditional alignment procedure dealing with rubbing of organic films in not able to solve satisfactorily the aforementioned problems.

The radical improvement may bring alternative methods of LC alignment. Among them the so-called "particle beam" alignment methods are of the best promise. It is a generalized name of methods operating with the beams of different particles (ions, neutrals, electrons and mixtures thereof). These particles enter into the substrate obliquely to generate surface anisotropy, which is an obligatory condition of planar/tilted LC alignment.

The particle beam alignment methods can be divided in two groups. In the first group, particle beams, usually beams of accelerated ions, cause modification of the alignment films (etching, molecular bond breaking, etc.). The enhanced interest to the ion beam alignment, known over several decades [1], is excited by recent publications of IMB group [2,3]. Subsequently, alignment properties in case of different feed gases and alignment materials were investigated [4,5]. In the second group of methods, particles deposit on the substrate forming alignment layer. This principle was suggested by Janning in 1972 [6]. In his experiments highly uniform LC alignment was observed on SiO_x films obtained by oblique vapor deposition. In the following studies of this process, several alignment modes were observed [7] and different alignment of LC with positive and negative dielectric anisotropy was discovered [8,9]. In addition to vapor deposition, Motohiro and Taga [10] observed uniform LC alignment on the SiO_x layers obliquely deposited by the ion beam sputtering. The latter technique, however, is surprisingly poorly elucidated in literature.

The characteristics of LC alignment on the ion beam processed and ion beam sputtered substrates are studied with us in-depth by using sources with the closed electron drift (CED) designed for etching and sputtering, respectively. We compare alignment on the substrates obtained by these two methods. The alignment modes, stability and uniformity of LC alignment are considered. We draw conclusions about the most effective applications of each alignment procedure. We also conclude that CED sources in extended configuration can be easily adapted for the alignment treatment of large-area substrates, including fabs of last generations.

Source and irradiation setup

In contrast to electrostatic Kaufman source used by IBM group and in subsequent studies [2-5] we employed anode layer sources (ALS) from the family of electro-dynamic closed electron drift sources with the "race track" geometry of glow discharge [11-13]. A general construction of the etching type ALS is presented in Fig. 1. The electrons circulating in the crossed electric and magnetic fields in a

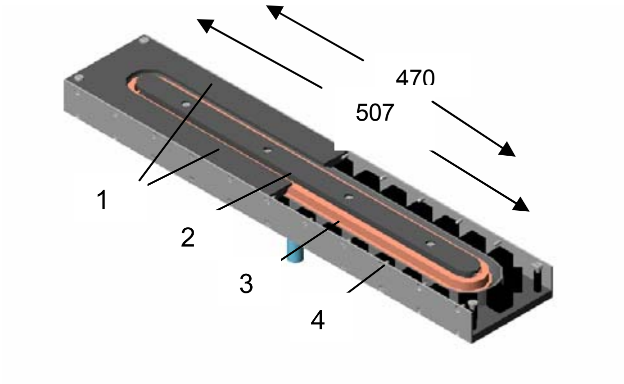

Fig. 1. ALT used in our studies. 1 – outer cathodes; 2 – inner cathode; 3 – anode; 4 – permanent magnets.

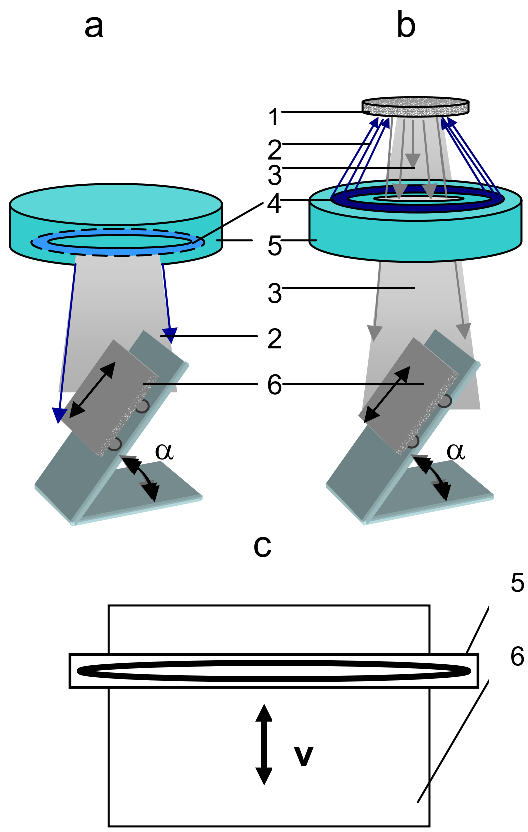

Fig. 2. Expose geometry in case of etching (a) and deposition (b) processes. C – top view of sample scanning system. 1 - target; 2 – ion beam (primary beam); 3 – atomic beam (secondary beam); 4 – discharge area; 5 – ALS; 6 – substrate on moving platform.

slot formed by inner and outer cathodes and anode ionize the feed gas atoms (usually, argon). The ions and electrons involved are thrusted out of the slot due to high positive potential of anode. Because of the "race track" geometry of slot, the source generates two "sheets" of ions or, more precisely, accelerated plasma.

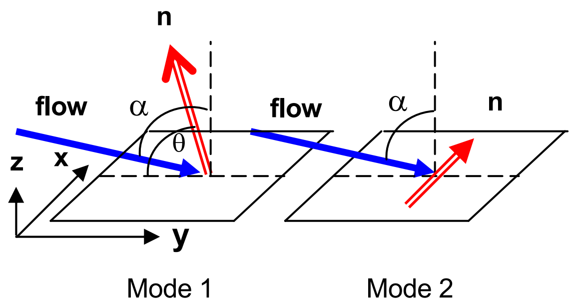

Fig. 3. Irradiation geometry and LC alignment in the 1st (a) and the 2nd (b) modes.

The sputtering modification of this source was designed by Izovac Ltd. [14]. We used a target made from silica and so sputtered SiO_x alignment layers [15]. The substrates were set obliquely with respect to flux of ions or sputtered particles and cyclically moved across the particle "sheets" in the course of processing (Fig. 2). The translation speed was 1-4 mm/s. Combining elongated sources and cycling translation we were able to increase the linear size of substrates to 40 cm. This limitation was caused only by linear part of the particle "sheet". To avoid using of large substrates, we realized mosaic principle: the large substrates were substituted with the substrates of smaller size (20x30 mm^2) placed in different parts of 40x40 cm^2 holder plate.

In the etching alignment regime, anode potential U, discharge current I, ion current density j and exposure time t were varied in the ranges: U=450-900 V, I=8-60 mA, j=0.2-20 $\mu A/cm^2$ and t=0.25-10 min. The typical values for the sputtering alignment regime were U=3700 V and I=400 mA.

Alignment results

Etching alignment technique. The types of LC alignment (alignment modes) observed for LC with positive and negative dielectric anisotropy $\Delta\varepsilon$ are different. For LC with $\Delta\varepsilon>0$ used for TN and STN LCD, we have observed two modes of uniform LC alignment with different easy axis orientation (Fig. 3). In the 1st mode, the easy axis is in the incident plane of ion beam and LC tilts towards incidence direction of the beam. The pretilt angle θ is usually in the range 0^o-8^o and can be easily varied by the beam incidence angle, ion energy and expose time. In the 2nd mode, not observed in ion beam alignment experiments based on the use of Kaufman source, the easy axis is perpendicular to the plane of incidence. Obviously, pretilt angle is zero in this mode, independently on expose parameters. Figure 4 shows that the transition from the 1st mode to the 2nd mode occurs with the increase of irradiation time. A similar transition takes a place when one increases the current density of the Ar ions. In other words, the type of alignment is controlled by the irradiation dose.

LC with $\Delta\varepsilon<0$, commonly used for VA, align in the 1st mode. The pretilt angle is $20^0<\theta<45^0$. However, at very low irradiation dose ($j\leq0.5$ μA/cm^2, E= (400-600) eV, and $\tau_{exp}\leq1$ min), on hydrophobic alignment layers, tilted vertical alignment can be realized [13]. The electrooptic operation of LC cells based on ion beam processed substrates is very similar to that of the cells based on standard rubbing process.

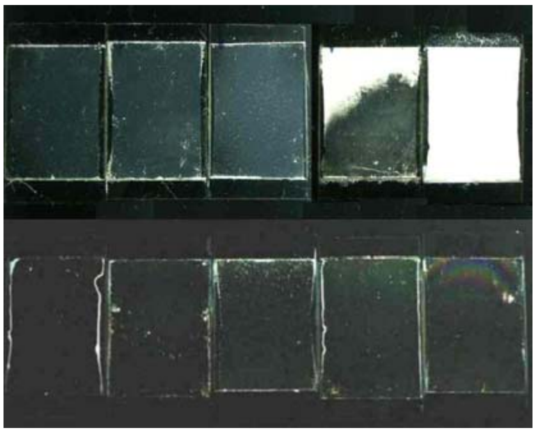

Fig. 4. The set of asymmetric cells viewed between two crossed polarizers. The tested PI substrates in the cells have been irradiated during 1, 2, 4, 6, 10 min (set (a)), and 1, 2, 10, 20, 40 min (set (b)), respectively. Irradiation conditions: cycling regime, $\alpha=70^0$, $j=8$ μA/cm^2, E=600 eV. The cells are filled with LC 5CB ($\Delta\varepsilon>0$) (set (a)) and MJ961180 ($\Delta\varepsilon<0$) (set (b)).

Sputtering alignment technique. The films produced by the oblique ion beam deposition displayed 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. For LC with $\Delta\varepsilon>0$ the alignment in the 2nd mode is observed (Fig. 3) independently on the deposition angle and thickness of SiO_x films. In turn, LC with $\Delta\varepsilon<0$ aligns in the 1st mode with a tilt towards direction of deposition. The pretilt angle vs. deposition angle curves are presented in Fig. 5. One can observe pretilt angle decay with the increase of the angle of deposition, which is evident for the thickness of SiO_x films larger than 10 nm. The pretilt angle also shows monotonic decay with the thickness of the deposited film in case of large deposition angle ($\alpha>80^o$), Fig. 6. 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 electro-optic performance in the VA cells based on the developed SiO_x coatings [15].

Sputtering/etching and sputtering/sputtering alignment processes. The combination of several processes was investigated to generate pretilt angle for LC with $\Delta\varepsilon>0$ on SiO_x substrate. To achieve this, it is necessary to implement additional process breaking the out-of-plane symmetry of the 2nd mode. This was realized by the two-step processing in two different ways. In the first case, we used approach previously described for the vapor deposition alignment process [16]. The film was deposited by the flow incidence in *y* direction under the angle α_2 followed after the deposition in *x* direction under the angle α_1 (Fig. 3). At the thickness of the second layer d_2 larger than 3-4 nm, the easy axis of LC is perpendicular to the particles incidence plane of the second deposition step (*x* direction). If $d_2<3$ nm, the easy axis lies in the *yz* plane and the pretilt angle is non-zero. The LC tilts towards the deposition direction in

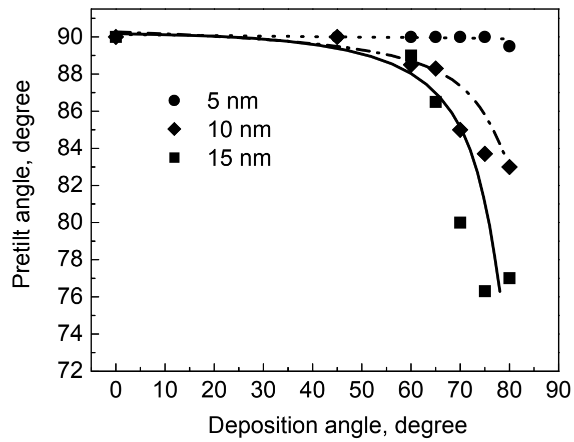

Fig. 5. Pretilt angle vs. deposition angle curves for the SiO_x films of different thickness. Standard values of discharge voltage and discharge current. LC MLC6608.

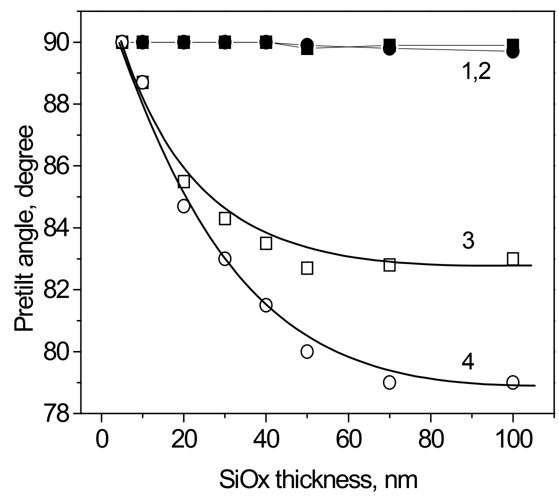

Fig. 6. Pretilt angle as a function of thickness of SiO_x coatings. Standard values of discharge voltage and discharge current. 1 – $\alpha=60^o$, LC MJ961180; 2 – $\alpha=60^o$, LC MLC6608; 3 – $\alpha=85^o$, LC MJ961180; 4 – $\alpha=85^o$, LC MLC6608.

the second process. The pretilt angle is less than 2^o but enough good for IPS mode.

In the second method, deposition process was combined with the etching one. At first the film is deposited in *x* direction under the angle α_1 and then it is etched with the ion beam in *y* direction under α_2. By using low irradiation dose one can break alignment symmetry and induce tilted LC alignment with easy axis in *yz* plane. The tilt direction corresponds to the direction of ion beam. The value of pretilt angle 5^o was achieved. This suits well for TN and STN modes.

Alignment uniformity. To judge the alignment uniformity on large surfaces, we modeled them by setting small aligning substrates (20x30 cm^2 by size) parallel each to other, but in different places of large holder (mosaic principle). The width of holder was close the width of plasma "sheet". LC alignment on different substrates was compared. For the treatment times longer than the time of one translation cycle, the alignment on different substrates was very similar. In case of etching processing, the in-plane deviation of easy axis is within 1^0 and it even decreases with a number of translation cycles. The difference in pretilt angle on different substrates (LC with $\Delta\varepsilon>0$, etching process and LC with $\Delta\varepsilon<0$, sputtering process) was within the measurement accuracy.

Table 1. LC alignment modes realized by ion beam etching and sputtering deposition processes.

Process / LC type	Etching	Sputtering
LC with $\Delta\varepsilon>0$	1st mode, $0^0\leq\theta\leq90^0$ – low dose 2nd mode, $\theta=0^0$ – high dose	2nd mode, $\theta=0^0$ – any dose, any deposition angle
LC with $\Delta\varepsilon<0$	1st mode, $20^0<\theta\leq90^0$ – any dose, any etching angle	1st mode, $80^0<\theta\leq90^0$ – any dose, any deposition angle

Alignment stability. As we earlier established, the degradation of the alignment of LC with $\Delta\varepsilon>0$ with a time of sample storage (alignment aging) is a serious problem of etching processing [12]. It can be partially overcome by the selection of proper materials, first of all from the class of plasma coatings, and optimization of processing conditions. The problem remains in the case of deposition/etching procedure of alignment. At the same time, aging is not observed on the sputtered alignment layers (LC with $\Delta\varepsilon>0$) and double sputtered layers (LC with $\Delta\varepsilon<0$) [15].

Conclusions

The etching and sputtering deposition ion beam processes cause variety of LC alignment modes summarized in Table 1. The most technologically attractive are alignment cases with pretilt angle. We consider etching process and combination of two sputtering processes as the most perspective ones for LC with $\Delta\varepsilon>0$ and single sputtering process as the most effective for LC with $\Delta\varepsilon<0$. These processes realized on the base of extended sources (e.g., ALS) suit very well for the alignment treatment of large-area substrates, including substrates of last industrial generations.

Acknowledgement

These studies were carried out in frame of INTAS project 03-51-5448.

References

1. M.J. Little et al., US Patent No 4,153,529 (1979).

2. P. Chaudhari et al, *Jpn. J. Appl.Phys*., 37 (1-2), L55 (1998).

3. P. Chaudhari et al., *Nature*, 411, 56 (2001).

4. J.Y. Hwang, Y.M. Jo. D.S. Seo, S.J. Rho, D.K. Lee, and H.K. Baik, *Jpn. J. Appl. Phys*., 41, L654 (2002).

5. K.H. Yang, G.T. Liang, S. Tanaka, and H. Endoh, Proc. IDMC'03, 82.

6. J. Janning, *Appl.Phys.Lett*. 21(4), 173-174 (1972).

7. W. Urbach, M. Boix, and E. Guyon, *Appl.Phys.Lett*., 25 (9), 479-481 (1974).

8. H. Vithana, Y.K. Fung, S.H. Jamal, R. Herke, P.J. Boss, and D.L. Johnson, *SID'95 Digest*, 873-876.

9. M. Lu, K. Yang, T. Nakasogi, and S. Chey, *SID'00 Digest*, 446-449.

10. T. Motohiro and Y. Taga, *Thin Solid Films*, 185, 137-144 (1990).

11. V. Zhurin, H. Kaufman, and R. Robinson, *Plasma Sources Sci. Technol*., 8, 1 (1999).

12. O. Yaroshchuk, R. Kravchuk, A. Dobrovolskyy, L. Qiu, O. D. Lavrentovich, *Liq.Cryst*., 31 (6) 859 (2004).

13. O. Yaroshchuk, R. Kravchuk, A. Dobrovolskyy, P.C. Liu, C.D. Lee, *J.SID*, 13/4, 289 (2005).

14. V. Shiripov, A. Khokhlov, S. Maryshev, M. Levchuk, A. Khissamov, K. Krivetski, J. SID, 13/4, 315-320 (2005).

15. A. Khakhlou, A. Murauski, O. Yaroshchuk, E. Telesh, R. Kravchuk, J. SID, 14/3, 257 (2006).

16. E. Reynes, D. Rowell, and I. Shanks, *Mol.Cryst.Liq.Cryst*., 34, 105-110 (1976).