P-130: Plasma Beam Alignment of Reactive Mesogenes

Oleg Yaroshchuk *** and Ruslan Kravchuk***
Dept. of Crystals, Institute of Physics, NASci., prospekt Nauki 46, 03110 Kyiv, Ukraine
Owain Parri
Merck Chemicals Ltd., Chilworth Science Park, University Parkway, Chilworth, SO16 7QD Sauthamptom, UK

Abstract
We demonstrate that plasma beam processing of the alignment substrates, earlier recognized as an effective tool of liquid crystal alignment, provides excellent alignment of reactive mesogenes (RMs). For this processing we utilized anode layers source generating two sheet-like beams of accelerated plasma allowing to treat large-area substrates by sample movement across the plasma "sheets". The oblique treatment by plasma beam results in planar or oblique alignment of planar RMs (p-RMs) and homeotropic alignment of homeotropic RMs (h-RMs). The homeotropic alignment of h-RMs can also be achieved by normal processing with plasma beam or processing by diffuse (non-directed) plasma. Good alignment effect is observed for a big variety of organic and inorganic materials. The widely used in LCD technology glass, silicon and plastic substrates processed by plasma beam also demonstrate excellent RM alignment that excludes necessity to use additional alignment layers. Besides, in the case of flexible plastic substrates, roll-to-roll alignment treatment can be realized. Thus the developed method is an advance in technology of optical films based on RMs.

1. Introduction
Reactive mesogenes (RMs) are pure compounds or mixtures containing molecules capable to polymerize [1]. The polymerized layers of oriented RMs are typically used to form a passive (non-switchable) optical component of an LCD, such as compensation film or dichroic polarizer [1-5]. The layers can be in the form of separate films laminated to the outside of the LC display, or can be formed as part of the LC display cell, also known as "in-cell" application. Alignment of the RM layer before polymerization is critical for correct optical performance.

The planar/tilted alignment of RMs is usually achieved by rubbing a polymer substrate or film [1]. However, uniformity of LC alignment provided by rubbing is far from ideal that is especially critical for microdisplays. The rubbing causes electrical charging, dangerous for surface electronics, and surface dusting. Finally, this method is inefficient for non-flat substrates.

Another method to align RMM is photoalignment [6,7]. This method requires additional layer (alignment layer) between RMM film and substrate. The photoalignment material should be carefully selected to resist destructive action of solvent used to dissolve RMs. Besides, photoalignment method usually gives variable results and low anchoring, which cannot restrain disordering processes under RM polymerization. This leads us to the conclusion that other methods should be developed which avoid mechanical contact with the substrate, but provide rather strong anchoring.

Our approach is to adapt ion/plasma beam alignment technology, recently developed for conventional liquid crystals [8-11], for the alignment of reactive mesogenes. In this method the alignment surface is obliquely treated with a directed flux of accelerated particles (ions, neutrals or the mixtures thereof) generating anisotropy of surface relief and anisotropy of molecular bonds. We demonstrate high efficiency of this technique for planar/tilted and homeotropic alignment of RMs on a big variety of materials. The use of this technology makes needless special alignment coatings and so reduces number of manufacturing steps. Our technique provides high alignment uniformity on microscopic (micron size) and macroscopic (meter size) scale by substrate translation across the sheet-like plasma beam. The alignment processing of flexible plastic substrates is realized during their roll-to-roll rewind.

2. Experimental

2.1 Irradiation Setup
Our irradiation set up is based on anode layer source (ALS) from the Hall family of electrostatic sources [12]. It can work in the beam mode and in the diffusive mode without determined direction of plasma flux. In the beam mode ALS provides a collimated flux of accelerated particles from practically any gaseous feed. The particle flux is formed in the crossed electric and magnetic fields directly within the discharge channel. Because of high anode potential, the part of plasma is pushed out of discharge area so that beam of accelerated plasma is generated. In contrast to the Kaufman source widely used for the ion beam alignment processing, ALS does not contain grids and hot elements (such as filaments and other secondary electron sources); the structure is thus simple and allows one to substantially increase reliability.

We used ALS with a racetrack shape of glow discharge so that the source generates two "sheets" of accelerated plasma (Fig. 1). The linear part of glow discharge was about 40 cm. This allowed one to treat relatively large substrates (40x40 cm^2) by translation of solid substrates or roll-to-roll translation for flexible plastic films.

The feed gas was argon. The working pressure in our experiments was (2-10) 10^{-4} Torr. It determined current density of plasma ions, j. The ion energy controlled by anode potential U_a was within 200-1200 eV.

The exposure geometry preferably used is shown in Fig. 2. By

* Corresponding author: <olegyar@iop.kiev.ua>.

 ISSN/007-0966X/07/3801-0694-$1.00

rotation of source, the incidence angle of plasma beam was varied. The incidence angle typically used was about 75°. 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 about 2 mm/s. The substrates were treated entirely or partially. In the latter case, the masks of different configuration were utilized.

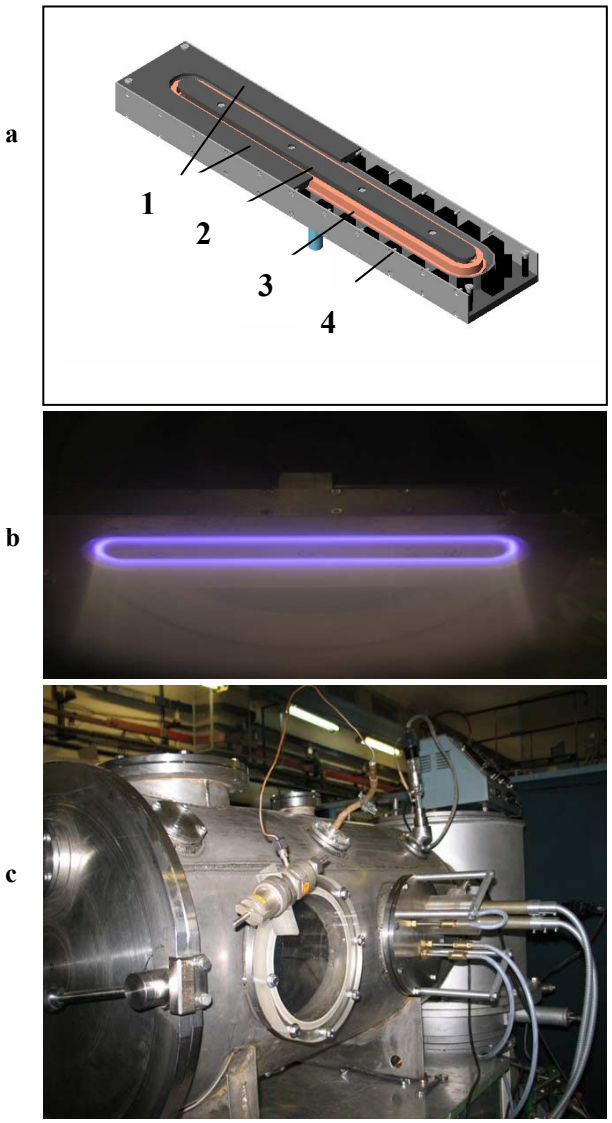

Figure 1. Sketch of ALS (a), photograph of ALS and generated plasma "sheets" (b), and photograph of plasma beam setup (c). ALS structure: 1 – outer cathodes, 2 – inner cathode, 3 – anode, 4 – permanent magnets.

2.2 RM films

As bounding substrates for RMs we used:

1) polymer layers (polyimide, polyvinylcinnamate and polymethylmethacrylate layers, as well as color filter layers);
2) bare glass substrates (microscope slides from Fisher Scientific);
3) bare silicon wafers;
4) plastic flexible strips (TAC and COP isotropic and anisotropic films).

We used planar RM mixtures RMM141 and RMS04-073 and homeotropic mixture RMS04-007. The mixtures RMS04-073 and RMS04-007 were obtained in a form of solution, while the mixture RMM141 was dissolved in toluene (30 wt.%). The RM

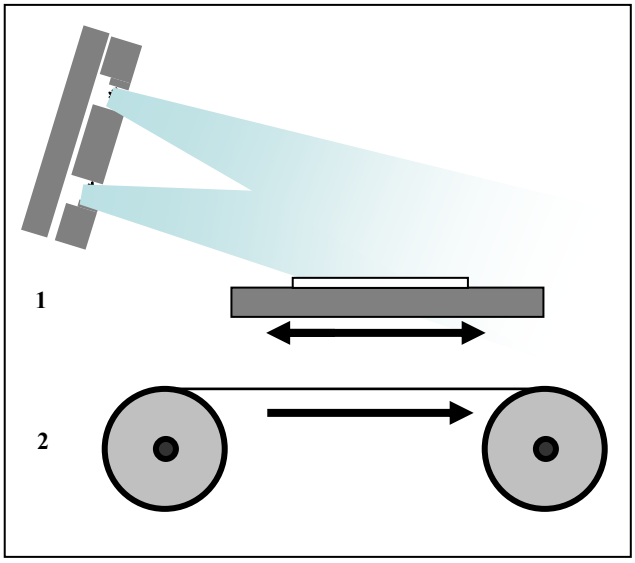

Figure 2. Plasma beam exposure geometry. 1 – cycling translation regime (mainly used for rigid substrates); 2 – roll-to-roll translation regime (used for flexible plastic strips).

films were obtained by spin coating RM solution on appropriate substrates. Just after spin coating the film was kept 1 min at 60°C to evaporate solvent and improve RM alignment. Then film was irradiated by broad spectrum UV light from high-pressure mercury lamp with the irradiation intensity of 50 mW/cm^2 during 1 min.

The quality of RM alignment was examined by sample observation in light box and polarizing microscope. The retardation properties were studied by null ellipsommetry technique [13].

3. Results

3.1 Alignment quality

First of all, the efforts were paid to optimize processing conditions for good RM alignment. In fact, the optimized conditions for RMs were the same as for conventional LC mixtures. At these processing conditions we achieved excellent alignment of RM films on all substrates involved in our tests. Figure 3 shows alignment of planar RM on the color filter films. One can clearly see difference in RM alignment between the plasma processed part (rectangular area in the middle of the film) and the unprocessed area in the peripheral part of the film. Fig. 4 shows that alignment is also highly uniform on microscopic level. The alignment of the same high quality is also realized on color filter arrays used in real color LCD. This suggests simplified stacking of optical LCD films especially useful for their in-cell disposal.

Figure 5 demonstrates that p-RM mixture can be well aligned on plastic substrate. The corresponding plastic strip was treated with

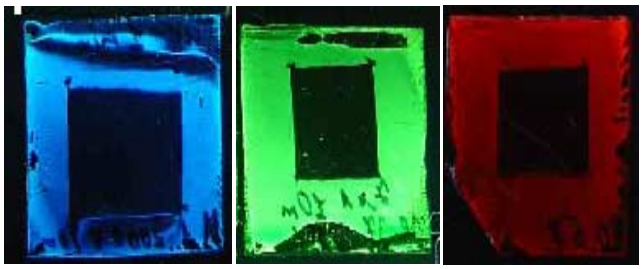

Figure 3. Layers of p-RM RMM141 deposited on color filter films partially processed by plasma beam (rectangular area in the middle of sample). Treatment conditions: α=75°, j=6-8 μA/cm², U_a=600 V. The substrates are cyclically moved (2 mm/s, 5 min) during irradiation. Samples are viewed between two crossed polarizers.

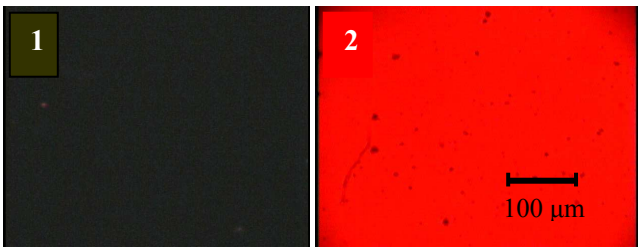

Figure 4. Microphotographs of sample 3 from Fig. 3 viewed between crossed polarizers. 1 – dark state; 2 – bright state.

a plasma beam in a course of roll-to-roll translation. Fig. 6 shows analogous film with alignment patterns. Such example can be curved without any damage of RM films.

The homeotropic RM RMS04-007 aligned well on all substrates involved in our tests. Note that plasma processing step was not important for some of them from the viewpoint of RM alignment, but it always improved adhesion of RM films. However, for plastic substrates, plasma treatment was principally important to obtain homeotropic alignment of good uniformity. The positive result was obtained for oblique and normal irradiation as well. Moreover, processing with a diffuse plasma (diffusive mode of ALS source) also radically improved quality of homeotropic alignment. The conditions are also found for tilted alignment of h-RM. This case is described in the next section.

3.2. Optical properties of RM films

Curve 1 in Figure 7 shows angular dependence of phase retardation measured by null ellipsometry method for RMM141 film deposited on blue filter film shown in Fig. 3. Optically, this sample is equal to positive A plate that proves planar alignment of RM's molecules. A qualitatively same result is obtained for other kind of p-RM – RMS04-073. The type of alignment of these RMs does not depend on alignment material and exposure conditions.

Curve 2 in Figure 7 corresponds to phase retardation vs rotation angle curve for h-RM RMS04-007 film on color filter layer. This retardation profile corresponds to positive C plate having optical axis coinciding with a film normal. This reflects homeotropic alignment of RM's molecules. Qualitatively, RM alignment is the same on untreated and plasma treated substrates.

On TAC films, in some range of exposure doses, we detected

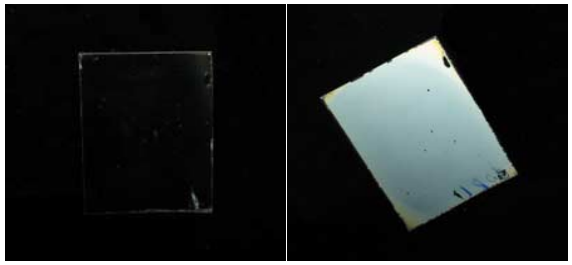

Figure 5. Film of p-RM RMS04-073 deposited on COP isotropic substrate obliquely irradiated with plasma beam (α=75°, j=6-8 μA/cm², U_a=600 V, roll-to-roll rewind with a velocity of 2 mm/s). Film is viewed between a pair of crossed polarizers.

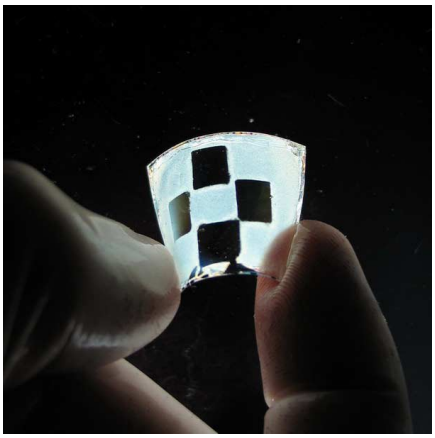

Figure 6. Film of p-RM RMS04-073 deposited on TAC isotropic substrate obliquely irradiated by plasma beam through a mask. Treatment conditions: α=75°, j=6-8 μA/cm², U_a=600 V. Sample is viewed between two crossed polarizers.

tilted alignment of RMS04-007 layers. These layers have optical

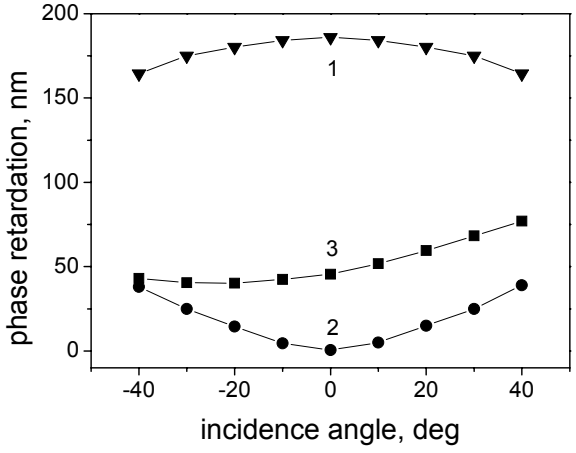

Figure 7. Phase retardation vs sample rotation curves for RMM141 film aligned with color filter substrate (1), RMS04-007 film aligned with color filter substrate (2), and RMS04-007 film aligned with TAC film (3).

properties of positive O plates. The corresponding retardation vs rotation angle function is presented with curve 3 in Fig. 7.

4. Conclusions

We suggest effective method of RM alignment avoiding direct contact with the alignment substrate, providing high alignment uniformity, pattering and good adhesion to the alignment substrate. A special alignment layer between the substrate and RM film is needless. The alignment treatment in the roll-to-roll manner is realized for the plastic substrates. The developed alignment process suits well for the modern technology of anisotropic optical films based on RM. In particular, based on this process, positive A, positive C and O compensation films are obtained. We believe that plasma alignment process can also be useful for the alignment of RMs designed for other applications, such as organic TFTs and OLEDs [15].

5. References

[1] D.J. Broer, H. Finkelman and K. Kondo, *Macromol. Chem.*, 189, p. 185, 1988.

[2] M. Verrall, O. Parri, K. Skjonnemand, K. Slaney, *Proc. SPIE*, **4658**, p. 59, 2002.

[3] H. Hasebe, K. Takeuchi, and H. Takatsu, *J. Soc. Info. Displays*, **3**/3, p. 139, 1995.

[4] B.M.I. Sande et al., *J. Soc. Info. Displays*, **13**/8, p. 627, 2005.

[5] E. Peeters, J. Lub, W.P.M. Nijssen, J. Steenbakkers and D.J. Broer, *Proc. Eurodisplay'05*, p. 165.

[6] P.J. Shannon, W.M. Gibbons and S.T. Sun, *Nature*, **368**, p. 532, 1994.

[7] M. Schadt, H Seiberle, A. Schuster and S.M. Kelly, *Jpn. J.Appl. Phys.*, **34**, p. 3240, 1995.

[8] M.J. Little et al. *US Patent* 4,153,529 (1979).

[9] P. Chaudhari et al., *Nature*, **411**, p. 56, 2001.

[10] O. Yaroshchuk et al., *Proc. Eurodisplay'02*, p.421 (2002).

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

[12] E. Jang, H. Song and S.-D. Lee, *Jpn. J. Appl. Phys.*, 45(46), p. L.1238, 2006.

[13] V. Zhurin, H. Kaufman, R. Robinson, *Plasma Sources Sci. Technol*., **8**, p. 1, 1999.

[14] O. Yaroshchuk, T. Sergan, J. Lindau, S.N. Lee, J. Kelly and L.-C. Chien, *J. Chem. Phys*., **114**, p. 5330, 2001.

[15] M. Grell, D.D.C. Bradlay, *Adv. Mater*., **11**, p. 895, 1999.