Vacuum particle beam methods for alignment of reactive mesogens

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ABSTRACT

Vacuum particle beam processes of liquid crystal alignment are successfully extended to reactive mesogens (RMs). In this series, etching process is preferable for planar alignment, while deposition processes provide excellent homeotropic alignment of RMs. By combination of these processes various laminated and patterned structures are obtained, which suggest attractive solutions for the technologies of optical and electronic films.

1. INTRODUCTION

In the recent years we observe increasing interest to so called particle beam (PB) processes of liquid crystal (LC) alignment, which is believed to be capable to substitute rubbing procedure in the alignment of conventional liquid crystals. Here, as the particles are meant atoms, ions, electrons and the mixtures thereof, such as plasma. These particles, depending on their energy, reactivity, etc, are capable of etching a treated surface or can condense on it forming aligning layers. Due to oblique incidence of particle beam, the top layer of the substrate becomes anisotropic which causes LC alignment.

The PB processes produce LC alignment of exceptionally high quality with a widely varied pretilt angle and anchoring energy. They surpass rubbing technique in alignment uniformity. Also, they yield inorganic aligning coatings allowing to improve thermal and photo-resistance of the LC alignment. In spite of the number of advantages over the rubbing, the PB alignment methods have not still found industrial application. This is caused by several unsolved problems, such as image sticking and alignment aging [2,6,7].

It is known that, along with application in electro-optic cells, LC materials have found other application such as anisotropic optical films (retarders [8] and polarizers [9]) and surface electronic devices [10]. In contrast to electro-optic cells, these new applications do not require reorientation of LC molecules in an external field, i.e., LC director is passive. For these applications special classes of LCs ("passive" LCs) are usually used, providing solid anisotropic films under certain conditions. These LCs include reactive mesogens (RMs), lyotropic LCs and LCs being in a solid state at ambient temperatures (glassy LCs).

Our general goal is to extend the PB methods to the classes of passive LCs. Because, in a course of exploitation, director of these LCs is fixed, the problems mentioned above for the fluid, electro-optic type LCs, are eliminated.

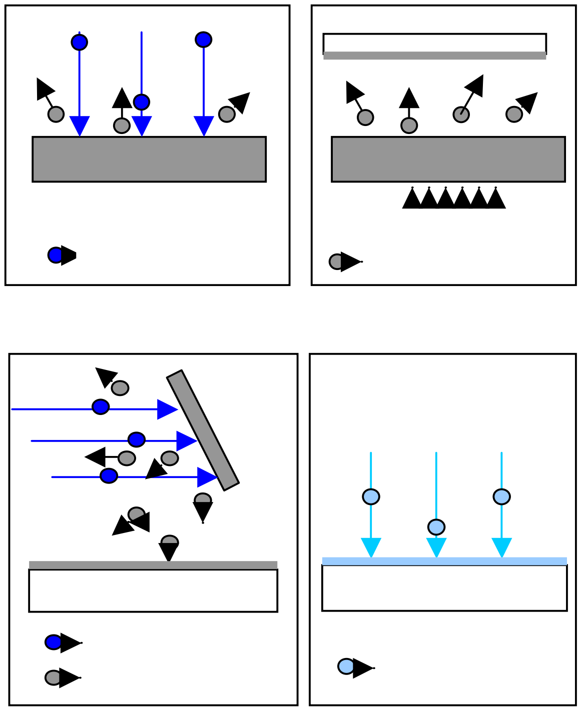

Fig. 1. Particle beam etching and deposition processes:
(a) ion/plasma beam etching; (b) vapor deposition; (c) ion/plasma beam sputtering deposition; (d) direct deposition from ion/plasma beam.

In the present paper we consider efficiency of the PB methods for reactive mesogens. Along with mesogenic core, the molecules of these LCs contain one or several reactive groups capable to polymerize. Because of this, the RM films can be aligned in a conventional way (with

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the aligning substrate(s)) and then solidified by photo- or thermal polymerization. These compounds have found application in optical and electronic devices.

We demonstrate high potential of PB methods for alignment of RMs enabling single layer and multilayer films with desirable uniform or patterned alignment to be realized.

2. PB PROCESSES FOR LC ALIGNMENT

The effect of particles on the aligning substrate depends on their energy and reactivity. If the particle energy is higher than 100 eV, surface etching (milling) process dominates. If the particle energy is below this value and particles reactivity is higher, deposition process is preferable.

Fig. 1 schematically presents the fundamental PB processes that have been adapted for LC alignment: (a) ion/plasma beam etching [1,2], (b) vapor deposition [3]; (c) ion/plasma beam sputtering deposition [4]; (d) direct deposition from ion/plasma beam [5]. In the *etching* process, highly accelerated particles cause breaking of surface molecular bonds and material ablation from the substrate. The deposition processes differ with a way of formation of working particles causing film deposition. In the *vapor deposition* process these particles are thermally extracted from some material by electrical or e-beam heating. This process is characterized by the lowest particle energy (of the order of kT) resulting in low-density coatings. In the *sputtering deposition* process, the working particle beam is formed from the particles ablated from the target material due to bombardment with other particles having sufficiently high energy. Finally, in case of *direct deposition*, the working particles originate from the gaseous phase subjected to plasma discharging.

3. EXPERIMENTAL

3.1. Particle beam treatment

The plasma beam etching, sputtering deposition and direct deposition processes were involved in our research. They were realized by using plasma sources of Hall family; the anode layer source (closed drift source) [11,12] was used for etching and sputtering deposition, and the end-Hall source [11,13] was used for direct deposition. Due to very simple construction, these sources are very reliable and can be easily scaled up. The use of linear sources of this class allows the large-area substrates to be treated by unidirectional translation or roll-to-roll rewinding. Earlier, we successfully adapted these processes for alignment of conventional LCs [2,5,14].

As the aligning substrates we used slides of bare glass and polyimide coated glass, as well as flexible plastic strips of TAC and PET materials. During the PB processing, the particles impinged on the aligning substrate obliquely so that the angle α between the substrate's normal and the PB was 70^{o}-80^{o} (Fig. 2). The rigid substrates were translated, while flexible strips were subjected to roll-to-roll rewinding. The translation speed of the substrates was 1-4 mm/s.

3.2. Samples

We used RMs from Merck developed for planar (p-RMs: RMM141, RMM256C, RMM684, RMM- 698), tilted (t-RMs: RMM19B) and homeotropic (h-RMs: RMS04-007) alignment. The RM films were produced by spin coating the RM solution on the surface processed by particle beam. For better alignment, the coated films were heated to 50^{o}C and then polymerized via UV treatment.

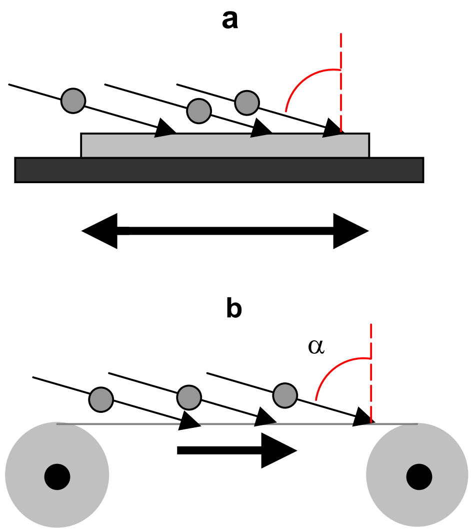


Fig. 2 Particle beam processing scheme for (a) rigid substrates and (b) flexible strips.

3.3. Alignment test and optical measurements

The alignment of RMs was tested by inspecting samples placed between pair of polarizers by naked eye and with polarizing microscope. The optical retardation of these samples was studied by null ellipsometry technique [15].

4. RESULTS

4.1 Single layer films

Basically, both etching and deposition processes are universal, i.e., can be applied for RMs designed for various types of alignment. However, as we realized, etching procedure is considerably more effective for p-RMs and t-RMs, while sputtering processes are preferable for h-RMs. Highly uniform alignment of p- and t-RMs was realized on a big number of substrates, such as color filters, plastic films, glass, silicon, etc. As an example, Fig. 3a demonstrates p-RM film coated on isotropic plastic strip. The alignment quality of such films is considerably better than the quality of rubbing aligned films, because of very high microscopic uniformity. The p-RM and t-RM films demonstrate retardation profiles typical for positive A and positive O optical films, respectively (Fig. 4). On the other hand, highly uniform alignment of h-RMs was realized on various inorganic coatings like SiO_2, TiO_2, Al_2O_3. Fig. 3b demonstrates h-RM films aligned on isotropic plastic strip coated with SiO_2 layer. Optically, these films are equal to positive C films, Fig. 4.

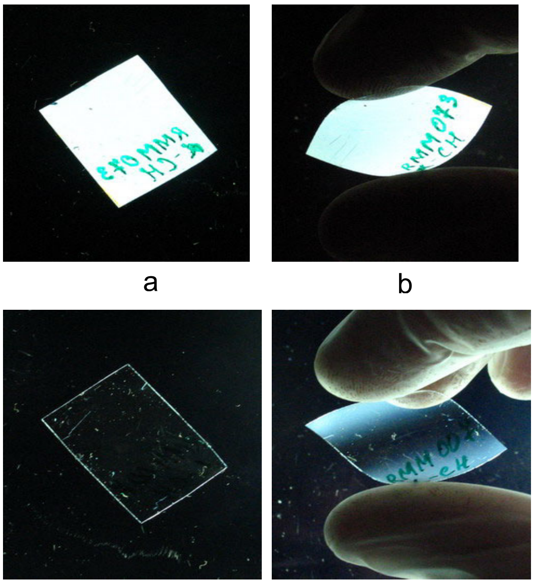


Fig. 3. Photographs of RM films with (a, b) planar and (c,d) homeotropic alignment deposited on isotropic plastic (TAC) substrates. The films have optical properties of +A and +C films, respectively.

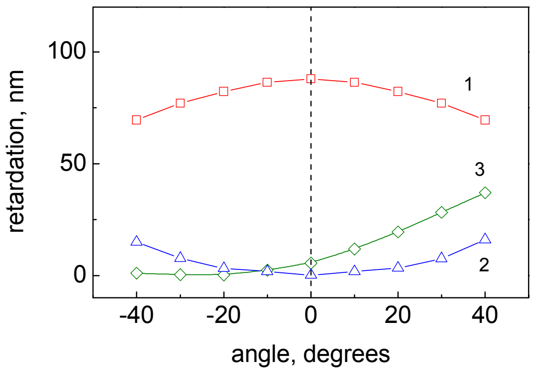


Fig. 4. Retardation vs rotation agle obtained for (1) p-RM, (2) h-RM, and (3) t-RM.

The etching procedure was also successfully applied for the planar alignment of RMs designed for electronic applications [16].

4.2 Multilayer films

Particle beam processes suggest easy way for manufacturing of laminated structures, *i.e.* structures consisting of multiple RM sub-films with desirable RM alignment. As we found out, the etching process allows to decouple planar (tilted) alignment of two adjacent RM films. In other words, alignment of RM layer coated on the top of other RM layer can be effectively controlled by PB etching. Surprisingly, this cannot be achieved by rubbing procedure; in this case, the alignment direction associated with the ordering axis in the lower RM film overcomes alignment direction generated by rubbing. The homeotropic RM alignment on the top of p- or t-RM film can be easily obtained by coating this film with thin inorganic layer (SiO_2, Al_2O_3, etc.). The realized multilayer structures are presented in Fig. 5. The described approach can be used to design complex compensation films, stacks of polarizing and retardation films, *etc*. As an example, Fig. 6 demonstrates two-layer films of p-RMs with the angle between the alignment

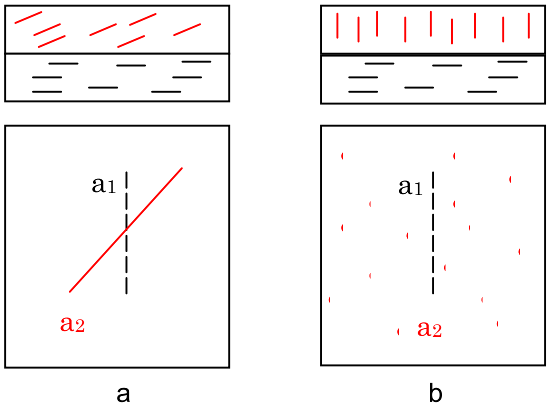
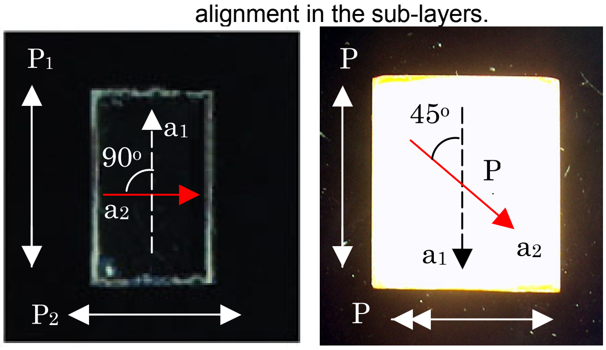


Fig. 5 Structures of realized two-layer RM films.

(a) film with planar RM alignment in the sub-layers, (b) film with planar and homeotropic RM alignment in the sub-layers.



a b

Fig. 6 Photographs of two-layer RM films with planar alignment. Alignment axes in the layers form angle (a) 90° and (b) 45°.

directions in the layers 90° and 45°. These structures can be used to design negative C films [17] and achromatic retarders [18], respectively.

4.3. Films with patterned alignment

The combination of etching and deposition processes was readily applied to produce samples with patterned RM alignment. The realized structures and photographs of corresponding samples are presented in Fig. 7. Some of these structures san be considered as prototypes of patterned retarders and polarizers highly requested by modern LCD technologies (transflective LCDs, stereoscopic LCDs, etc.).

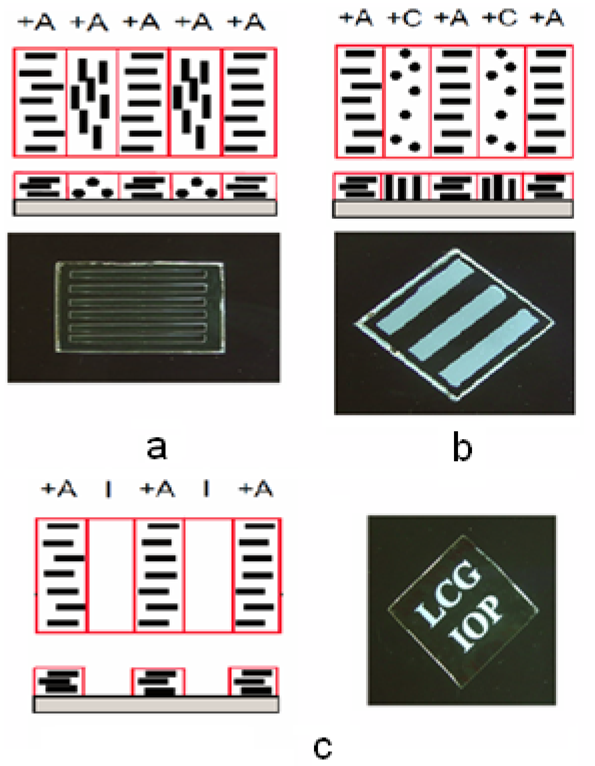


Fig. 7 The realized patterned structures and photographs of corresponding samples

4. CONCLUSIONS

Particles beam processes, such as ion/plasma beam etching, ion/plasma beam sputtering and direct ion/plasma beam deposition, recently developed for alignment of conventional LCs appeared to be highly effective for RMs. They provide RM alignment with exceptionally high microscopic uniformity on practically any material used in LCD manufacturing. The combination of these techniques allows to pattern desirably the RM alignment and to produce laminated structures with controllable RM alignment in sub-layers of these complex films. This makes the particle beam alignment methods rather promising for anisotropic organic films used in optical and electronic applications.

Acknowledgement

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