Basic Properties of Cell Fabricated by Ion-beam Treatment for In-plane Switching LCD

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Abstract

We investigated the horizontal alignment properties such as surface morphology, pretilt angle, and polar and azimuthal anchoring energy of organic alignment material-coated surface treated by ion beam. In this investigation the energy and incident angle of ion beam were changed. We also fabricated an in-plane switching (IPS) cell by ion beam alignment. The results showed similar voltage-transmittance characteristics to those of a rubbed cell and better dark state.

Keywords : ion beam, AFM, rubbing, IPS, pretilt angle, anchoring energy

1. Introduction

Liquid crystal (LC) molecule is aligned by inducing anisotropy on the surface of a substrate. There are several techniques to introduce anisotropy on the surface: rubbing [1], stretching polymer [3], langmuir-Blodgett film [4], oblique angle deposition of SiO_X [5], and polarized UV radiation of polymer films [6]. Amongthem, The most generally used technique is the rubbing method because of its high productivity. However, this technique has some disadvantages [7]. Which include the debris left by the cloth during the rubbing process, electrostatic discharge that can influence the electronic circuitry just below the surface of the rubbed polyimide, and non-uniform alignment direction at small size pixel and large size panel for high image quality. To solve these problems, a non-contact alignment method would be highly desirable for future generations of large and high-resolution liquid crystal displays. Since the introduction of the alignment technique by ion beam by IBM [8,9], research activities have been conducted for its practical application to liquid crystal display (LCD) [10-13].

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A low energy beam of ions is used to bombard the surface of polyimide film. The advantages of ion beam induced alignment over the other techniques are (i) non-contact alignment. (ii) a low energy beam which ensures that only the surface layers are effected so that the number of radicals induced by broken bonds, for example under UV radiation is minimum, and, this prevents charge from building up when a voltage is applied across a liquid crystal cell, and (iii) a large area of uniform and parallel beams can be readily obtained. This is a problem with oblique deposition of SiO_X. Lastly, (iv) ion beams are already familiar to the electronics manufacturing community and are compatible with a clean room environment [7].

In order to optimize the display performance, first, it is important to know which properties of the surface modified by ion beam parameters induce aligning characters. Second, it is necessary to be able to control the basic alignment properties by ion beam parameters such as ion beam energy, incident angle, and incident time, suitable for each mode of LCDs.

In this paper, we measured the change of polyimide surface conditions by AFM (atomic force microscopy) in varying ion beam conditions. The characteristics of unit LC cells fabricated by ion beam such as microscopy photograph, pretilt angle, polar and azimuthal anchoring energy, and voltage holding ratio were compared with that manufactured by the rubbing method. The results show that ion beam is good for homogeneous alignment of LC, especially, IPS mode because of good uniformity and low pretilt angle. The contrast ratio of IPS mode is still too low for television application because of the light leakage at dark state due to the scratches in rubbing process. Low pretilt angle is strongly recommended for viewing angle symmetry and reducing light leakage.

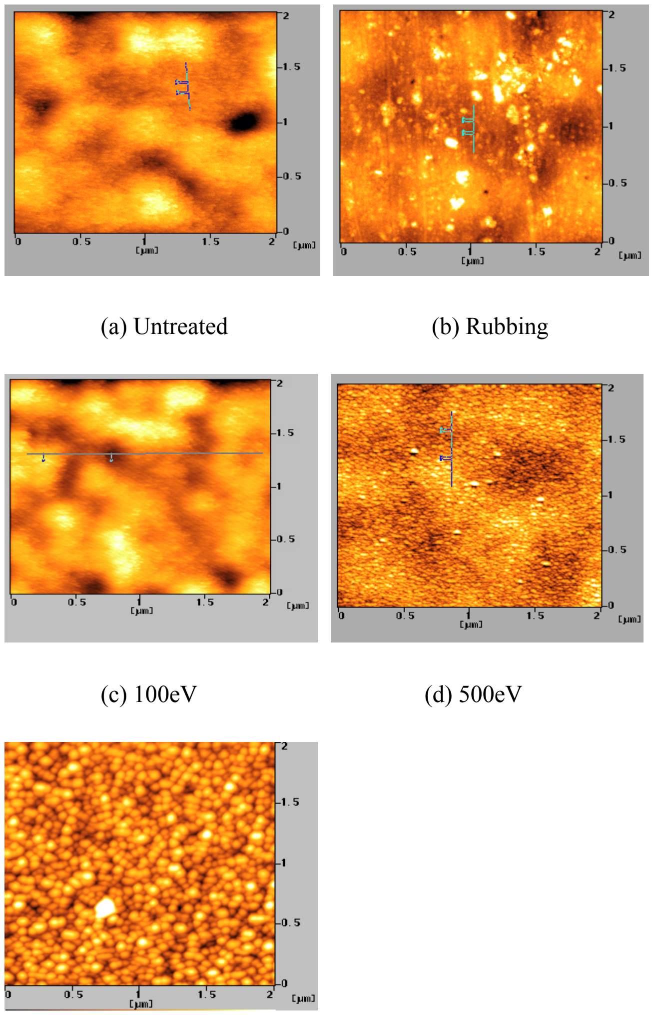
2. Experiments

The cells were prepared for the experiment. Indium-Tin-Oxide (ITO) coated on glass substrates were used as electrodes for all of the cells. The substrates were spun coated with polyimide RN-1702 as the alignment material, pre-baked at 80 ℃ for 10 minutes, and cured at 250 ℃ for 2 hours. Then, the substrates were bombarded by a low energy argon ion beam. A cold hollow cathode (CHC) type was used as an ion source to yield ion beam. Initial vacuum and ion beam operation vacuum were 10^{-6} and 10^{-4} torr respectively. Argon gas flow was 7sccm. The ion beam current density was between 25 $\mu A/s^2$ and 100 $\mu A/s^2$. And expose time was 40 s. In our experiment, we changed the ion beam energy (100 eV, 400 eV, 500 eV, 1000 eV) and incident angle (15 °, 30 °, 45 °). We used 3.65 μm spacer for cell gap control and ML-0223 for liquid crystal. We made three cells for each ion beam parameter and measured their properties.

3. Results and Discussion

3.1 Surface morphology

Fig. 1 shows the AFM images for (a) non-treated, (b) rubbing-treated and (c)-(e) ion beam-treated polyimide (RN-1702, Nissan) surface, respectively. Ion beam incident angle was 30 °. The beam energy was (c) 100 eV, (d) 500 eV and (e) 1000 eV. The ion beam-treated one was more uniform than the rubbing-treated one. Rubbing-treated surface was damaged by the scratching with rubbing cloth but ion beam treated one did not show any no serious damages. Fig. 2 shows the measured roughness of the surface by various alignment methods. The roughness of ion beam-treated surface was found to have increased by strong ion beam energy and high incident angle, because the higher incident angle and the stronger energy we treat the surface, the more impact power is transmitted on it.



(a) Untreated (b) Rubbing

(c) 100eV (d) 500eV

(e) 1000eV

Fig. 1. Surface images by AFM

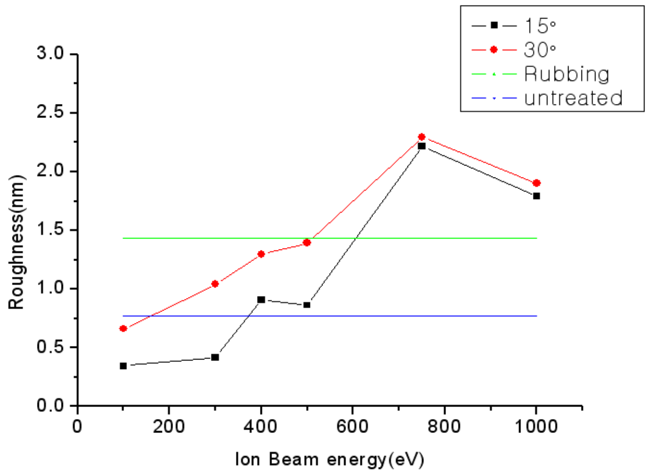


Fig. 2. Surface roughness by ion beam energy and incident angle.

3.2 Microscopy photograph of fabricated LC cell

Fig. 3 shows the microscopy photographs of fabricated LC cells deigned for the configuration of λ/2 retardation, anti-parallel aligned and in normally dark state, in cross polarizer. We applied some voltage to show the easily aligned state. There are some scratches and non uniform alignment in rubbing method (see Fig. 3(a)). However, ion beam aligned cell has good uniformity at the energy where the roughness of ion beam treated surface is greater than that of rubbing.

3.3 Pretilt angle

We measured the pretitlt angles of rubbing and ion beam-aligned cells by the crystal rotation method. The pretilt angle was measured for a nematic liquid crystal cell, when the cell was rotated around the midpoint of the cell the retardation Θ(β) of light passing through the cell. This can be expressed by the following equation.

$$\Phi(\beta) = \frac{2\pi}{\lambda} d\, f(\alpha, \beta) \tag{1}$$

where *d* is the cell gap of the liquid crystal cell, λ is the wavelength of the incident radiation, and *f*(α, β) is a function of the pretilt angle α and the rotation angle β. β is defined as the angle between the incident light beam and the direction normal to the cell. *f*(α, β) is expressed as follows.

$$\begin{aligned} f(\alpha, \beta) &= \frac{1}{c^2}(a^2 - b^2)\ \sin\alpha\cos\alpha\sin\beta \\ &\quad + \frac{1}{c}\left(1 - \frac{a^2b^2}{c^2}\sin^2\beta\right)^{1/2} - \frac{1}{b}\left(1 - b^2\sin^2\beta\right)^{1/2} \\ a &= \frac{1}{n_e}, \quad b = \frac{1}{n_o}, \\ c^2 &= a^2\cos^2\alpha + b^2\sin^2\alpha\ , \end{aligned} \tag{2}$$

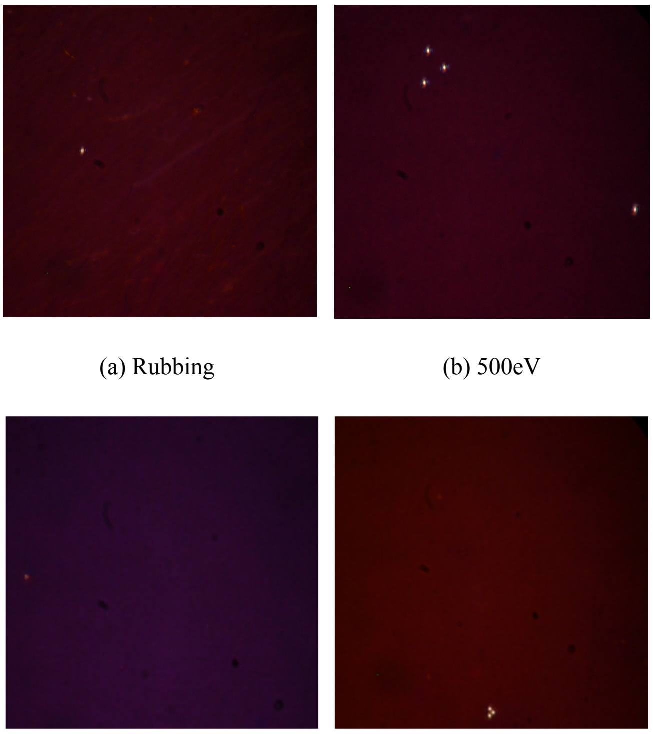
where n_o and n_e are the ordinary and extraordinary refractive indices of nematic liquid crystal, respectively. That transmission of light through this uniaxial section placed between the cross polarizers and oriented with its principal plane at 45° with respect to the plane of polarized light is given by

$$\begin{aligned} \mathrm{T}(\beta) &= \frac{1}{2}\sin^2(\ \Theta(\beta)). \\ \Theta(\beta) &= \frac{1}{2}\Phi(\beta), \end{aligned} \tag{3}$$

We measured the transmittance and the retardation as a function of the incident angle by using eqs. (1) and (2). For an angle β_x where the retardation $\Theta(\beta_x)$ becomes a maximum, transmittance $T(\beta_x)$ is maximum. An implicit relationship between α and β_x is obtained by differentiating eq. (2) with respect to β and equating the result to zero.

$$\begin{aligned} &\frac{1}{c^2}(a^2 - b^2)\ \sin\alpha\cos\alpha \\ &-\frac{a^2b^2}{c^3}\left(1 - \frac{a^2b^2}{c^2}\sin^2\beta_x\right)^{-1/2}\sin\beta_x \\ &+b\left(1 - b^2\sin^2\beta_x\right)^{-1/2}\sin\beta_x = 0. \end{aligned} \tag{4}$$

Fig. 4 shows the pretilt angle of ion beam aligned cell, which is coated by (a) RN-1702 polyimide (Nissan) and (b) PIA-5310 polyimide (Chisso). Both polyimides are



(a) Rubbing (b) 500eV

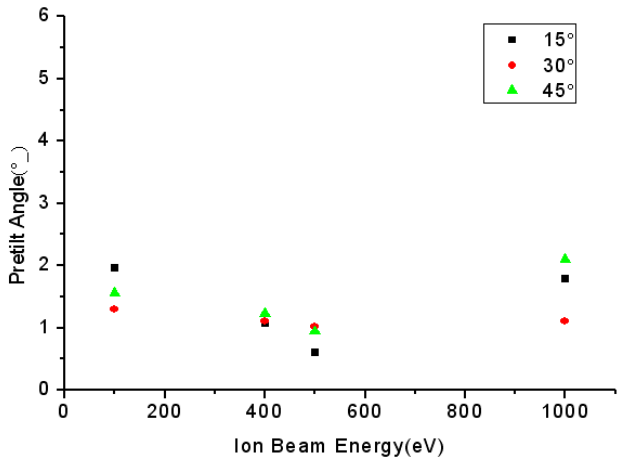
(c) 750eV (d) 1000eV

Fig. 3. Microscopy photograph of fabricated LC cells.

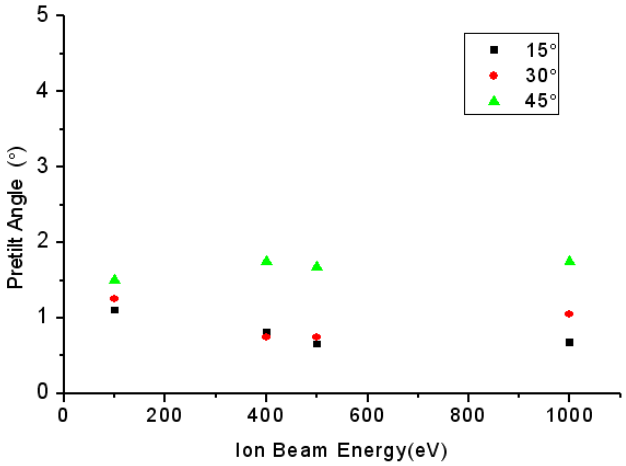
commercially used for IPS. Their pretilt angle range in rubbing alignment is between 1.5 ° and 2.0 °. The pretilt angle of the ion beam-aligned cell is similar to or lower than that of rubbing. In the IPS mode, low pretilt angle is needed to obtain high contrast ratio because pretilt angle makes director profile asymmetrical leading to light leakage. So in the IPS mode, the lower the pretilt angle is, the better the contrast ratio will be.

3.4 Polar and azimuthal anchoring energy

Polar anchoring was measured by using the saturation voltage method [14] and the azimuthal anchoring energy by[15]. Fig. 5 shows the measured anchoring energy. (Figs. 5(a) and (b)) show the polar anchoring energy for RN-1702 and PIA-5310 respectively. (Figs. 5(c) and (d)) show the



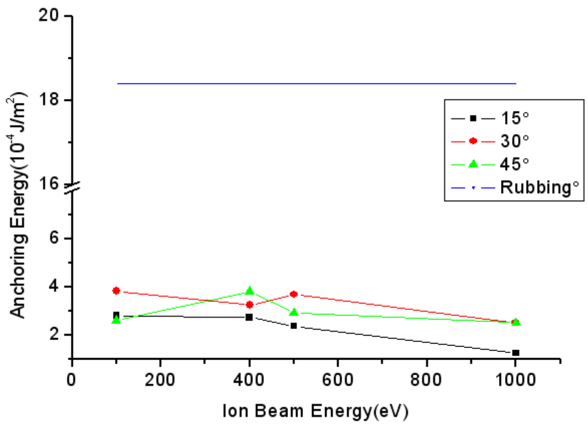
(a) RN- 1702 polyimide



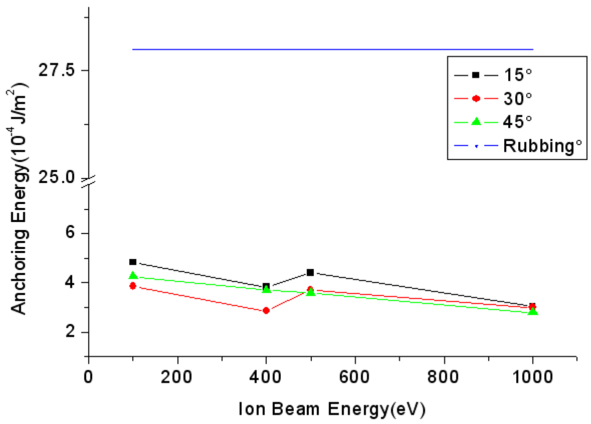
(b) PIA-5310 polyimide

Fig. 4. Pretilt angle measured by the crystal rotation method.

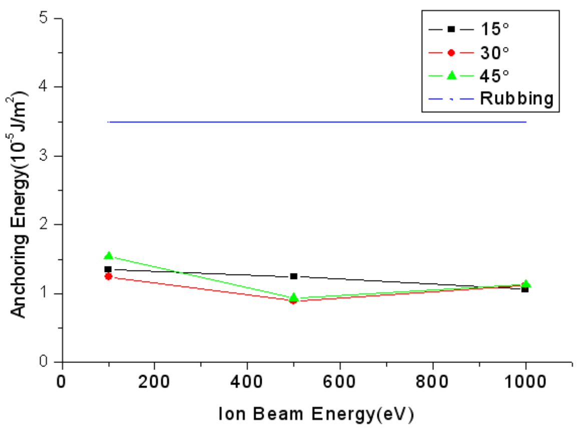
azimuthal anchoring energy. The dashed line in each figure represent the energy of the rubbing. A can be seen that the polar anchoring energy of the ion beam alignment is lower than the energy of rubbing by ten to four times. The energies of rubbing and ion beam alignment is strong and



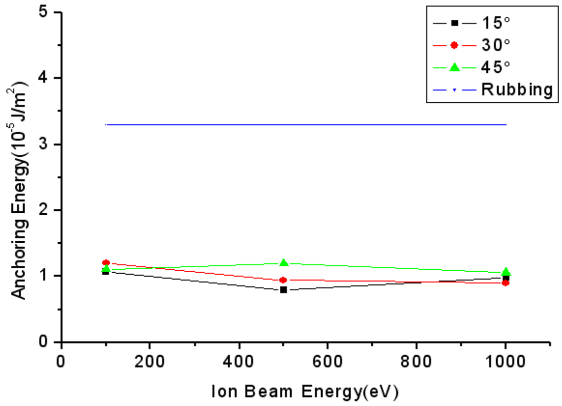
(a) Polar anchoring energy for RN-1702



(b) Polar anchoring energy for PIA-5310

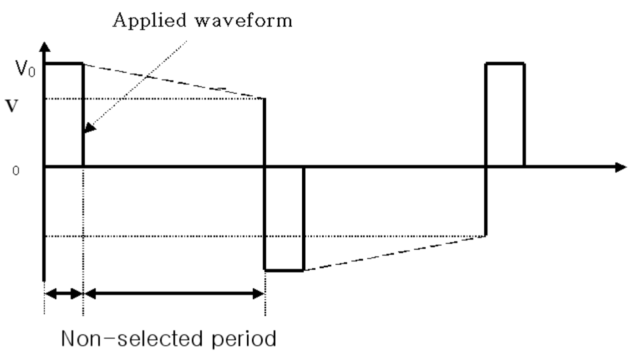


(c) Azimuthal anchoring energy for RN-1702

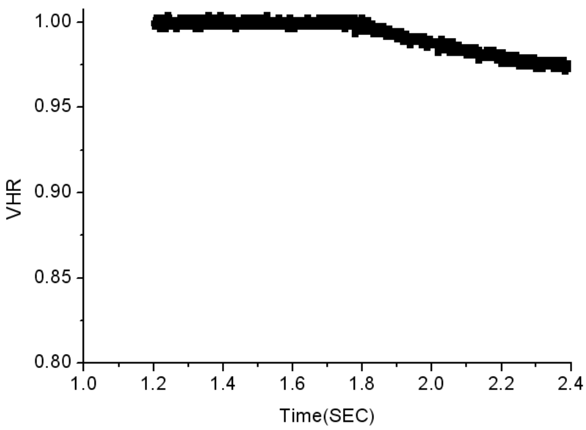


(d) Azimuthal anchoring energy for PIA-5310

Fig. 5. Anchoring energy of rubbing and ion beam aligned.



(a) Applied voltage waveform



(b) Voltage holding ratio of ion beam-treated cell

Fig. 6. Voltage holding ratio measurement.

medium anchoring regimes respectively. However, for azimuthal anchoring energy both are medium anchoring

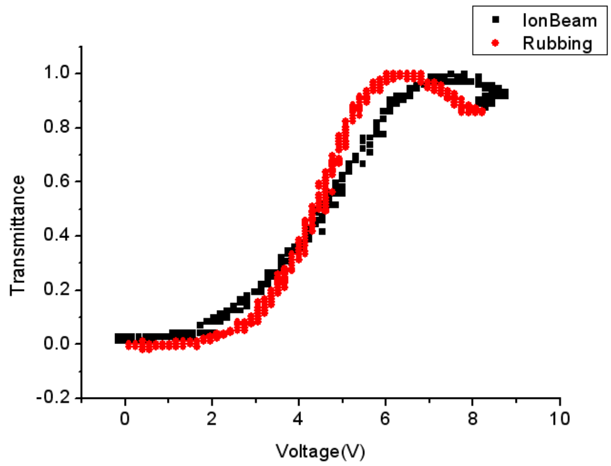


Fig. 7. Voltage-transmittance measurement.

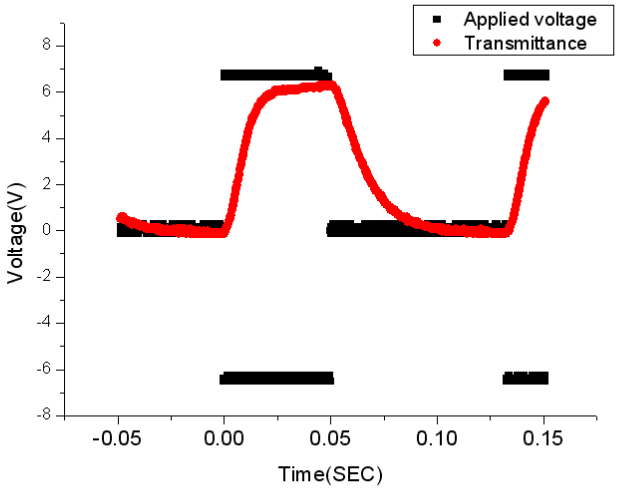
energy regime. This anchoring energy affects response time. Basically, the response time of each ion beam-aligned cell is as good as rubbing-aligned cell and so we think the energy of ion beam alignment is sufficient for LCD.

3.5 Voltage holding ratio

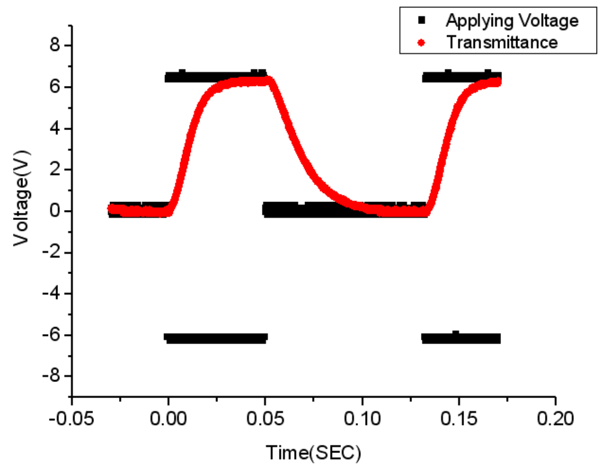
We measured the voltage holding ratio of ion beam treated LC cell to check the applicability of the ion beam alignment method to TFT (Thin Film Transistor) LCD. Fig. 6(a) shows the applied voltage waveform for selected period (v_0) and the maintained the voltage for non selected period (v). We measured the voltage holding ratio with the transmittance method. Fig. 6(b) shows the measured data of voltage holding ratio of the cell fabricated by ion beam. Its transmittance is decayed in the non selection period. The voltage holding ratio of all the cells aligned by ion beam is over 98 %. This is similar to the results of the cell made by rubbing.

3.6 IPS cell fabricated by ion beam alignment

We made several IPS cells of which the electrode had a width of 3 um, and distance of 5 um. The alignment methods were ion beam (500 eV, 30 °) and rubbing. The cell gap was 4.85 um and 3.85 um. Polyimide, PIA-5310, was used as shown in Fig. 7, the V-T curve of ion beam alignment is as good as rubbing. Especially, the relaxation times of ion beam and rubbing are both 29 ms for the cell gap of 4.85 um and 18.8 ms and 17.8 ms for the cell gap of 3.85 um. The response time is more dependent on cell gap than that of alignment method. In addition, Fig. 9 shows a good dark state of ion beam alignment in IPS cell (a), but

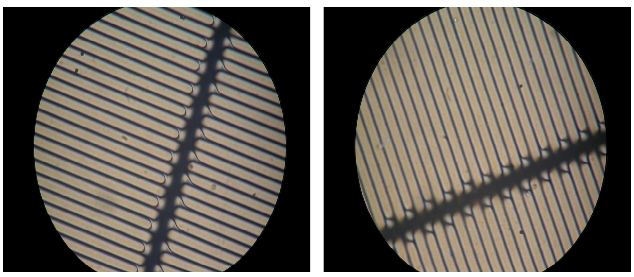


(a) Ion Beam-aligned IPS cell



(b) rubbing-aligned IPS cell

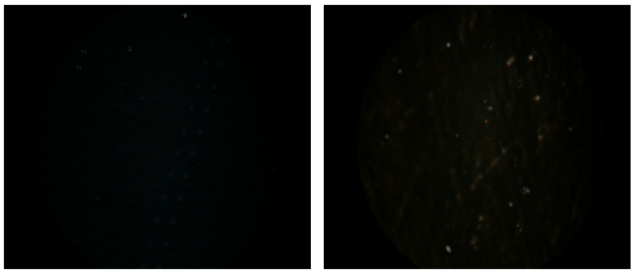
Fig. 8. Relaxation time measurement.



(a) Ion Beam-aligned IPS cell (b) rubbing-aligned IPS cell

Fig. 9. Bright state of IPS cell.

rubbing is worse than ion beam alignment even though there is no difference in bright state, as shown in Fig. 8.



(a) Ion Beam-aligned IPS cell (b) rubbing-aligned IPS cell

Fig. 10. Dark state of IPS cell.

4. Conclusion

We investigated the basic properties of ion beam alignment and applied to IPS cell. Ion beam alignment method was found to have better aligning properties than rubbing method. Futhermore, voltage-transmission and response characteristics of ion beam-treated cells were found to be as good as the cells fabricated by rubbing. These results show that the ion beam alignment method is a good candidate for IPS LCD.

References

[1] X. Y. Gong, T. Yamaguchi, H. Kan, T. Makino, T. Iida, T.Kato, M. Aoyama, Y. Hayakawa, and M. Kumagawa, *Jpn. J. Appl. Phys*. **36,** 2614 (1997).

[2] D. Gallet and G. Hollinger, *Appl. Phys. Lett*. **62,** 982 (1993).

[3] Y. Fukuda, Y. Suzuki, N. Sanada, S. Sasaki, and T. Ohsawa, *J. Appl. Phys*. **76,** 3059 (1994).

[4] P. S. Dutta, K. S. Sangunni, H. L. Bhat, and V. Kunar, *Appl. Phys. Lett*. **65** , 1695 (1994).

[5] X. Y. Gong, T. Yamaguchi, H. Kan, T. Makino, K.Ohshimo, M. Aoyama, M. Kumagawa, N. L. Rowell, and R. Rinfret, *Appl. Surf. Sci*. **113/114**, 388 (1997).

[6] Y. Fukuda, Y. Suzuki, N. Sanada, S. Shimomura, and S. Masuda, *Phys. Rev. B*, **56** ,1084 (1997).

[7] J. S. Gwag0, C. G. Jhun, G.-D. Lee, S. J. Cho, J. C. Kim, and T.-H Yoon, *J. Appl. Phys*. **96**, 257 (2004).

[8] P. Chaudhari *et. al, Jpn. J. Appl. Phys*. **37**, L55 (1998).

[9] P. Chaudhari *et. al*, *Nature*, **411,** 56 (2001).

[10] J. L. West and L. Su, *et. al*, in *Society for Information Display* (2002), p. 1102.

[11] J. S. Gwag, in *International Meeting on Information Display* (2002), p. 409.

[12] D-S. Seo, in *International Meeting on Information Display* (2002), p. 508.

[13] J. S. Gwag and K.-H., Park, *et. al*, *Jpn. J. Appl. Phys*. **42**, 468 (2000).
[14] A. Sugimura and T. Miyamoto *Appl. Phys. Lett.* **72** (3) (1998).
[15] Joao G. Fonseca and Yves Galerne, *Appl. Phys. Lett.* **79** (18) (2001).