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Van der Waals force contribution to the vertical alignment of liquid crystal on Al_2O_3 films using ion-beam method

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ABSTRACT

This study demonstrates liquid crystal (LC) alignment on Al_2O_3 films using the ion-beam (IB) method as well as the optimization of the IB irradiation condition. Uniform LC alignment was achieved at an IB incident energy of 1800 eV with an IB incident angle of 45°, while inferior LC alignments were observed in other tested conditions. The pretilt angles and transmittances of the LC cell were also shown as part of the same trend for the LC alignment states. This result was subject to van der Waals forces which were caused by topographical changes during the IB process.

1. Introduction

Liquid crystal (LC) alignment is considered a core technology for the development of LC displays (LCDs) [1]. The regular pretilt angle is a particularly important factor because it determines device performance such as contrast, threshold voltage, and switching stability. In order to uniformly align LC molecules, polyimide (PI) is conventionally used as the alignment layer material, and the rubbing method is used to induce alignment of the LC molecules. However, the traditional rubbing method for LC alignment has major limitations, such as debris and electrostatic discharge, which produce local defects causing degradation of display quality. In order to overcome these limitations, noncontact techniques for the LC alignment have been intensively researched, including ultraviolet (UV) photoalignment [2–4] and the ion-beam (IB) method [5–9]. Noncontact alignment technique can be applied not only to organic layer but also to inorganic layer as the alignment layer. We reported a noncontact alignment process which uses ion beam irradiation to obtain controllable pretilt angle of LCs on PI layer [5]. Furthermore, LC molecules on inorganic materials such as Ta_2O_5 and γ-Al_2O_3 can be aligned horizontally and vertically [8,9]. Specially, the use of inorganic thin films in LC alignment for improving the electro-optical performance of LCDs is a promising concept for LCD technology, and LC alignment on inorganic thin films using IB and UV irradiation has been studied by several groups [4,6–9].

This study demonstrates vertical LC alignment on Al_2O_3 films using the IB method and the optimization of the IB irradiation condition. We already knew, from a previous study [9], that uniformly vertical LC alignment on Al_2O_3 films was obtainable at an IB incident energy of up to 1800 eV. Therefore, research about LC alignment capabilities as a function of the IB incident angle was accomplished in this study. In addition, the origin of the van der Waals force which influences the LC molecules to align on an LC alignment layer was demonstrated and shown to be caused by both chemical and physical changes. In particular, the topographical increase in nano-scale during the IB alignment process strengthens the van der Waals force, resulting in a uniformly vertical LC alignment at an IB incident energy of 1800 eV with an IB incident angle of 45° and an irradiation time of 2 min.

2. Experimental details

Analyses of Al_2O_3 films with 20 nm thickness were performed on indium-tin-oxide (ITO)-coated glass. Prior to the deposition of Al_2O_3 films, the ITO-coated glass substrates were cleaned via sonification with acetone and methanol, rinsed in de-ionized water, and then finally dried with N_2 gas. The Al_2O_3 films were deposited onto ITO-coated glass using the atomic layer deposition (ALD) technique. The deposition temperature was 300 °C, and tri-methyl-aluminum [$Al(CH_3)_3$] and H_2O were used as the precursors. These conditions yield an Al2O3 growth rate of 0.2 nm/cycle. Fig. 1 shows the thickness and morphology of Al_2O_3 film via a field-emission scanning electron microscopy (FESEM) (S-4200; Hitachi) image. The operating voltage of FESEM was 15.0 kV.

The Al_2O_3 films were exposed to Ar^+ IB plasma at an energy of 1800 eV for 2 min at various incident angles in the range of 15°–75° with

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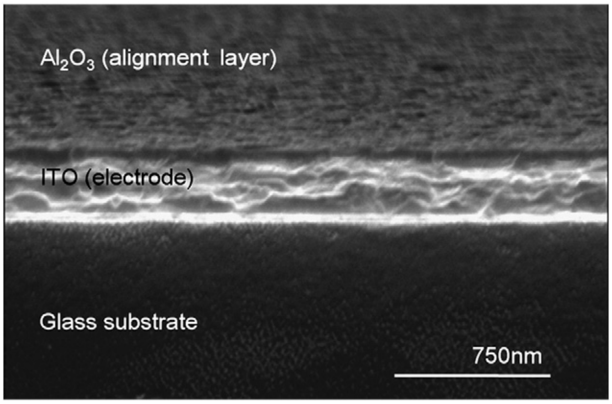

Fig. 1. FESEM image of the Al_2O_3 films deposited on ITO-coated glass.

increments of 15°. The incident angle of IB was constant over the whole substrate as IB is collimated by a magnetic field.

The LC cells were fabricated using Al_2O_3 films deposited onto ITO-coated glass substrates. The LC cells were constructed with a pair of the substrates mounted antiparallel to each other. Nematic LC (MJ98468; Merck) with a dielectric anisotropy ($\Delta\varepsilon$) of -4 was injected into the cells. The gap of the cells was 60 μm for the measurement of the pretilt angle and polarized microscopy (BXP 51; Olympus). A crystal rotation method (TBA 107; Autronic) was used to measure the pretilt angles of the LC, and the alignment states of the LCs were observed using photomicroscope images. The optical transmittance of the Al_2O_3 film was measured using an ultraviolet visible near-infrared scanning spectrophotometer (UV-3101PC; Shimadzu) in the spectral range of 250–800 nm. In order to detect surface roughness and morphology, we used atomic force microscopy (AFM) (Autoprobe CP Research System; Thermomicroscopes) and FESEM. AFM images were obtained in the non-contact mode with commercially available cantilevers with nominal spring constant of 3.2 N/m. The contact angles of the Al_2O_3 surface before and after IB irradiation were measured by the sessile drop technique with de-ionized water using a Phoenix 300 surface angle analyzer (SEO) and then analyzed with IMAGE PRO 300 software.

3. Results and discussions

The transmittance spectrum for the Al_2O_3 on ITO-coated glass substrates is shown in Fig. 2. For comparison, those of the PI film on ITO-coated glass substrates and plain ITO-coated glass substrates were also observed. The Al_2O_3 thin-film transmittance was stabler than that of the PI films in the wavelength range of approximately 380 nm to 750 nm and was similar to that of plain ITO-coated glass. This is because the ALD-processed Al_2O_3 at 300 °C was oxidation enhanced and, therefore, repaired the oxygen vacancies within the Al_2O_3 layer [10] and could potentially improve the total LCD panel transmittance.

We measured the pretilt angle using the crystal rotation method at room temperature in order to confirm the vertical LC alignment. Fig. 3 shows the pretilt angle of LC molecules on IB-irradiated Al_2O_3 films as a function of incident angle with an incident energy of 1800 eV and an exposure time of 2 min. A precise pretilt angle of 89.9° was obtained at an incident angle of 45°, and pretilt angles with large error were obtained in other conditions. In a strict sense, a uniform LC alignment was accomplished at an incident angle of 45°, and an inferior LC alignment was shown to be obtained away from the incident angle of 45°.

The alignment states and transmittances of LC cells were observed in order to verify the potential for various practical applications. Most especially, the achievement of a uniform LC alignment with a regular pretilt angle of LC is necessary in order to avoid creation of disclination in LC cells. Fig. 4(a) shows photomicrographs of antiparallel LC cells for LC cells fabricated using IB-irradiated Al_2O_3 films as a function of incident angle. As shown in this figure, the LC cells show improved LC alignment at an incident angle of 45° and inferior LC alignment at other conditions. These results are replicated in the behavior of the pretilt angle as shown in Fig. 3. Moreover, Fig. 4(b) shows that the transmittance of the LC cell strongly corresponds to the behavior of the LC alignment states. A good match between the red line representing the experimental data and the blue line representing the simulation data is obtained only at the incident angle of 45°. The transmittance of the LC cell with a latitudinal rotation of $\pm 70°$ was determined from the LC cell rotation while the He-Ne laser penetrated the LC cell.

Physical investigation using AFM and FESEM was performed in order to evaluate the surface topography of the Al_2O_3 film. Fig. 5 shows AFM and FESEM images of the films before and after the IB irradiation with the incident energy of 1800 eV, the incident angle of 45°, and the irradiation time of 2 min. The two respective root-mean-square values were 1.1 nm and 2.5 nm, showing that the IB irradiation had an effect on the roughness. The rough structures formed by the IB irradiation were observed in Fig. 5(d). These results indicate that IB irradiation induces topographical influences on a nanometer scale, increasing the effective surface area and thus causing the van der Waals force to increase [11]. The LC molecules are anchored to the alignment layer by the van der Waals force, therefore, in this case, a powerful van der Waals force can help to align the LC molecules on the Al_2O_3 layer. In more detail, we measured anchoring energy of LC on Al_2O_3 layer. At IB incident angle of 45°, weak anchoring energy of 4×10^{-5} J/m^2 was measured, and at the

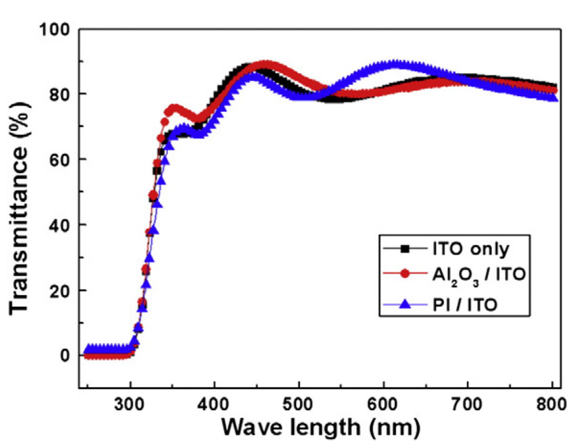

Fig. 2. Transmittance spectra for the Al_2O_3 film on ITO-coated glass substrates, PI film on ITO-coated glass and plain ITO-coated glass.

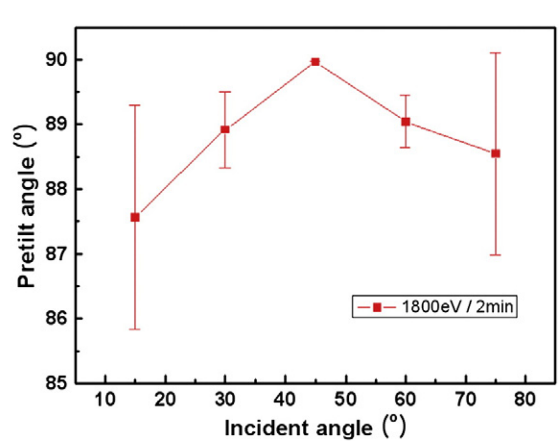

Fig. 3. Pretilt angles of IB-irradiated LCs on Al_2O_3 films as a function of the IB incident angle.