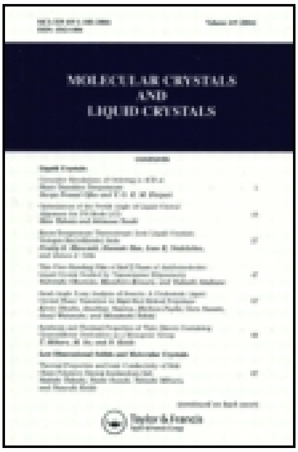

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Alignment Characteristics of Liquid Crystal Molecules on Titanium Dioxide Thin Film

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We present the characteristics of titanium dioxide (TiO_2) inorganic film deposited by RF magnetron sputtering for liquid crystal display applications in this paper. TiO_2 films supported vertically aligned liquid crystal (LC) molecules based on ion-beam (IB) irradiation time dependence. Uniform alignment was obtained only when the incident time was two minutes with 1.8 keV of incident energy and an incident angle of 45°. Energy from uniform high-density plasma by IB irradiation affected the interaction between the TiO_2 layer and LC molecules to produce vertical alignment of the LC molecules.

Keywords titanium dioxide film; ion beam irradiation; alignment layer

Introduction

Liquid crystal display (LCD) technologies have evolved rapidly and represent a variety of techniques that meet growing demands using materials and methods. A common production technique involves the rubbing of a substrate surface to produce aligned LCs. However, serious limitations of this technique include debris and electrostatic discharge from the rubbing cloth that cause local defects, streaks, and adverse effects on the driver integrated circuit [1]. In order to address these problems, non-contact processes have been explored including alignment [2], plasma treatment [3], and ion beam (IB) bombardment [4–6]. Among these, the IB irradiation method has emerged as a promising alternative process. IB irradiation can produce uniform high-density plasma over a wide range and is therefore feasible for the alignment process of inorganic materials.

The use of inorganic materials for applications such as electronic devices, optoelectronic devices and organic thin film transistors (OTFTs) is increasing, especially in the

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LCD industry. Inorganic materials have advantages compared to organic materials as they diminish some of the shortcomings of aligned organic materials.

The use of inorganic materials with high permittivity can reduce voltage loss due to the production of an aligned LC layer that represents a trade-off for regarding capacitance [8]. For example, Ta_2O_5, HfO_2, and Al_2O_3 can be applied to reduce effective power consumption by decreasing the LC driving threshold voltage [7]. Among potential inorganic materials, TiO_2 is considered one of the most promising due to its remarkable properties: low cost with high dielectric constant, high refractive index, large band gap, and excellent transparency [9]. TiO_2 is not a insulator, but it possesses a wide semiconductor band gap (band gap energy, Eg $\sim$ 35eV), and therefore displays leakage and 'breakdown' behavior that is different from that of insulating metal oxides [10]. As a result, TiO_2 can be used in LC alignment layers.

Previously, we described LC orientation characteristics on IB bombarded TiO_2 films with an incident IB energy [11]. In this paper, we introduce the characteristics of a TiO_2 alignment layer with vertical LCs produced by IB irradiation as a function of irradiation time.

Experimental

TiO_2 films 200 nm thick were deposited on ITO (1737 Corning Glass) substrate coated substrates via RF magnetron sputtering in a 5 mTorr chamber and a target power of 100 W at room temperature for 30 min. O_2 and Ar gas flow rates were 30 and 20 SCCM, respectively, where SCCM indicates the number of cubic centimeters per minute at STP. The films were irradiated with Ar IB using a DuoPIGatron-type IB system with a positively charged current density of 1.8 mA/cm^2 at various irradiation times from 1–3 min at an incident angle of 45° with 1.8 keV energy intensities. The substrates were fabricated in an anti-parallel configuration with a cell gap of 60 um to measure the pretilt. The negative nematic LC ($\Delta\varepsilon = -4$; MJ98468, Merck) was injected into the cell. The refractive indices in the ordinary and extraordinary axes were 1.4833 and 1.5684, respectively. The isotropic transition temperature was 75°C.

Results and Discussion

Figure 1 shows the X-ray diffractometry (XRD, DMAX-2500; Rigaku, Japan) patterns of TiO_2 films deposited on ITO-coated glass substrates. The crystallinities and orientations of the films were investigated by XRD in a $\theta - 2\theta$ scan mode using a Ni-filtered Cu Kα source in 20–80°. As shown in Figure 1, there were no clear crystalline properties indicating that the sputter-deposited TiO_2 film was amorphous. Therefore, the bond that was originally arranged in a disorderly fashion was aligned by IB irradiation, which induced a good balance with LC molecular interactions to achieve vertical alignment.

Figure 2 shows polarized optical microscopy (POM) images of the observed LC cells as a function of irradiation time. A real-time confocal microscope (MX50-CF, Olympus, Japan) was used to examine the fabricated structures. The principles of LC orientation using IB irradiation on thin films are considered by chemical changes or physical destruction. As shown in Figure 2, different alignment states were observed when IB irradiation time was changed. For an exposure time of 1 min in Figure 2(a), the TiO_2 layer and LC molecules induced random planar alignment that was affected by IB irradiation. However, when irradiated for 2 min, vertically aligned LCs were observed in Figure 2(b). Therefore,

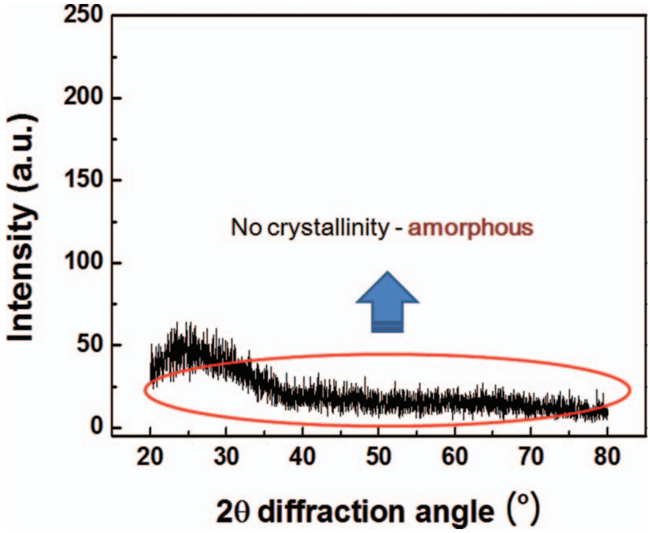

Figure 1. XRD patterns of TiO_2 film deposited on an ITO coated glass substrate by sputtering.

the energy from the electrons accelerated by the arc power supply with a sufficiently high voltage to dissociate and ionize the Ar atoms and molecules can affect alignment depending on exposure time.

LC alignment on inorganic materials is explained by van der Waals interactions between LC molecules and the alignment layer. Before IB irradiation, strong van der Waals interactions between the TiO_2 layer and LC molecules induce random alignment. Energy from the uniform high-density plasma induced by IB irradiation affects the interactions between the TiO_2 layer and LC molecules. Weak van der Waals interactions result in vertical alignment due to the maximization of the molecular interaction between LC molecules.

Figure 3 shows the measured pretilt angle as a function of exposure time. Pretilt angles were measured by the crystal rotation method (TBA 107 tilt-bias angle evaluation device, Autronic). Under different IB irradiation times, fixed 1.8 keV IB energy and incident angle of 45°, the pretilt angles of the TiO_2 layer for exposure times of 1, 2 and 3 min were 0.10°,

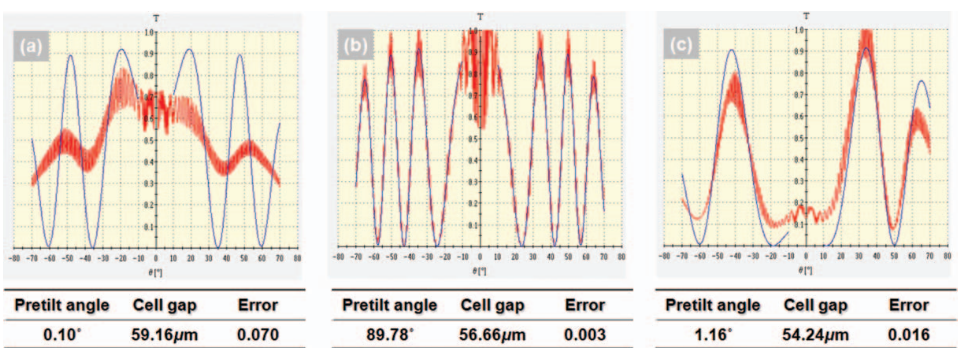

Figure 2. Pretilt angles on the TiO_2 film for an incident energy of 1.8 keV and an angle of 45° IB irradiated for (a) 1 (b) 2 and (c) 3 min.

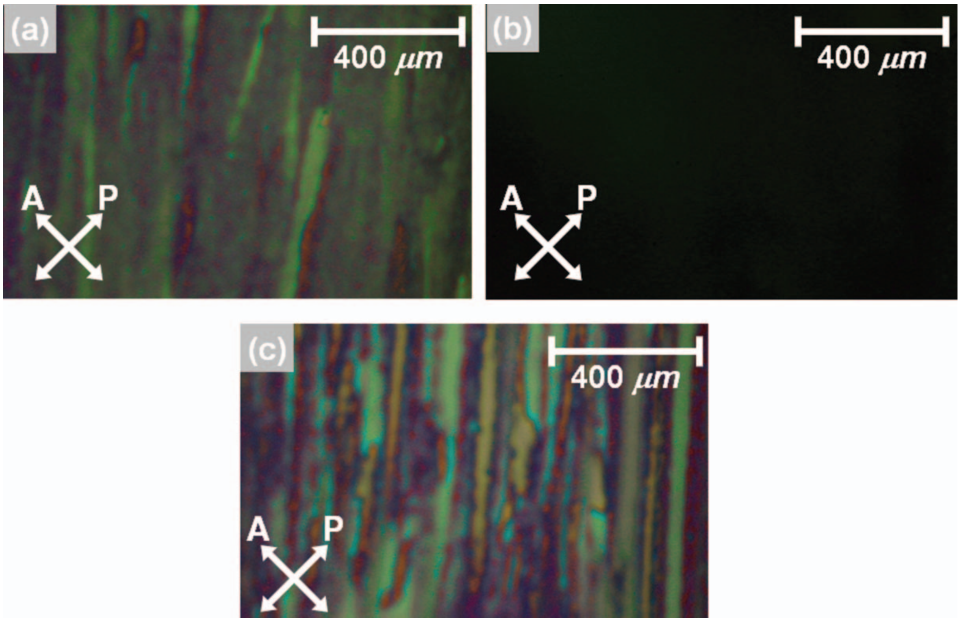

Figure 3. Polarized optical microscopy (POM) images of the observed LC cells as a function of (a) 1 (b) 2 and (c) 3 min irradiation.

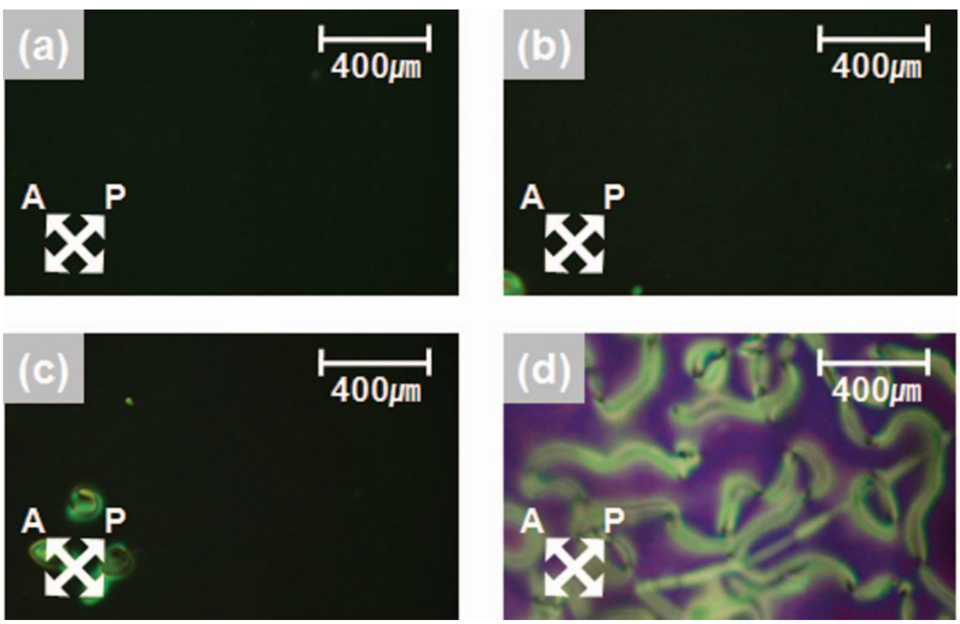

Figure 4. Thermal stabilities of LC alignment under high temperatures. Annealing temperatures were (a) 90, (b) 120, (c) 15, and (d) 180°C.

89.78° and 1.16°, respectively. The IB irradiated TiO_2 displayed a vertical alignment only when irradiated for 2 min.

Figure 4 shows the results of reliability and stability tests of the LC alignment under harsh conditions, such as high temperatures. The TiO_2 layers were irradiated with 1.8 keV for 2 min at an incident angle of 45°, then the fabricated LC cell was annealed for 30 min on a 90°C, 120 °C, 150°C and 180°C hotplate and observed by photomicroscopy. The LC cell maintained a stable aligned state until 120 °C of the thermal stress test. However, 150°C showed an unstable state of LC orientation as shown in Figure 4(c) and cracking was observed at 180 C in Figure 4(d). Surface reformation of TiO_2 thin film by IB irradiation leads to the anchoring of LC molecules. Low thermal stability of LCs on TiO_2 compared with polyimide film indicates that an LC cell fabricated with inorganic materials may have a low anchoring energy. Although LCs deteriorated when exposed to high temperatures, they remained within a sufficient range for advanced LCDs.

Conclusions

Titanium dioxide with high purity and fine uniform particles offers excellent optical properties, high refraction indexes and water dispersibility. A TiO_2 thin film was irradiated and the IB irradiation time was controlled. Irradiated TiO_2 layers were applied to the LC alignment layer. IB exposure time affected vertical alignment and therefore performance. POM images of LCs produced with various irradiation times indicated that 2 min of exposure to a fixed IB energy of 1.8 KeV led to sufficient surface reformation of the TiO_2 for the production of a suitable alignment layer. In addition, the weak anchoring energies of LC molecules on IB irradiated TiO_2 was ascertained by its thermal stability at low temperatures.

Acknowledgment

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