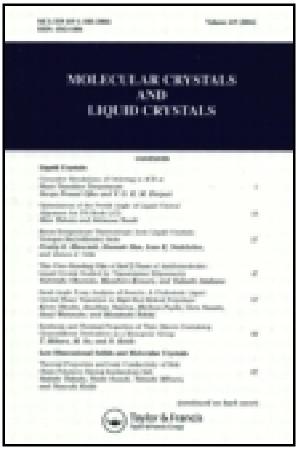

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Vertical Alignment of Liquid Crystal on a-SiON Thin Film Exposed by Ion Beam

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We study the properties of the vertical alignment of liquid crystal on amorphous SiON (a-SiON) thin film exposed by ion beam. a-SiON thin films are deposited on the indium-tin-oxide coated glass substrates by using radio-frequency magnetron sputtering system in the temperature range from 25 to 400°C. The transmittance and surface roughness of a-SiON thin films are enhanced with the increase in deposition temperature. After the substrates were deposited by sputtering system, we exposed them to ion beam and fabricated vertical alignment liquid crystal cells. As a result, the fabricated liquid crystal cells show uniform pretilt angle range from 88 to 89° and high thermal stability over 100°C for 20 hours.

Keywords: ion beam; liquid crystal display; SiON; vertical alignment

INTRODUCTION

Liquid crystal (LC) alignment is an important issue in fabricating liquid crystal displays (LCDs). LC alignment method can be classified into two categories: one is contact method and the other is non-contact method. Rubbing is the most widely used contact method [1]. Although rubbing method has advantages such as simplicity of process, reliability of LC alignment, it also has problems such as the generation of electrostatic charges on the thin film transistor (TFT),

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debris and scratches. Thus, the non-contact methods such as the oblique evaporation [2,3], photo-alignment [4,5], and ion beam alignment method [6–9] have been proposed to solve the drawback of rubbing method. However, oblique evaporation and photo alignment have disadvantage respectively such as non-uniformity in large-size substrate, weak anchoring energy and low thermal stability. The ion-beam alignment method has attracted a fair amount of attention such as uniformity in large-size substrate, strong anchoring energy and high thermal stability.

Recently, several inorganic materials such as diamond like carbon, SiO_x, SiN_x and SiC have been proposed as candidates of LC alignment layer by using ion-beam exposure [10–11]. Among them, SiN_x film is used in the TFT-LCDs industry as an insulator. In the TFT-LCDs industry, after SiN_x is deposited on TFT as an insulator layer, polyimide coated on SiN_x layer or etched SiN_x layer can be used for the alignment of LC molecules. If LC molecules are aligned on SiN_x film, several processes such as etching of SiN_x film, coating and rubbing of polyimide layer can be removed.

However, in our preliminary test, LC molecules were not aligned on SiNx film vertically. On the contrary, LC molecules were aligned vertically on SiON film that was obtained by flowing oxygen gas in the chamber during the deposition process. The resistivity and transmittance of SiON film was similar to SiN_x Fim. Hence, SiON film can be used as an insulator layer and alignment layer in TFT LCD.

In this paper, we deposited SiON films on indium tin oxide (ITO) coated glass substrates with the variation of deposition temperature and time and studied the properties of the vertical alignment of LC on a-SiON thin films exposed by ion beam.

EXPERIMENTS

Part 1: The Property of SiON Thin Films Deposited in Various Deposition Temperature

SiON thin films were deposited on ITO coated glass substrates by using RF-magnetron sputtering system. Figure 1 shows the schematic diagram of the sputtering system used for the experiments.

The initial and working pressure of the vacuum chamber were 5×10^{-6} and 1×10^{-2} torr, respectively. The sputtering gun is fixed at an angle of 60° from the glass substrate. We rotated the substrate with a rotational velocity of 13 rpm for uniform deposition. The flow velocity of the argon and oxygen gas in the chamber during the

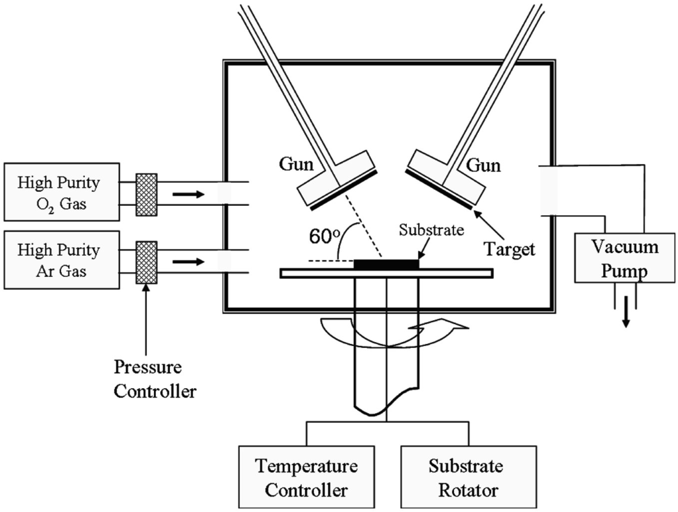

FIGURE 1 Schematic diagram of a RF-magnetron sputtering system.

deposition was 50 and 5 sccm, respectively. The working pressure was controlled by high quality argon gas (99.999%) and oxygen gas (99.999%). In order to verify the dependency of the transmittance and morphology of the film on temperature, the deposition temperature was varied from 25 to 400°C. The thickness of SiON thin films was uniformly controlled to 50 nm, which was independent to the deposition temperature.

Part 2: Vertical Alignment of LC Molecules and Optical Property of Fabricated Cells Using Ion-Beam Method

After SiON films were deposited on the substrates, we exposed ion-beam on SiON film surface for uniform vertical alignment of LC molecules. The ion-beam source was a cold hollow cathode type with Ar+ ions as an ion source. Figure 2 shows ion-beam exposure system. We controlled ion-beam power, exposure time, exposure angle, and distance between ion-beam source and SiON film. After ion-beam was exposed on SiON film surface, we fabricated test cells and checked vertical alignment state and stability. We optimized ion-beam parameters for uniform vertical alignment of LC molecules. Vertically aligned LC cells with a cell gap of 4.2 μm were fabricated with a negative LC material (MLC-6608, $\Delta n = 0.083$, $\Delta\varepsilon = -4.2$, Merck).

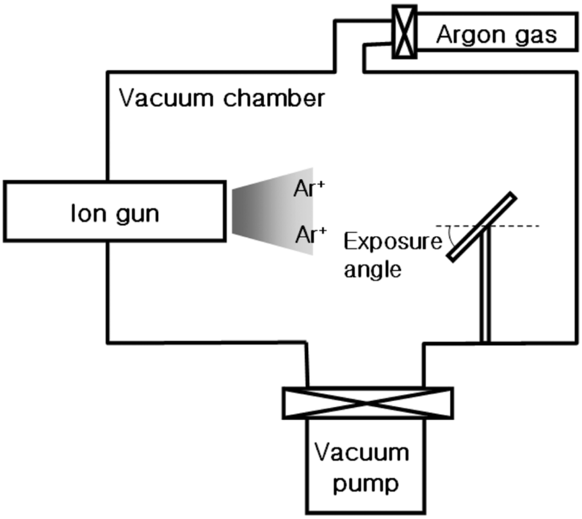

FIGURE 2 The ion-beam exposure system.

RESULT

Part 1: The Property of SiON Thin Films Deposited in Various Deposition Temperature

In LCDs industry, the transmittance of alignment layer is important because transmission rate was related with low power consumption. In general, it has been reported that inorganic thin film has lower transmittance than organic one. Especially, SiO_x thin film, which is one of the most being studied inorganic alignment materials of LCDs, has the disadvantage that the transmittance of SiO_x thin film was reduced compared with polyimide [12]. We measured the transmittance of SiON thin film deposited in various temperature and compared with SiO_x thin film. Figure 3 shows the measured spectral transmittance of SiO_x and SiON. The transmittance of SiON thin film was increased by 1.3 and 4.3% at 25 and 400°C, respectively, compared to that of SiO_x. The transmittance of SiON thin film was also enhanced with the increase in deposition temperature. This experimental result was the same that the transmittance of several inorganic thin films could be enhanced with the increase in deposition temperature [12,14].

We measured the surface morphology and structure to find the reason why the transmittance of the SiON films was enhanced with the increase in deposition temperature. The crystal structure of the

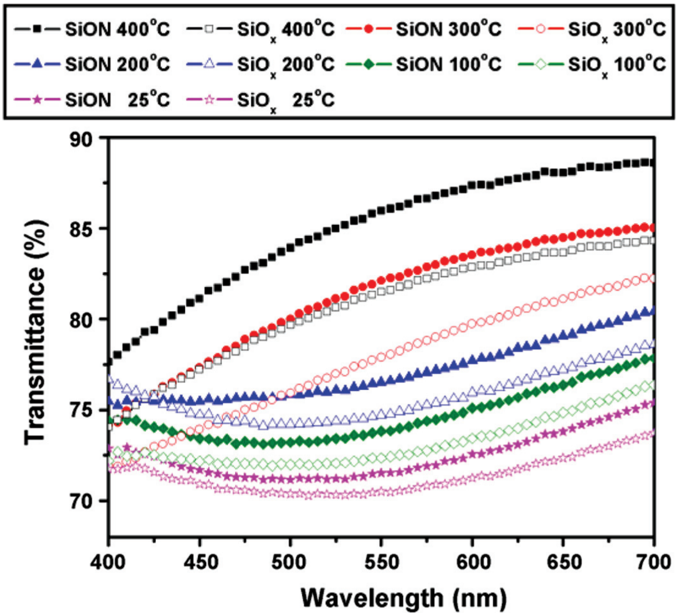

FIGURE 3 Spectral transmittance of SiON and SiOx thin films for various deposition temperature.

SiON films was investigated with x-ray diffraction (XRD, Bruker D8 Advance with a Lyuxeye, Cu $\lambda = 1.54056$ Å). The surface morphology of the films was measured by atomic force microscopy (AFM, SEIKO SPA 400) using a non-contact mode. Figure 4 shows the AFM image and surface roughness of SiON films. As shown in Figure 4, the roughness of the SiON film surface was decreased and the grain size was increased with the increase in deposition temperature. The grain size

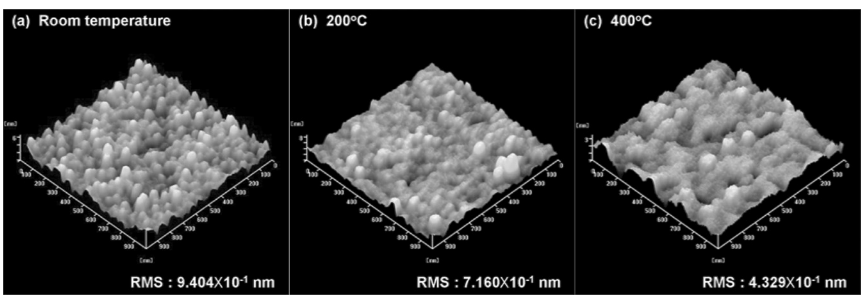

FIGURE 4 AFM image of SiON thins film for various deposition temperature.

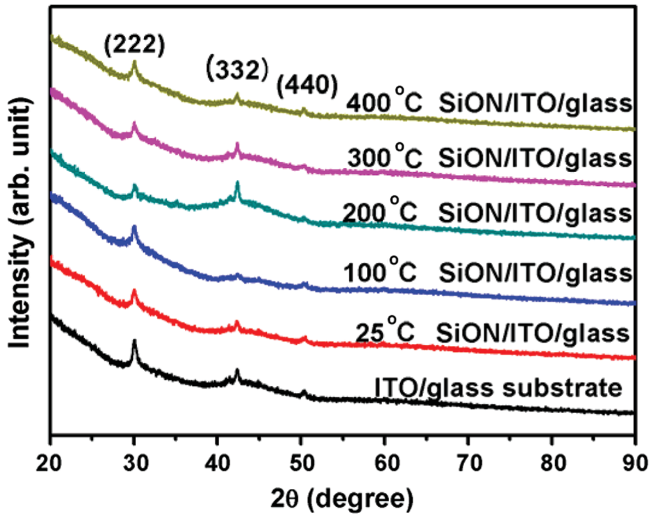

FIGURE 5 XRD data of SiON thin film for various deposition temperature.

of several inorganic thin films could also be increased with the increase in deposition temperature [15,16].

However, we observed that the thin films were not crystallized at low temperature as well as high temperature as shown in Figure 5. Figure 5 shows the XRD data of SiON thin films for various deposition temperature. As shown in Figure 5, we could not observe SiON peaks, but In_2O_3 peaks [17,18], which means that SiON thin films are amorphous. Although the surface roughness and transmittance of the SiON thin films were enhanced with the increase in deposition temperature, the SiON thin films were not crystallized. Therefore, the reason of the enhancement of the transmittance is the increase in grain size and the decrease in surface roughness.

Part 2: Vertical Alignment of LC Molecules and Optical Property of Fabricated Cells Using Ion-Beam Method

After we deposited a-SiON films on substrates with RF-magnetron sputtering, we exposed ion-beam on the a-SiON films with optimized ion beam exposure parameters for uniform vertical alignment of LC molecules. The ion-beam energy, the incident angle, current density of ions and exposure time were 60 eV, 80°, $1 \sim 5 \times 10^{13}$ ions/s·cm^2 and 1 s, respectively.

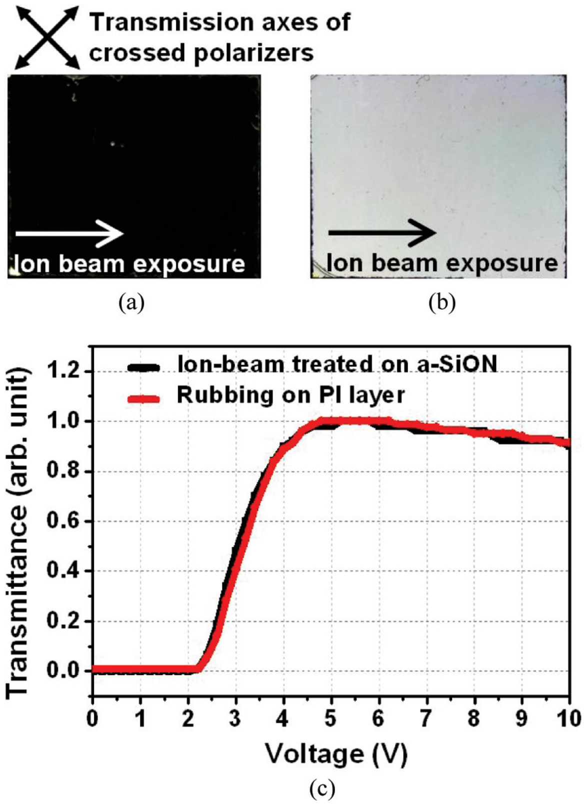

FIGURE 6 Vertically aligned LC cell between crossed polarizers in the applied voltage off (a) and on (b) states, and its electro-optic characteristics (c).

In a vertically aligned LC cell, the negative LC (N-LC) molecule is aligned perpendicular to the substrates of the cell. An electric field can be applied to reorient the LC molecules in the cell. Figure 6(a) and 6(b) show the cell placed in between crossed polarizers in the field-off and on states, respectively. The optic axis of the N-LC cell is oriented at 45° relative to the transmission axes of the crossed polarizers. As shown in Figure 6(a), in the field-off state, the N-LC molecules align vertically on the substrates and we can observe a dark state. As shown in Figure 6(b), in the field-on state of 5 V, the N-LC molecules align parallel to the substrates and we can observe a bright state. Figure 6(c) shows the measured electro-optic characteristics as a function of applied voltage for the ion-beam exposed cell made of SiON

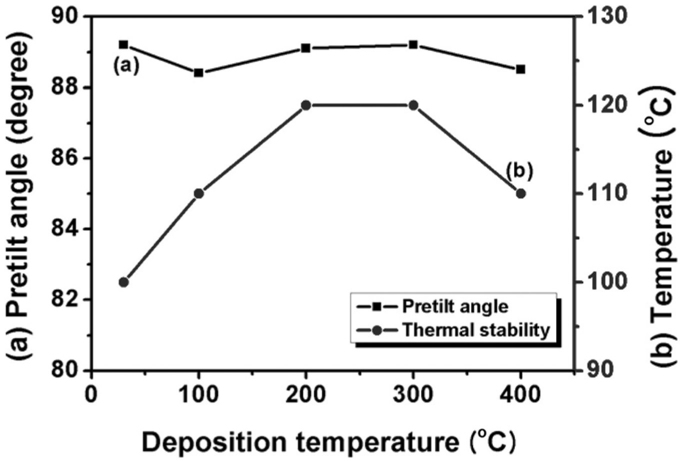

FIGURE 7 Pretilt angle and thermal stability dependence on deposition temperature of SiON thin films.

film and the cell made of vertical polyimide. As shown in Figure 6(c), the electro-optic characteristics are the similar. The threshold voltage was 2.2 V. As we know from Figure 6, the optic axis of the N-LC molecules is parallel to the direction of the ion beam exposure. This indicates that the N-LC molecules are aligned parallel to the ion beam exposure direction.

Figure 7 shows the pretilt angles and thermal stability of the fabricated cells for various deposition temperature. The pretilt angles were measured by the crystal rotation method. All of the test cells have high pretilt angle ranging from 88 to 89°. This indicates that the N-LC molecules align vertically and uniformly. In our experiment, the thermal stability of LC cell is measured by observing the maximum temperature where the pretilt angle of the cell can recover to its own pretilt angle after 20 hour thermal treatment. The LC cells were stable in the temperature ranges of 100 to 120°C for 20 hours. With this criteria, the maximum stability of LC cell is about 120°C for 20 hours at the deposition temperature range of 200 to 300°C.

CONCLUSIONS

We studied the properties of the vertical alignment of LC molecules aligned on a-SiON thin film alignment layer exposed by ion beam. We deposited SiON thin film on ITO coated glass substrates by RF-magnetron sputtering system. The deposition temperature was varied from 25 to 400°C and the deposited SiON thin films were amorphous. The transmittance of SiON thin film was increased 1.3 and 4.3% at 25 and 400°C compared to that of SiOx. The transmittance and surface roughness of SiON thin film was enhanced with the increase in deposition temperature. After the substrates were deposited by sputtering, we exposed them to ion beam with optimized parameters for vertical alignment of LC molecules and fabricated vertically aligned LC cells. The measured pretilt angles of the fabricated cells were 88 to 89° and the thermal stability of 100–120°C for 20 hours was obtained. Therefore, a-SiON alignment layer can provide high pretilt angle which is necessary for vertical alignment of LC molecules and high thermal stability over 100°C.

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