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Homogeneously aligned liquid crystal molecules on reformed poly (methyl methacrylate) via ion-beam irradiation

Hae-Chang Jeong [a], Hong-Gyu Park [a], Ju Hwan Lee [a], Sang Bok Jang [a], Byeong-Yun Oh [b], Jeong-Min Han [c], Dae-Shik Seo [a,*]

[a] Information Display Device Laboratory, Department of Electrical and Electronic Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Republic of Korea
[b] ZeSHTech Co., Ltd., Business Incubator, Gwangju Institute of Science and Technology, 123, Cheomdangwagi-ro, Buk-gu, Gwangju 500-712, Republic of Korea
[c] Department of Electronic, Seoil University, Jungnang-gu, Seoul 131-702, Republic of Korea

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ABSTRACT

We demonstrated uniform LC alignment using IB-irradiated poly(methyl methacrylate) (PMMA) as an alignment layer. We confirmed the topographical changes on PMMA caused by IB irradiation. Moreover, the wettability and chemical modification of the PMMA surface were investigated as functions of incidence angle. The results show that PMMA irradiated with IB at an incidence angle of 30° had a higher molecular polarity than PMMA irradiated with IB at other incidence angles, resulting in strong van der Waals interactions between the surface and LC molecules. The LC cells containing PMMA irradiated with IB at an incidence angle of 30° exhibited good thermal stability (180°) compared with LC cells containing conventional rubbing PI (150°). In addition, LC molecules on PMMA irradiated with IB at an incidence angle of 30° were observed to switch faster than those on conventional rubbing PI. Therefore, PMMA irradiated with IB under the optimal conditions may allow for PMMA to be applied in advanced LC devices as an alternative alignment layer.

1. Introduction

The alignment of liquid crystals (LCs) is one of the most important core technologies for the realization of high-quality LC devices. Rubbing, which is conventionally used in LC display industry, is a good alignment method for LC devices; however, since the process involves a contact with alignment layer, it causes some problems such as the generation of debris, local defects, and accumulated charge [1,2]. In the last few years, the ion-beam (IB) technique has been widely and intensively studied as a candidate for LC alignment to produce high-quality LC devices [1,3–7]. However, the process has been primarily applied to inorganic materials such as SnO_2 [7,8], ZnO [9], HfO_2 [10], Al_2O_3 [11], and La_2O_3 [12]. Recently, several composite oxides such as HfYGaO have been reported as suitable for high-performance LC devices [13]. The effects of IB irradiated polymers on LC alignment have been reported only on polyimide [5,6], and carbon like diamond [1,4].

Poly(methyl methacrylate) (PMMA) is widely used transparent polymer. Sometimes called organic glass, PMMA is characterized by its high heat and chemical resistance and low cost of production. Therefore, PMMA has been widely applied in light-weight windows [14], and opto-electronic devices such as light-emitting diode [15], solar cell [16], battery [17] and surface-enhanced Raman scattering substrates [18]. In most cases, PMMA has been used for colloidal blending with conducting particles including gold, quantum dot, and carbon-nanotube because it could fill conducting particles in excluded volume on PMMA [19], effectively forming a segregated conductive network. In contrast, Vesel et al. treated PMMA with oxygen plasma to alter its wettability and aging characteristics [20]. This plasma treatment oxidized the surface of PMMA, increasing its hydrophobicity.

In this study, we demonstrated uniform LC alignment by using IB-irradiated PMMA as an alignment layer with incidence angle changed. Scanning electron microscopy (SEM) were performed to compare PMMA before and after IB irradiation. To reveal the alignment mechanism of the LCs, contact angle (CA) measurements and X-ray photoelectron spectroscopy (XPS) were conducted as functions of the IB incidence angle. The LC alignment state on IB-irradiated PMMA was evaluated by using polarized optical microscope (POM). Pretilt angle of LCs was calculated by using crystal rotation measurement. Moreover, twisted-nematic (TN)-LC cells were fabricated with IB-irradiated PMMA and their electro-optical performances were measured and compared with that of

* Corresponding author.
E-mail address: dsseo@yonsei.ac.kr (D.-S. Seo).

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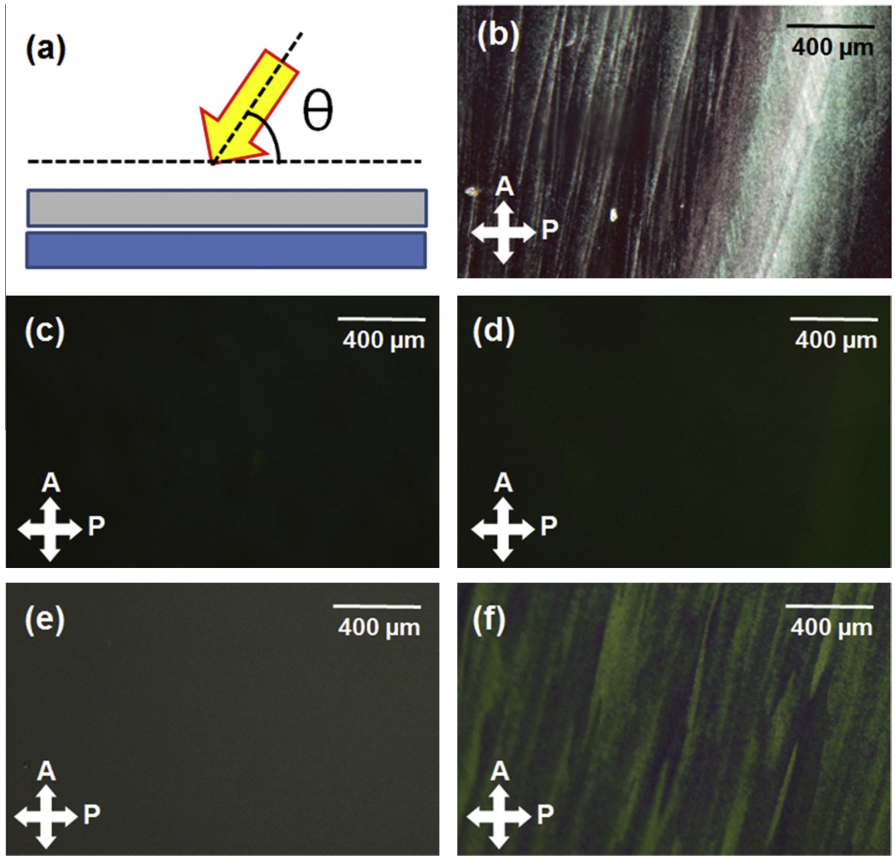

Fig. 1. (a) Schematic of IB irradiation on PMMA with incidence angle θ. (b) POM images of LC cells with non-treated PMMA. (c)–(f) POM images of LC cells irradiated at incidence angles of (c) 30°, (d) 45°, (e) 60°, and (f) 90°.

TN-LC cells fabricated with rubbing PMMA and rubbing PI. We confirmed that the LC molecules were aligned on IB-irradiated PMMA at certain incidence angles. Thus, the IB process can be considered as an alternative LC alignment method for high-quality LC displays.

2. Experimental

2.1. Preparation of PMMA films

PMMA powder (20 wt%; molecular weight ~ 15,000; Sigma Aldrich) was dissolved in 2-methocyethanol (2ME). Acetic acid and mono-ethanolamine (MEA) were added to increase the stability of the solution. The solution was stirred for 4 h at 65 °C and aged for 1 d. The prepared solution was spin-coated onto indium-tin oxide coated glass (ITO glass) at a spin rate of 3000 rpm for 30 s. The coated substrate was annealed at 65 °C for 2 h in a furnace. A Duo PI Gatron ion-beam system was used. The PMMA film coated on the substrate was irradiated by Ar^+ IB plasma at 1800 eV with a current density of 1.1 mA cm^{-2} for 2 min. The incidence angle was varied (30°, 45°, 60°, and 90°). The refractive indices of prepared PMMA and IB irradiated-PMMA were 1.481 and 1.485, respectively, and the film thickness of PMMA was 125 nm, which is obtained via ellipsometry (alpha SE; J.A. Woollam Co., Inc.) by taking five different points on the sample.

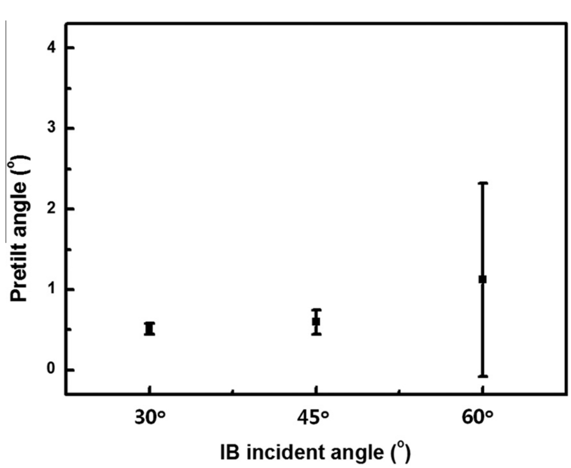

Fig. 2. Average pretilt angles and their deviation for LC cells with PMMA irradiated at incidence angles of 30°, 45°, and 60°.

2.2. Fabrication of liquid crystal cells

The two types of LC cells were fabricated using the IB-treated PMMA films as an alignment layer. The first is an antiparallel configuration with a cell gap of 60 μm was made to calculate pretilt angle, and examine POM images which can evaluate the alignment state. The second is the TN mode with a cell gap of 2.5 μm for measuring electro-optical (EO) performance including threshold voltage, and response time. The prepared LC cells were filled with a positive LC (MJ001929, $n_e = 1.5859$. $n_o = 1.4872$ and $\Delta\varepsilon = 8.2$; Merck) by capillary action.

2.3. Characteristics of PMMA

POM images were observed with a BXP 51 microscope (Olympus) to evaluate the alignment state and thermal stability.