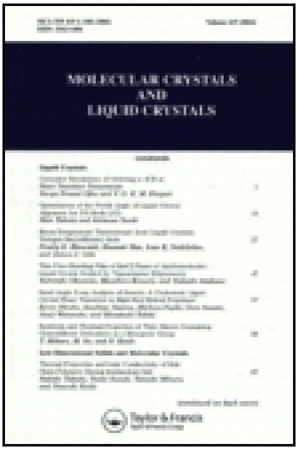

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We investigated liquid crystal (LC) alignment as a function of ion beam (IB) incident angles and electro-optical (EO) characteristics of twisted nematic (TN)-liquid crystal displays (LCD) on polyimide (PI) surfaces. X-ray photoelectron spectroscopic analysis showed that the intensity of C=O chemical bonding decreased, while that of C–O chemical bonding increased for increasing IB incident angles. This indicates that the dipole-dipole interaction between C–O chemical bonding and the LC molecules has a chemical alignment effect. A good uniform alignment of nematic LCs on PI surfaces by the IB irradiation was observed, and good EO properties of IB-aligned TN-LCDs on PI surfaces were achieved.

Keywords: electro-optical characteristics; ion-beam; liquid crystal alignment; polyimide; TN-LCD

INTRODUCTION

Uniform liquid crystals (LCs) must be aligned to achieve high image quality in LC displays (LCDs) [1]. As LCD applications require increasingly large display sizes and high image quality, uniform LC alignment and LC movement are becoming more important [1,2].

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Non-contact methods using ion beam (IB) irradiation, UV alignment, and oblique deposition have been the subject of recent intense investigations aimed at replacing the conventional rubbing method that has serious limitations such as unreliability and non-uniformity on large substrates, as well as defects from dust and electrostatic charges that occur during the rubbing process [1,3,4]. Moreover, the rubbing method requires a cleaning process to remove these defects, which slows the manufacturing process and reduces the cost effectiveness. Therefore, non-contact techniques are very important [1,5–7].

We demonstrated the feasibility of IB-irradiated LC alignment on a polyimide (PI) layer as an alternative to the conventional rubbing process. The pretilt angle was measured as a function of the incident IB angle, and a chemical investigation of the surface of the LC alignment layers was conducted to explain the LC alignment mechanism. Twisted-nematic LCDs (TN-LCDs) were fabricated and the electro-optical (EO) characteristics of the cells were examined to estimate the potential of non-rubbing technology.

EXPERIMENTAL

We prepared indium-tin-oxide (ITO) coated glass substrates, and uniformly coated them with PI using a spin-coating machine. The PI layer was imidized at 230°C for 60 min. The 50-nm-thick layers were irradiated at room temperature with an Ar IB for 1 min at various incident angles in the range of 15°–75°. The Ar IB system with a DuoPIGatron ion source used in this study is shown in Figure 1. The IB energy was 1800 eV for all samples. Extra PI substrates were rubbed using a rubbing machine to obtain comparison samples. These substrates were fabricated in an antiparallel configuration as TN-LCDs with cell gaps of 60 and 5 μm, which were used to measure the pretilt angle and EO characteristics, respectively. The cells were assembled and filled with positive nematic LC (NLC; TC = 72°C, $\Delta\varepsilon = 8.2$, Merck). To estimate the state of the LC alignment, the ability of the NLCs to align on the IB-irradiated PI surfaces was observed using a photomicroscope (Olympus BXP 51) with crossed polarizers. The pretilt angle of the NLCs was measured by the crystal rotation method at room temperature, and the chemical bonding states of the film surfaces were analyzed using X-ray photoelectron spectroscopy (XPS; PHI 5800 ESCA system; Physical Electronics). In addition, the voltage–transmittance (*V*–*T*) and response time (RT) performance of these LCDs were measured using an LCMS-200 (EO equipment from Sesim Photonics Technology).

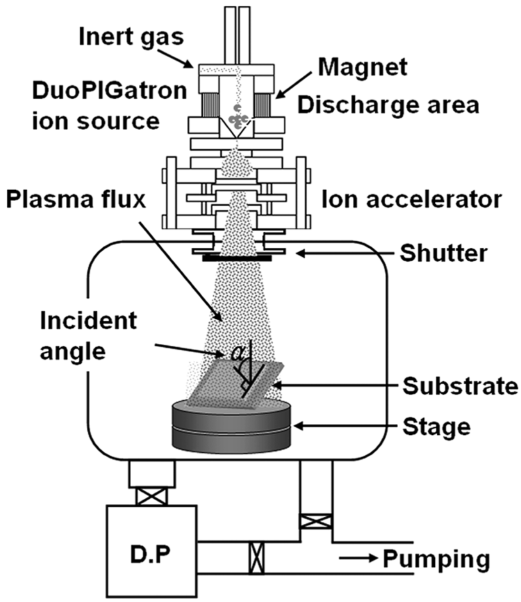


FIGURE 1 Schematic diagram of the IB system with the DuoPIGatron ion source.

RESULTS AND DISCUSSION

Figure 2 shows photomicrographs of antiparallel cells between crossed polarizers of the NLC alignment on the rubbed PI surface and on the IB-irradiated PI surfaces for various IB incident angles. The uniform dark state of the LC molecules on the rubbed PI surface is evident in Figure 2(a). Figure 2(b) shows the random orientation of LC molecules on the non-irradiated PI surface, and Figures 2(c) and (d) show uniform dark states with IB incident angles of 15° and 45°, respectively. However the LC molecules were not fully aligned for greater IB incident angles, as shown in Figure 2(e). These results indicate that IB irradiation has the capability to align LCs uniformly.

Figure 3 shows the pretilt angles measured on the IB-irradiated PI surfaces as a function of IB incident angle. A low pretilt angle of less than 1° for all the samples was observed. These results indicate that IB alignment on a PI surface is suitable for the in-plane switching mode [8], and that the polar anchoring energy can be strong [9].

The chemical bonding properties of atoms were characterized, and the curve-fitting of XPS data for PI irradiated with IB at various

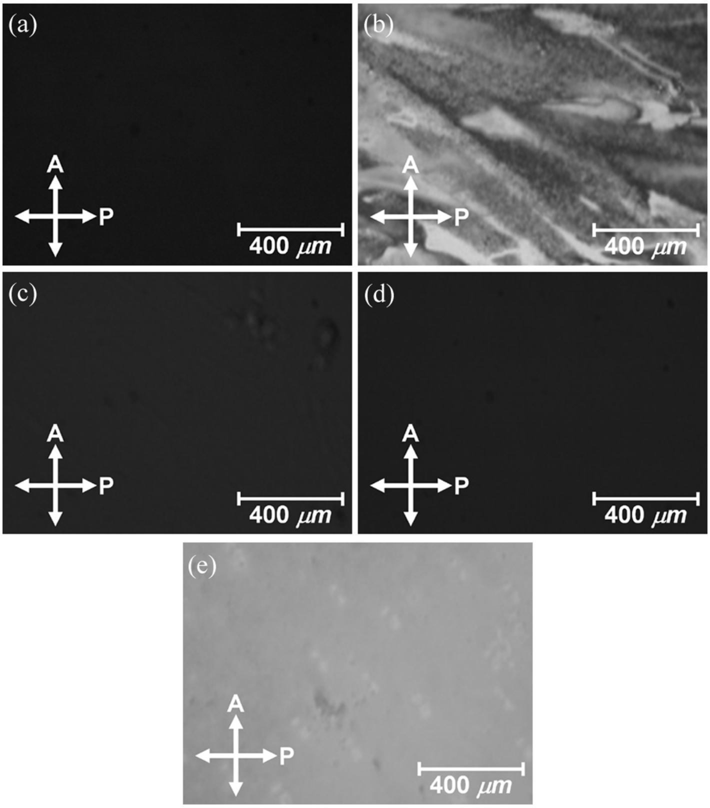


FIGURE 2 Polarizing optical photomicrographs of the (a) rubbed PI surface; NLCs on the PI surfaces irradiated with various IB incident angles of (b) 0°, (c) 15°, (d) 45°, and (d) 75°. (A: analyzer, P: polarizer).

incident angles is shown in Figure 4. The core-level XPS spectra of C 1 s were decomposed into four components centered at 284.7, 285.5, 286.3, and 288.6 ± 0.1 eV, respectively, which are typical locations for the two benzene rings (C=C bonds), the carbon atoms in the benzene ring (C–C bonds), the C–O or C–N single bonds, and the imide rings (C=O bonds) [10]. The atomic percentage of the C=O double bonds decreased and that of the C–O or C–N single bonds increased, while the percentage of the C=C and C–C remained constant. These results imply that the pretilt angle of the LCs on the PI layer gradually increased due to the increase in the C–O single bonds, and thus the dipole-dipole interaction had a chemical alignment effect between the C–O single bonds and the LC molecules [11]. Figure 5 shows the

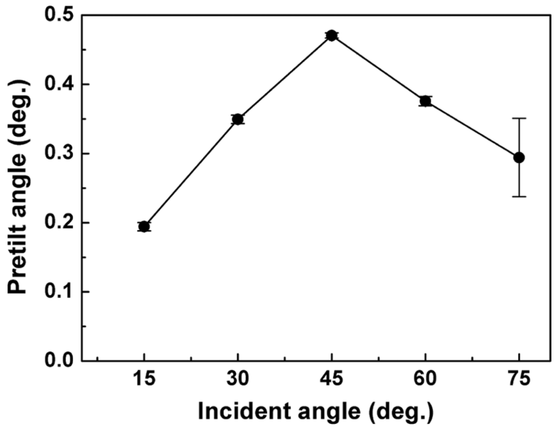


FIGURE 3 Pretilt angle on the IB- irradiated PI surfaces as a function of the IB incident angle.

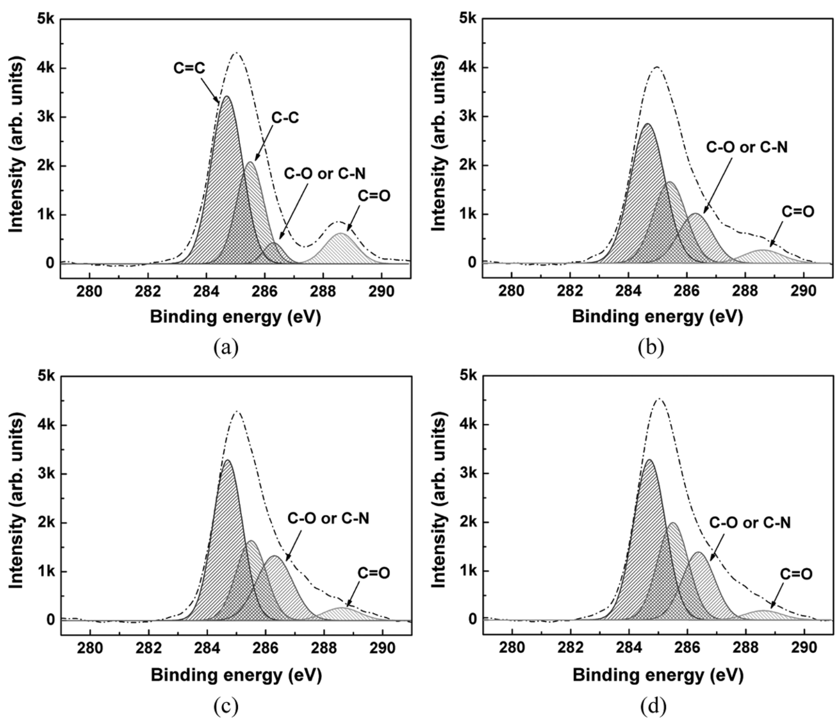
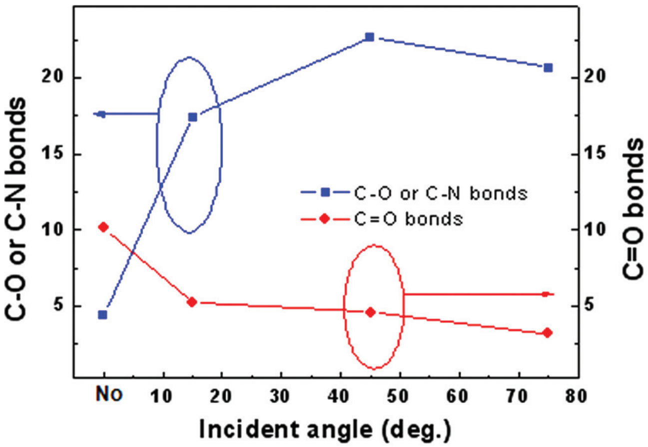


FIGURE 4 Curve-fitting of XPS data for PI surfaces irradiated with various IB angles: (a) no irradiation, (b) 15°, (c) 45°, and (d) 75°.



(a)

Components of the peak	IB incident angle (deg.)			
	No	15	45	75
C–O or C–N bonds	6.40	17.41	21.66	20.65
C=O bonds	14.14	5.24	4.60	3.19

(b)

FIGURE 5 The atomic percentage area of chemical bonding state deconvoluted from the C 1 s spectra of the PI layers irradiated with various incident angles.

changes in the atomic percentage area of bonding state in C–O or C–N single bonds and C=O bonds with no irradiation and increased IB incident angles are summarized.

Figure 6 shows the *V–T* and RT characteristics of the TN-LCD on the rubbed PI surface and IB-irradiated PI surface for an incident angle of 45° and an irradiation energy of 1800 eV. Figure 5(a) shows that the threshold voltages of the rubbed and IB-irradiated TN-LCDs were 1.06 V and 1.42 V, respectively, for a transmittance of 90%. Figure 5(b) shows that the rise times of the rubbed and IB-irradiated TN-LCDs were 1.39 and 2.62 ms, respectively, while the fall times were 12.32 and 7.86 ms. These results are related to the polar anchoring energy, which was 1.62 Jm^{-2} and 4.84 Jm^{-2} on the rubbed and IB-irradiated PI surfaces, respectively [12,13]. Therefore, the EO characteristics of the IB-irradiated PI with strong anchoring energy were superior to those of rubbed PI.

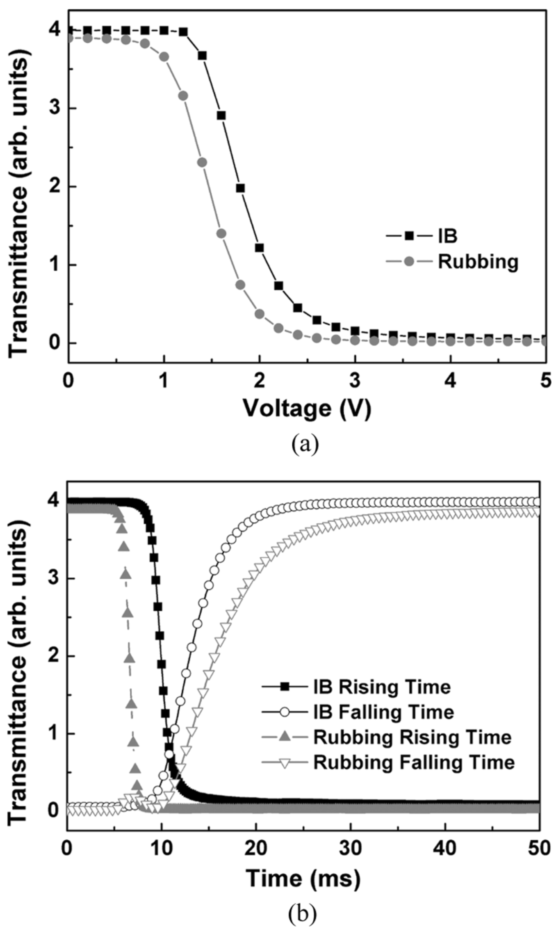


FIGURE 6 *V–T* and RT characteristics in the TN-LCD on the rubbed PI surface and the IB-irradiated PI surface for an incident angle of 45° and an irradiation energy of 1800 eV.

CONCLUSIONS

We achieved good alignment characteristics using the IB alignment method on a PI surface for an IB incident angle of 45° and an IB irradiation energy of 1800 eV. A low pretilt angle of less than 1° was obtained, and the NLC alignment capabilities showed a bell-shaped curve for increasing IB irradiation angles. XPS chemical structure analysis indicated that the change of the pretilt angle was due to a chemical interaction between the C–O single bonds and the LC molecules. In addition, the EO characteristics of the TN-LCD using the IB method were superior to those obtained using the rubbing method.

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