7.6: Atmospheric Plasma Tool and Process for Tuning Pretilt Angle in the VAN Cells

Oleg Yaroshchuk, Ruslan Kravchuk, Sergiy Pogulyai, and Vyacheslav Tsiolko
Institute of Physics, NASU, prospect Nauki, 46, 03680 Kyiv, Ukraine

Abstract

The processing of the aligning layers by a gaseous stream of active particles generated in the atmospheric pressure barrier discharge is considered as a method for tilted vertical alignment (VA) of liquid crystals (LC). The low-dose processing of VA type aligning layers by this stream yields uniform tilted alignment with pretilt angle q continuously tuned in the range $85^o < q < 90^o$*, but with insufficient alignment uniformity in the field on state. The high-dose processing results in poor LC alignment even before the field application. The results however can be radically improved when the active particles processing is combined with rubbing. In this case, high-quality tilted alignment is realized with the pretilt angle continuously changed in the range* $0^o < q < 90^o$ *combined with a uniform switching in the electric field. This makes combination of atmospheric plasma and rubbing processes rather attractive for industry, especially for those cases when pretilt angle of LC should be continuously tuned.*

1. Introduction

Perfection of LCD strengthens demands to liquid crystal (LC) alignment. They include very high alignment uniformity (on both macroscopic and microscopic levels), adjustable pretilt angle and anchoring strength, easy pattering procedure, high alignment stability with regard to heat, light and chemical reactivity.

The conventional rubbing technique commonly used in a mass production of LC devices can not frequently satisfy these demands. To meet them, several new alignment processes are recently proposed, which deal with the particle beams such as the beams of accelerated ions or plasma [1-4]. The flux of active particles directed obliquely to the treated substrate causes its anisotropic milling (etching) [3] and angularly selective destruction of intramolecular bonds [2]. This results in very uniform alignment with tunable anchoring and easy axis. By using these techniques, the pretilt angle of LC *q* can be continuously changed in the range $0^0 < q < 90^o$ [4, 5]. Moreover, the mentioned processes can be readily applied for the alignment treatment of large area substrates [4] and creation of alignment patterns [1, 3]. Besides nematic LCs, the mentioned processes are quite effective for ferroelectric smectic LCs [6] as well as "passive" LCs, such as reactive mesogens for optical end electronic films [7].

The main factor hindering industrial application of the ion/plasma beam alignment processes is a necessity of high vacuum for their realization; the residual and working pressure should be of the order of 10^{-5} Torr and 10^{-4} Torr, respectively. To realize this regime, expensive high vacuum equipment is necessary. Besides, this process consumes essential time, first of all, because of partial or full depressurization steps required for reloading of aligning substrates to the processing chamber. These drawbacks cause strong desire to transfer the particle beam alignment processes to the range of atmospheric pressures.

The first attempt in this direction was recently made by the group from Seoul National University [8]. The authors used the atmospheric plasma processing (APP) set up based on a barrier discharge. The stream of Ar gas passed through the discharge area feeding the discharge and blowing active particles out of the discharge in the direction of the alignment substrate. By this way, tilted alignment is claimed to be realized with a pretilt angle varied in the range 0^o-90^o.

In addition, very recently, group from ITRI (Taiwan) joined this research and published first results obtained for the linear source of atmospheric plasma [9]. In this paper the processes of rubbing, high-vacuum plasma and atmospheric plasma are compared. It is demonstrated that switching contrast of the cells based on the rubbing and high-vacuum plasma alignment processes are comparable. At the same time, switching contrast of the cells prepared by using atmospheric plasma alignment is considerably lower (by factor 1.7).

The results of [8] and [9] indicate sufficiently high uniformity of LC alignment on microscopic scale. At the same time, the quality of LC alignment on macroscopic level remains unclear. A poor switching contrast detected in [9] gives us a reason to believe that this quality is not very high.

Our goal is to make a deeper insight into the atmospheric plasma processing (APP) for the LC alignment and approach it to industrial applications. In the present paper we consider alignment characteristics of VA type LC on the polyimide substrates subjected to atmospheric plasma. The case of single plasma processing is compared with the case of combined plasma processing and rubbing.

2. Experimental

2.1. Atmospheric Plasma Setup and Processing

Similarly to [7], the plasma processing setup developed in our lab is based on the barrier discharge principle. A schematic diagram of this setup is presented in Fig. 1. The active particles 2 generated in barrier discharge 1 are extracted from the discharge area by a gas expulsion with a speed of 1 m/s. The gas stream with the involved active particles is directed to the substrate 3 containing polyimide coating on the top. The distance between the plasma jet and the substrate was about 3 mm and the angle between the substrate's normal and the stream direction was about 60^0. The gas feed system 5 varied volume velocity of the gas supplied from the gas cylinder 6 in the range 0.1–10 l/min. As the feed gas argon was utilized. The power supply 8 (0–15 kV, 400 Hz) was used to power the gas discharge. The measuring device 7 allowed to measure a discharge voltage and to estimate a discharge power. The substrate 3 together with a moving platform 4 was translated forward and backwards with a speed 2 mm/s under the particle stream 2. The scanning of aligning layers was controlled by PC. In the exposure process the processing dose was varied by changing discharge power, gas stream velocity and number of scans. The processed layers were kept in exsiccator before assembling the LC cells. The time period between the plasma processing and cell assembling was shorter then 3 h.

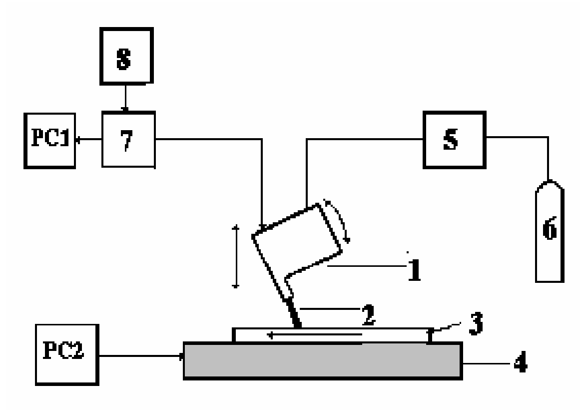

Fig. 1. A schematic diagram of atmospheric plasma processing setup. 1 – barrier discharge block, 2 – flow of active particles, 3 – substrate, 4 – moving system, 5 – gas feed regulation system, 6 – gas cylinder, 7 – gas parameters measuring block, 8 – power supply.

2.2. Substrates and LC cells

As aligning layers we used the films of polyimide AL2021 (JSR, Japan) designed for homeotropic alignment. The polyimide films were spin coated on the glass/ITO slides, backed at 180^{o}C over 45 min and subjected to atmospheric plasma treatment. In the first series of cells the substrates subjected to only plasma beam were utilized. In the second series, plasma processed substrates were additionally rubbed. The rubbing was provided by shifting manually on the aligning film the iron bar glued over with a velvet cloth. The rubbing was provided in the direction of plasma beam processing. The rubbing conditions were equal for all aligning layers. Based on the obtained substrates the antiparallel cells (with the antiparallel rubbing/plasma processing directions in the opposing substrates) were assembled. A cell gap was 18 µm and 6 µm, in the pretilt angle and electro-optical measurements, respectively.

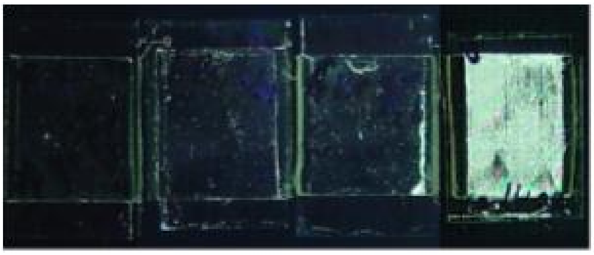

Figure 2. A series of LC cells based on plasma processed substrates viewed between crossed polarizers. The cells differ in a number of scans of aligning substrates, N; N=4, 6, 8 and 14 for cells 1, 2, 3, and 4, respectively. The discharge power is 6 W and the stream velocity is 9 l/min.

2.3. Testing Methods

(1) The alignment quality was evaluated by sample observation between the crossed polarizers, with the unaided eyes and in the polarizing microscope. (2) The pretilt angle was estimated by crystal rotation method. (3) In the electro-optic tests, transmittance of LC cells placed between crossed polarizers was measured as a function of applied alternative voltage. The wavelength of testing light in experiments (2) and (3) was 628 nm.

3. Alignment Results

3.1. Atmospheric Plasma Processing

According to Fig. 2 (cells 1-3), APP produces sufficient alignment quality for relatively low exposure doses. The pretilt angle θ in these cells is tuned from 90° to 89° by changing number of scans, discharge power and volume velocity of feed gas (Fig. 3).

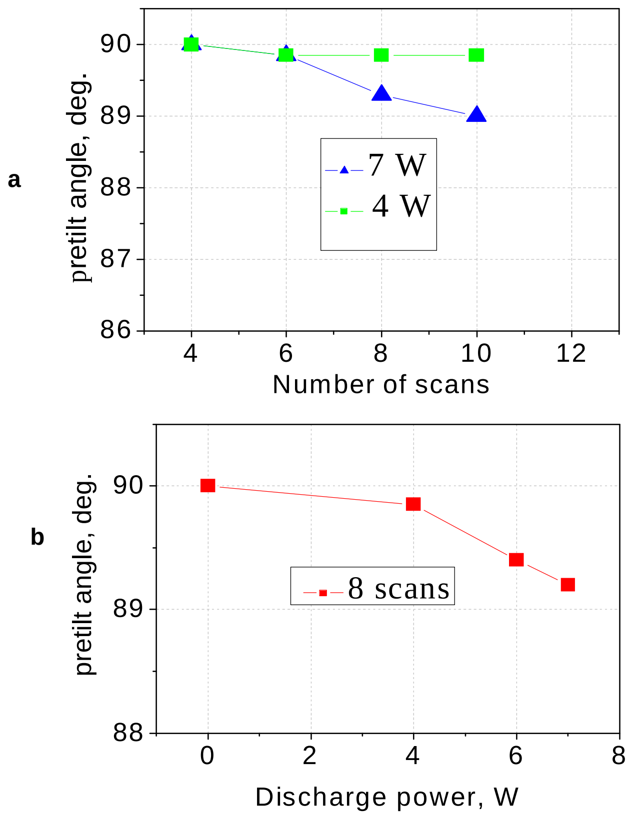

Figure 3. Pretilt angle as a function of (a) number of scans for discharge powers 4 W and 7 W and (b) discharge power for the fixed number of scans. The stream velocity of Ar particles is 9 l/min.

According to Fig. 2, increase of the dosage results in deterioration of high-pretilt-angle alignment and transition to a random planar state. This suggests that exposure dose should not exceed some critical value destructive for LC alignment. However, even before the critical dose, the processed substrates can not provide uniform reorientation of LC in the electric field, Fig. 4. The microscopic observations do not reveal reverse tilt domains in the on state that suggests that LC in different areas of the cell reorients in one direction according to the plasma induced direction of tilt. At the same time, the realized planar state is not uniform; one can detect some areas with good alignment, but, simultaneously, many areas with schliren texture typical for poor alignment. The poor in-plane alignment can be explained by poor directionality of particle stream. Comparing to high vacuum case, the mean free path of active particles is considerably shorter. This leads to strong divergence of particle beam; in fact we work in a quasi diffusive regime. Besides, experiencing many collisions before entering the aligning layers the particles lose energy that decreases efficiency of surface treatment.

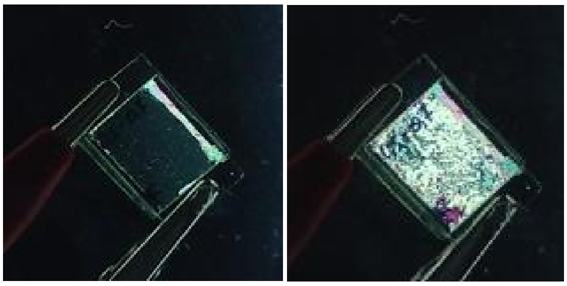

Figure 4. Photographs of LC cell based on atmospheric plasma processed PI films before (a) and during application of electric field of 6 V (b). The cell is placed between the crossed polarizers so that the angle between the in-plane projection of alignment axis and the polarizers is 45^o. Plasma processing parameters: 6 W, 9 l/min, 6 scans.

Thus, on the current stage, a sole atmospheric plasma treatment does not provide acceptable planar alignment of LC. Because of this, we switched over to the combination of atmospheric plasma processing and traditional rubbing. We believed that the first action will provide control of pretilt angle, while the second one will generate the in-plane anisotropy of the aligning film as a reason of uniform planar alignment.

3.2. Atmospheric Plasma Processing Combined with Rubbing

The images of LC cells based on the aligning films processed by a combination of atmospheric plasma flux and rubbing are presented in Fig. 5. There is evident that quality of LC alignment is rather good in a wide range of exposure doses.

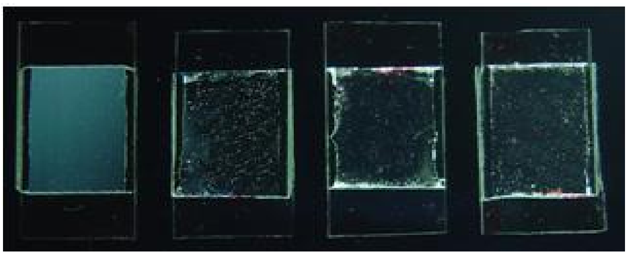

Figure 5. A series of LC cells based on the substrates processed by atmospheric plasma and rubbing viewed through a pair of crossed polarizers. The cells differ in a number of scans of the aligning substrates, N; N= 0, 2, 6 and 12 for the cells 1, 2, 3 and 4, respectively. The discharge power is 4 W and the stream velocity is 9 l/min.

The pretilt angle in the cells presented in Fig. 5 plotted as a function of scan number N is shown in Fig. 6. As is obvious, θ continuously decreases from 90^o to almost 0^o with the exposure dose. It is worthwhile mentioning that similar θ vs. N dependence we obtained in case of normal incidence of plasma beam on the aligning substrate.

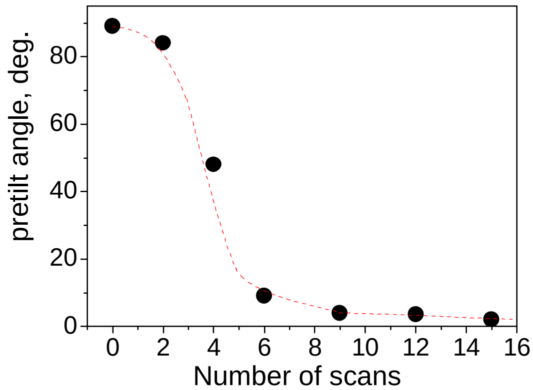

Figure 6. Pretilt angle as a function of number of scans for the cells processed by plasma stream and subsequently rubbed. The discharge power is 4 W and the stream velocity is 9 l/min.

The cells produced by using combination of atmospheric plasma and rubbing alignment processes demonstrate good switching characteristics in the electric field. Fig. 7 shows typical sample in the field off and on states. As is obvious, LC uniformly switches in the field demonstrating uniform planar alignment in the on state. In addition to Fig. 7, Fig. 8 presents T-V curves measured for the cells with different pretilt angles. As expected, decreasing of pretilt angle results in lowering of electro-optic contrast and, simultaneously, lowering of controlling voltage. Letting opportunity of the continuous control of pretilt angle, proposed alignment method allows to optimize the electro-optic performance of LC cells.

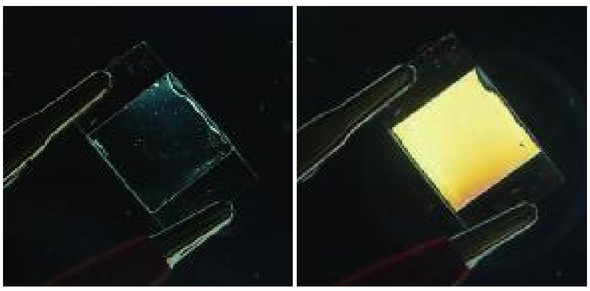

Figure 7. The photographs of LC cell based on PI alignment layers subjected to atmospheric plasma and rubbing before (a) and during application of electric field (4 V) (b). The cell is placed between the crossed polarizers so that the angle between the in-plane projection of alignment axis and the polarizers is 45^o. Plasma processing parameters: 4 W, 9 l/min, 2 scans.

The realized continuous tuning of pretilt angle has sufficiently high application potential. In the previous years a similar control was realized by combination of vacuum plasma and rubbing processes [10, 11] as well as by the processing with a directed flux of accelerated plasma [4, 5, 12]. In big contrast to these methods, the pretilt angle controlling in our case is realized at ambient conditions. Due to this, the method becomes simple and cheap for realization.

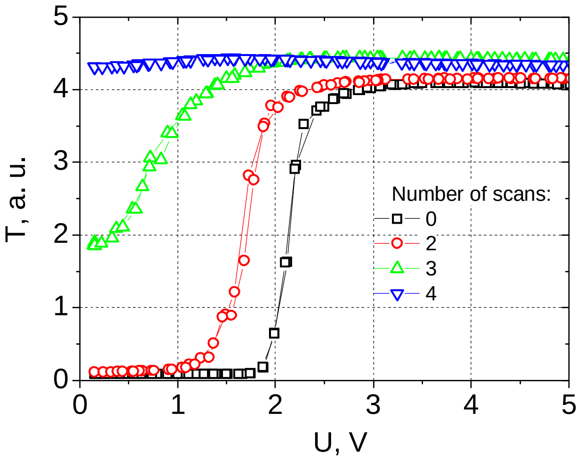

Figure 8. Transmittance vs. voltage curves for the set of cells based on plasma processed and rubbed aligning layers. Plasma processing parameters: 4 W, 9 l/min. Number of scans is varied.

4. Aligning Mechanisms

Finally, we consider microscopic mechanisms of pretilt angle change under the APP. In case of high vacuum plasma it was established that the continuous decrease of θ with exposure dose is caused by destruction of hydrophobic chains on the surface of aligning film [10, 11]. It was reasonable to assume that similar mechanism works in the case of atmospheric plasma.

This was confirmed by measuring contact angle of water on the treated surfaces. According to Fig. 9, the contact angle monotonically decreases with an exposure dose. This implies that treated surface loses hydrophobic fragments. The latter conclusion was further supported by AFM measurements.

5. Conclusions

On the current development stage, the atmospheric plasma treatment as a separate process can be successfully used for the continuous tuning of LC pretilt angle, but not for generation of in-plane alignment of acceptable quality. The alignment method can be radically improved by combination of the plasma treatment with a rubbing or, presumably, some other process effective for in-plane alignment. The advantages of these two separate processes can be beneficially combined; the plasma process will provide a full range control of pretilt angle, while the rubbing will effectively generate in-plane alignment. This modified alignment process can be easily incorporated in the production line of LC devices, because it predicts just inessential and cheap modification (realization of plasma jet treatment before rubbing) and is compatible with the in-line and roll-to-roll principles of modern manufacturing process.

6. Acknowledgements

This research was conducted in frame of the project 10/07-H (NASU, Ukraine).

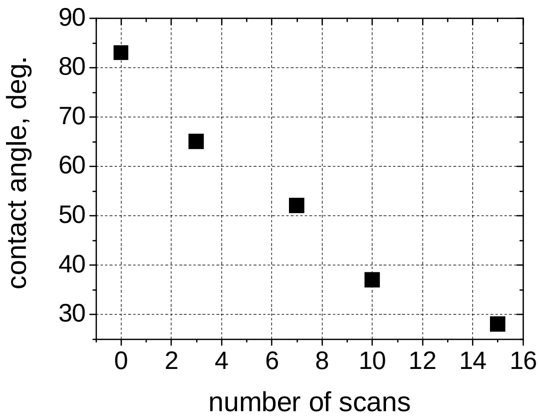

Fig. 9. Contact angle of water on PI film subjected to APP (3 W, 9 l/min) as a function of number of scans.

7. References

[1] P. Chaudhari et al., Nature, **411**, 56 (2001).

[2] J. Stoehr, M. G. Samant, J. Lu Ning, A. C. Callegari, P. Chaudhari, J. P. Doyle, J. A. Lasey, S.A. Lien, S. Purushothanam, and J. L. Speidell, Science, **292**, 2299 (2001).

[3] O. Yaroshchuk, R. Kravchuk, L. Qiu, O. D. Lavrentovich, Liq. Cryst., **31** (6), 859 (2004).

[4] O. Yaroshchuk, R. Kravchuk, A. Dobrovolskyy, P.C. Liu, C.D. Lee, J. Soc. Info. Display, **13**, 289 (2005).

[5] O.V. Yaroshchuk, A. D. Kiselev, and R. M. Kravchuk, Phys.Rev. E., **77**, 031706 (2008).

[6] G. Hegde, O. Yaroshchuk, R. Kravchuk, A. Murauski, V. Chigrinov, H.S. Kwok, J. Soc. Info. Display, **16**, 1075 (2008).

[7] O. Yaroshchuk, O. Parri, R. Kravchuk, S. Satayesh, M. Reijme J. Soc. Info. Display, **16**, 905 (2008).

[8] E. Jang, H. Song, S.D. Lee, Jpn.J.Appl.Phys., **46**, L.1238 (2006).

[9] C.Y. Lee, Y.L. Liu, C.H. Su, W.T. Hsieh, W.T. Hsu, IDW'08, 107 (2008).

[10] N. Shahidzadeh, A. Merdas, and W. Urbach, Langmuir, **14**, 6594 (1998)

[11] Y. Galerne and P. Hubert, Eur. Phys. J. B, **8**, 245 (1999).

[12] G.J. Sprokel and R.M. Gibson, J. Electrochem. Soc., **124**, 559 (1977).