Vertical alignment of liquid crystal on a-SiO_x film by using Ar^+ beam

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Abstract

We demonstrate the vertical alignment of liquid crystal on a-SiO_x film surface using the ion beam exposure. Liquid crystal can be aligned vertically by the rotational oblique evaporation of a-SiO_x film. However, the electro-optic switching behavior of liquid crystal along random directions results in disclination lines. We found that we can achieve highly uniform alignment of liquid crystal without disclination lines by using the ion beam exposure. We found from XRD and XPS data that the vertical alignment can be achieved when x approaches 1.5 at the a-SiO_x film surface. We have shown that the pretilt angle can be controlled by changing ion beam parameters, such as the ion beam energy, the angle of incidence, and the exposure time. We found that whether liquid crystals can be aligned vertically or homogeneously on a-SiO_x film can be predicted simply by measuring the change in optical transmittance by deposition of a-SiO_x thin film layers. We also have shown that a liquid crystal cell aligned vertically by the ion beam exposure exhibits the voltage-transmittance curve similar to that of a rubbed polyimide cell.

1. Introduction and experimental

The rubbing process for the nematic liquid crystal alignment[1] has many problems, such as the lack of controllability and the difficulty in achieving multi-domain structure. Various alignment techniques have been proposed as potential replacements of the rubbing method, such as the oblique evaporation[2-11] and ion beam alignment method.[12, 13] Ion beam exposure was applied to align liquid crystals on deposited inorganic materials. P. Chaudhari *et al.* reported electro-optical switching behavior of a liquid crystal cell aligned by the ion beam exposure on the diamond-like-carbon thin film surfaces.[12] Maximum values of the pretilt angle generated by the ion beam exposure were smaller than 10°. However, vertical alignment of liquid crystals by the ion beam exposure on an inorganic material has not been demonstrated yet.

In this paper, we propose a new technique for the vertical alignment of liquid crystal on a-SiO_x thin film surfaces by the ion beam exposure. To demonstrate the applicability of the ion beam alignment method to the fabrication of vertically-aligned (VA) liquid crystal displays (LCDs), we have shown that the pretilt angle of a VA cell can be controlled by changing the ion-beam conditions, such as the ion beam energy, the angle of incidence, and the exposure time. The ion-beam alignment can be used to form multi-domain structure in a VA cell as well. We examined a-SiO_x thin film surfaces before and after the ion beam exposure by using X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) experiments. To evaluate the performance of the proposed alignment technique, optical switching characteristics of a VA cell fabricated by using the ion beam exposure are compared with that fabricated by using the rubbing method.

We deposited a-SiO_x films on indium-tin-oxide (ITO)-coated glass substrates by using a RF-magnetron sputtering system. Base pressure of the deposition chamber was around 10^{-6} Torr, while the working process pressure was around 10^{-2} Torr. Pure argon (purity: 99.99%) was used as the inert gas in the chamber. Films with thicknesses ranging from 20 nm to 300 nm were deposited at temperatures ranging from 30°C to 300°C. A cold hollow cathode (CHC) type[13] was used as the source of Ar^+ ions to yield the ion beam. After the substrates were exposed to an ion beam, VA liquid crystal cells with the cell-gap of 3.8 μm were fabricated with a negative liquid crystal 'Merck MLC-6608.'[14, 15]

2. Results

Figure 1 shows images of vertical aligned liquid crystal cells between crossed polarizers without and with the ion beam exposure. Ion beam energy, the incident angle, current density, and exposure time were 60 eV, 80°, 3.12×10^{13} $Ar^+/s\cdot cm^2$, and 10 s, respectively. Without the ion beam exposure, liquid crystal molecules can be aligned vertically. However, upon applying an electric field to a cell, non-uniform alignment and disclination lines can be observed. On the other hand, with the ion beam exposure, we can achieve uniformity in switching behavior upon applying an electric field.

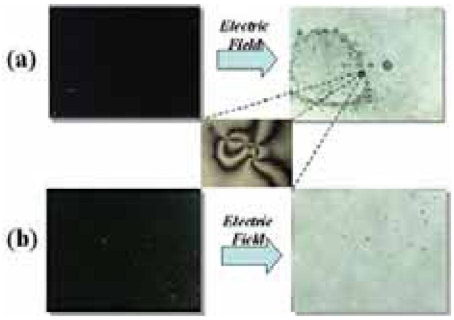

Fig. 1. Images of vertically aligned liquid crystal cells between crossed polarizers (a) without and (b) with the ion beam exposure on a-SiO_x film surfaces.

M. Ohgawara et al. reported that liquid crystal molecules can be aligned on the surfaces of a-SiO_2 thin films homogeneously.[16] However, we found that a-SiO_x thin films deposited at a temperature between 60°C and 120°C can align liquid crystal molecules vertically, while those deposited at a temperature lower than 60°C or higher than 120°C align them homogeneously. We examined a-SiO_x thin film surfaces before and after the ion beam exposure by using XRD and XPS experiments.

As shown in Fig. 2, XRD data of a-SiO_x thin films deposited at 100°C for the vertical alignment is quite different from those of a-SiO_x thin films deposited at 200°C for the homogeneous alignment. Films deposited at 100°C for the vertical alignment show spectral peaks corresponding to a-SiO_2, a-SiO, and p-Si, while films deposited at 200°C for the homogeneous alignment show the typical spectrum of a-SiO_2 together with a weak peak of p-Si. In other words, the film surface for the vertical alignment consists of a-SiO_2, a-SiO, and p-Si, while the film surface for the homogeneous alignment mainly consists of a-SiO_2. We also measured the XRD data after the ion beam exposure on a-SiO_x thin film surfaces, which remained the same after the ion beam exposure. In other words, the effect of the ion beam exposure cannot be observed by the XRD experiments.

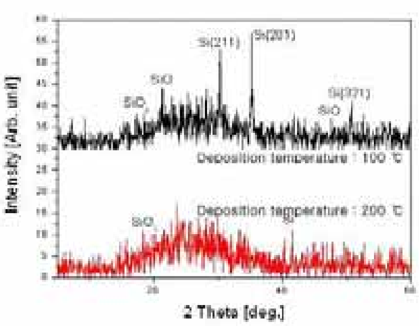

Fig. 2. XRD data of a-SiO_x films desposited at 100°C and 200°C.

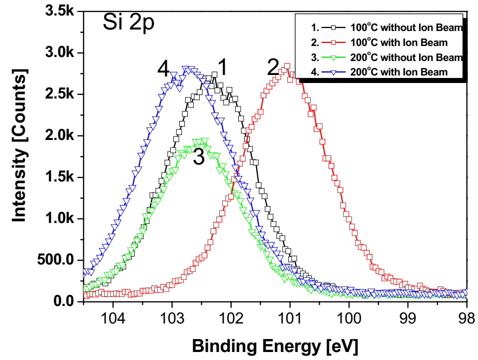

Fig. 3. XPS data of a-SiO_x films. (1) deposited at 100°C, before the ion beam exposure, (2) deposited at 100°C, after the ion beam exposure (3) deposited 200°C, before the ion beam exposure (4) deposited at 200°C, after the ion beam exposure.

To observe the effect of the ion beam exposure on a-SiO_x thin film surfaces, we did XPS experiments. XPS data show the coordination of Si and O atoms near the surface. In general, binding energy peaks of a-SiO_2 and Si in XPS data can be observed approximately at 103.4 eV and 99 eV, respectively, while that of a-SiO can be observed between 101 eV and 102 eV. Si 2p XPS data taken from a-SiO_x thin films before and after the ion beam exposure are shown in Fig. 3. They show us that the energy peak of a film deposited at 100°C for the vertical alignment is nearer to the peak of a-SiO than that of a film deposited at 200°C for the homogeneous alignment. It is consistent with the XRD data. The energy peak in a film deposited at 100°C for the vertical alignment shifts to the peak of a-SiO at 101 eV by the ion beam exposure, while that of films deposited at 200°C for the homogeneous alignment remains almost the same after the ion beam exposure. Although there are many parameters that affect the liquid crystal alignment, XRD and XPS data show us that the vertical alignment can be achieved when x approaches 1.5 at the a-SiO_x film surface, while homogeneous alignment can be achieved when x approaches 2.

Pretilt angles of fabricated liquid crystal cells were measured by the crystal rotation method.[17] Figure 4(a) shows the measured pretilt angles of liquid crystal cells aligned vertically by using the ion beam exposure on a-SiO_x thin film surfaces, as a function of the incident angle of the ion beam. The ion beam energy and the ion beam exposure time were 60 eV and 10 s, respectively. The maximum value of the pretilt angle changes with the increase of the exposure time and the ion beam energy. Maximum pretilt angle was about 89.1° at the incident angle of 80° and the ion beam energy of 60 eV, as shown in Fig. 4(b). Figure 4(c)

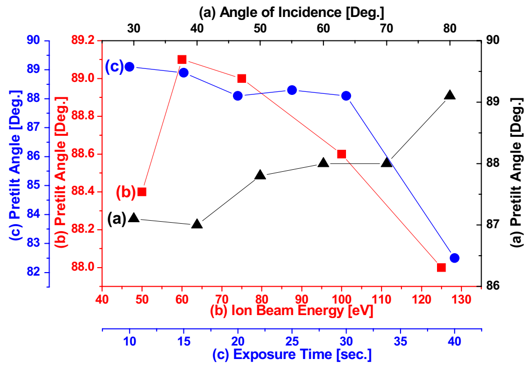

Fig. 4. Measured pretilt angles of ion beam aligned VA cells as a function of (a) the incident angle, (b) the ion beam energy, and (c) the exposure time.

shows the changes of the pretilt angle as a function of the exposure time when the ion beam energy (60 eV) and the incident angle (80°) were held constant. It is clear that any desired pretilt angle between 83° and 89° can be obtained by varying the exposure time, the incident angle, and the ion beam energy. The results indicate that the pretilt angle can be controlled by changing conditions of the ion beam.

Figure 5 shows the transmission of light as a function of the applied voltage in liquid crystal cells aligned vertically by the ion beam exposure on a-SiO_x thin films. The incident angle, the energy, and the exposure time of the ion beam were 80°, 60 eV, and 10 s, respectively. The result with the conventional rubbing alignment on the polyimide is also shown for comparison. The voltage-transmittance curve of an ion beam aligned cell is similar to that of a rubbed polyimide cell. The saturation voltage of an ion beam aligned cell is lower than that of a rubbing aligned cell. We also measured the thermal stability of an ion-beam-aligned VA cell, which showed stable behavior up to 120°C.

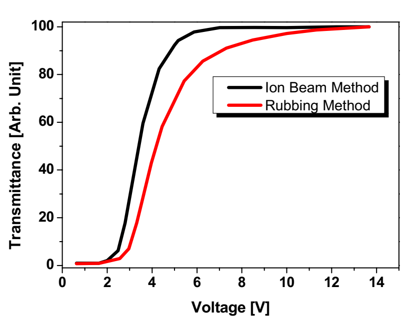

Fig. 5. V-T curve of a liquid crystal cell aligned vertically by the ion beam exposure on a-SiO_x thin film surface. V-T curve of a rubbed VA cell on polyimide surfaces is also shown for comparison.

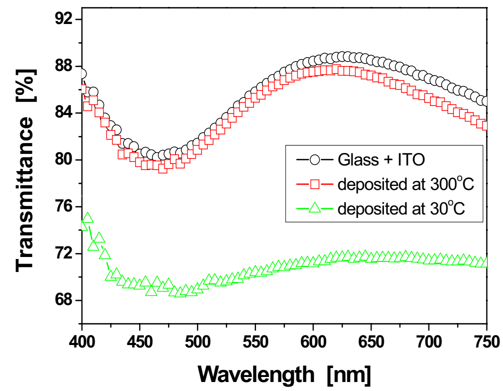

Fig. 6. Transmission spectra of deposited a-SiO_x film with the deposition temperature as a parameter.

In general, the transmittance of a-SiO_x film depends on the annealing temperature and oxygen contents [18, 19]. Figure 6 shows the transmission spectra of a-SiO_x film deposited on ITO-coated glass substrates at 30°C and 300°C (d = 10 cm). Optical transmittance of a-SiO_x film deposited at the temperature 30°C was about 13% lower than that of a substrate before deposition. On the other hand, optical transmittance of a-SiO_x film deposited at the temperature of 300°C remains almost the same as that of a substrate before deposition. Films deposited at a low-temperature (30°C) exhibit lower transmission over the visible wavelengths due to the increase in carrier concentrations during the deposition. Deposition at a low temperature decreases transmittance because of XRD peaks corresponding to a-SiO_2, a-SiO, and p-Si. Generally, deposition at a high temperature shows high transmittance due to the typical spectrum of a-SiO_2 together with a weak peak of p-Si. Therefore, we expect that low transmittance films deposited at a low temperature (30°C) can align liquid crystal molecules vertically, while high transmittance films deposited at a high temperature (300°C) can align liquid crystal molecules homogeneously. When d = 8 cm, we found that the lower transmittance of a-SiO_x film was independent of the deposition temperature (30°C ~ 300°C), as expected from XRD data, because all samples have similar XRD data irrespective of the deposition temperature. Thus, we can expect that all samples deposited with d = 8 cm can be used for the vertical alignment. We can conclude that film used for the vertical alignment shows a decrease in transmittance caused by the deposited SiO_x layer, while film used for the homogenous alignment shows a high value of transmittance almost the same as substrates before deposition. Therefore, vertical or homogeneous alignment of liquid crystals can be predicted simply by measuring the changes in optical transmittance by deposition of a-SiO_x thin films.

3. Conclusion

In conclusion, we have demonstrated a new method for vertical alignment of liquid crystal molecules by the ion beam exposure on a-SiO_x thin film surfaces as a non-contact alignment process. Although there are many parameters that affect the liquid crystal alignment, XRD and XPS data show us that the vertical alignment can be achieved when x approaches 1.5 at the a-SiO_x film surface, while homogeneous alignment can be achieved when x approaches 2. We can obtain any favorable pretilt angle by changing the incident angle, the ion beam energy, and the exposure time. We found that the voltage-transmittance curve of an ion beam aligned cell is similar to that of a rubbed polyimide cell. Liquid crystals can be aligned vertically if any of the following observations can be made from a-SiO_x film surfaces: the change in optical transmittance of substrates by deposition of the a-SiO_x film layer is observed. On the contrary, liquid crystals can be aligned homogeneously if the optical transmittance remains almost the same after deposition of the a-SiO_x layer. We believe that the ion beam alignment on inorganic thin film surfaces can be applied successfully to the fabrication of LCDs with large size, especially for applications to high performance LCD TVs. The ion beam alignment can be applied to form the multi-domain structure in VA cells as well.

4. Acknowledgements

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5. References

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