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Alignment of liquid crystal molecules on solution-derived zinc-tin-oxide films via ion beam irradiation

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HIGHLIGHTS

- ZTO alignment films were deposited by a solution process on ITO-coated glass.
- Uniform and homogeneous LC alignment was achieved on the IB-irradiated ZTO surface.
- Oxidation of ZTO films was confirmed using FESEM and XPS analysis.
- Enhanced EO characteristics of ECB cells based on ZTO films were achieved.

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ABSTRACT

We present the characteristics of annealing temperature-dependent, zinc-tin-oxide (ZTO) films deposited by a solution process for application in liquid crystal displays (LCDs). ZTO surfaces supported homogeneously-aligned liquid crystal (LC) molecules based on an ion beam irradiation system. Uniform LC alignment and a precise pretilt angle were obtained at an annealing temperature greater than 300 °C. The oxidation of ZTO films was confirmed using field-emission-scanning electron microscopy and X-ray photoelectron spectroscopy. The electro-optical characteristics of electrically controlled birefringence (ECB) cells based on the ZTO films were superior to those based on polyimide. Especially, IB-irradiated ZTO films exhibited superior performance with respect to response time. This result indicates that this approach will allow for the fabrication of advanced LCDs with high performance.

1. Introduction

Liquid crystal (LC) alignment is one of the most important techniques for LC applications and thus, studies have been consistently and intensively investigated. The conventional method is the rubbing process; however, it is accompanied by several drawbacks, such as accumulation of electrostatic charges, local defects, and the generation of debris, which is caused by mechanical contact between the fabric and film surface [1,2]. To overcome the disadvantages of conventional rubbed polyimide (PI), non-contact methods have been investigated for LC alignment including ultraviolet exposure [3–5], a nanocrystalline-induced self-alignment method [6,7], a wrinkle-induced nano-logging method [8], and ion-beam (IB) irradiation [1,2,9–14]. IB irradiation has especially attracted interest due to its controllability and reliability for LC applications, and application to oxide films. Because oxide films have diverse advantages for LC applications with electro-optical performance, such as a reduced threshold voltage, fast response of LC molecules, and hysteresis free characteristics, oxide films have recently attracted attention as candidate materials for LC cells based on conventional rubbed PI using IB irradiation. In addition, by using the solution process, the fabrication of thin oxide films including compound oxide materials can be achieved easily and cost effectively [15].

Zinc-tin-oxide (ZTO) from a solution process is a representative compound oxide material for semiconductor materials. Because

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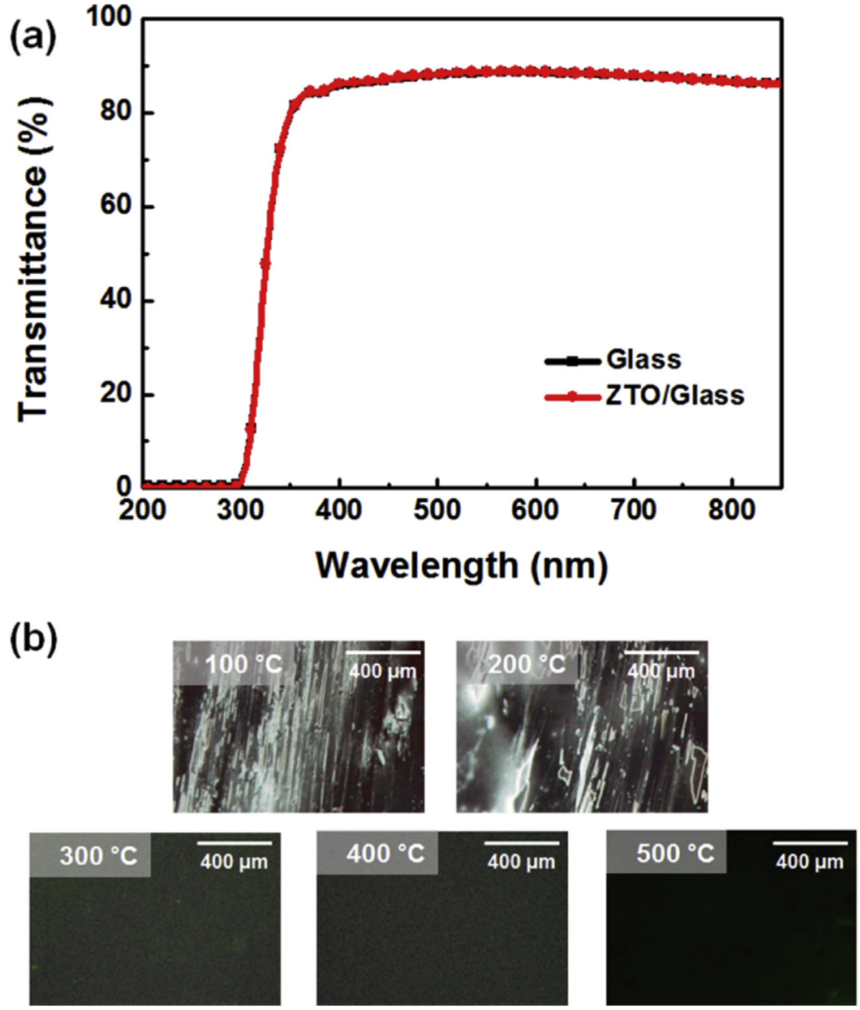

Fig. 1. (a) UV–Vis transmittance spectra of the solution-derived ZTO film and (b) Photomicrographs of LC cells based on ZTO films fabricated at various annealing temperatures. “A” denotes “analyzer” and “P” denotes “polarizer”.

ZTO is composed of heavy-metal cations with large radii, the energy band is dispersed by overlap between the adjacent orbitals, leading to a wide band gap (3.5 eV) that is associated with good transparency [16–18]. Moreover, ZTO film is well known for its chemical and physical durability. Therefore, thin films have been used for semiconductors without a passivation layer. In addition, ZTO film is characterized by a smooth surface morphology with a root-mean-square (RMS) roughness of less than 5 nm that is suitable for LC alignment in the range of 1–8 nm. These attractive attributes of ZTO films are expected to be useful as an LC alignment layer.

In this study, we demonstrate applicable LC devices exhibiting effective switching performance of LC molecules on IB-irradiated ZTO films. Stable homogeneous LC alignment on IB-irradiated ZTO films was achieved by adjusting the annealing temperature. To confirm the alignment property, polarized optical microscope (POM) analysis and the crystal rotation method were conducted. X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM) were used to elucidate the mechanism of LC alignment on the thin films. The electro-optical properties of the electrically-controlled birefringence (ECB) cells were measured to confirm the switching performance of LC molecules on the IB-irradiated ZTO films.

2. Experimental

ZTO films were prepared by a solution method. A 0.1 M ZTO solution was prepared for the alignment layer by dissolving zinc acetate dihydrate [$Zn(CH_3COO)_2 \cdot 2H_2O$] and tin(II) chloride [$SnCl_2$] in a solvent of 2-methoxyethanol (2 ME). A few drops of acetic acid and mono-ethanolamine (MEA) were added for stability and homogeneity of the composite solution. The solution was stirred at 75 °C for 3 h using a hot plate with a magnetic stirrer. The obtained homogeneous solution was aged for 1 day at room temperature. Indium-tin-oxide (ITO)-coated glass was used as the substrate. Prior to deposition of the ZTO films on the substrate, the ITO-glass substrates were subject to a typical cleaning process of electronic devices. The substrate was cleaned using ultrasonic vibration with acetone, methanol, and deionized water for 10 min each and then dried with N_2 gas. The prepared ZTO solution was spin-coated on the cleaned substrate, where the spin rate was 3000 rpm and the time duration was 30 s. The coated substrate was prebaked at 100 °C for 10 min and then annealed at 100, 200, 300, 400, and 500 °C for 1 h on a hot plate.

A Duo PI Gatron ion beam system was used for IB irradiation. The ZTO film on the substrate was exposed to Ar^+ IB plasma at various intensities of 1700 eV for 2 min. Using a Faraday cup system, the current density of the IB of positively-charged particles was