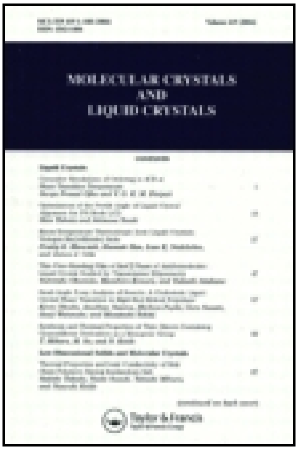

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Tilted Homeotropic Alignment of Liquid-Crystal Molecules Using the Rubbing Method

H. Seki [a], Y. Masuda [a], Y. Itoh [b] & T. Uchida [c]

[a] Department of Electrical Engineering, Faculty of Engineering, Hachinohe Institute of Technology, 88-1, Aza-Ohbiraki, Ohaza-Myoh, Hachinohe, Aomori, 037, Japan

[b] JES Co., Ltd., 794-1, Aza-Hirusawa, Nakano, Kanazawa, Yokote, Akita, 019-13, Japan

[c] Department of Electronics Engineering, Faculty of Engineering, Tohoku University, Aza-Aoba, Aramaki, Aoba-Ku, Sendai, Miyagi, 980, Japan

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Tilted Homeotropic Alignment of Liquid-Crystal Molecules Using the Rubbing Method

H. SEKI and Y. MASUDA

Department of Electrical Engineering, Faculty of Engineering, Hachinohe Institute of Technology, 88-1, Aza-Ohbiraki, Ohaza-Myoh, Hachinohe, Aomori 031, Japan

and

Y. ITOH†

†JES Co., Ltd., 794-1, Aza-Hirusawa, Nakano, Kanazawa, Yokote, Akita 019-13, Japan

and

T. UCHIDA‡

‡Department of Electronics Engineering, Faculty of Engineering, Tohoku University, Aza-Aoba, Aramaki, Aoba-Ku, Sendai, Miyagi 980, Japan

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It is well known that slightly tilted homeotropic alignment of liquid-crystal molecules is obtained by oblique evaporation followed by homeotropic treatment. However, this method has disadvantages in obtaining large area uniformity and productivity because of the requirement of large vacuum equipment. In this paper, a new alignment technique of slightly tilted homeotropic alignment using the rubbing method (THR method) is proposed, and its applicability to display devices is discussed.

Keywords: tilted homeotropic alignment, liquid crystals, rubbing method

1. INTRODUCTION

Liquid-crystal display devices have some merits, such as low driving voltage and low power consumption, and are most promising key devices for wide and high-definition flat panel displays of the future. In the conventional devices, homogeneous surface treatment is mainly adopted, and rubbing method is generally used for obtaining the homogeneous alignment. The molecular alignment of nematic liquid crystals has been considered to depend on physicochemical interactions and mechanical interactions related to the surface topology and anisotropic elasticity of liquid-crystal molecules. The former interaction seems to play a dominant role in ordering molecules parallel or perpendicular to the glass surfaces but the latter interactions seems to play a minor role, that is, it determines the orientation of molecules in the case of parallel alignment.[1]

A guest-host cell with a positive pattern display[2] and a electrically controlled birefringence cell use the homeotropic molecular alignment generally. They have poor contrast because of non-uniform alignment under application of a voltage. Therefore, slightly tilted homeotropic alignment is necessary to obtain the homogeneous alignment under application of a voltage.

There are several reports proposing a method of obtaining slightly tilted homeotropic alignment by using oblique evaporation such as rubbing with diamond paste followed by oblique evaporation,[3] ion beam etching followed by homeotropic surface treatment[4] or oblique evaporation followed by homeotropic surface treatment.[5] The authors have already reported the application of this process to the positive-type guest-host cell.[6,7] The cell displays positive patterns, that is, colored patterns on colorless background, unlike the usual cell. This positive pattern display seems to be more useful than the usual negative one in practical use. However, if this method is applied to large-area displays, the evaporation angle changes according to the position of the substrate, which affects the tilt angle, and hence the contrast of the display changes strongly according to the position. Ogawa *et al.* showed that five deposited metal oxide layers followed by rubbing and coating with homeotropic surfactant induces tilted homeotropic alignment.[8]

Considering these results, the authors have investigated the simple molecular alignment method using the rubbing technology to obtain tilted homeotropic alignment in detail. The surface of obliquely-evaporated metal oxide induces homogeneous alignment with small tilt angle. It is also well known that the rubbed surface gives slightly tilted alignment on the homogeneous surfactant. If this alignment is due to the surface anisotropic topology, the rubbed surface is considered to be useful not only for the tilted homogeneous alignment but also for the tilted homeotropic alignment.

Recently, the authors found that liquid crystals align homeotropically with a tilt angle of a few degrees by the homeotropic surface treatment of organic or inorganic substrate after rubbing. This fact implies that this process is effective for the investigation of the surface topology of the substrate. In this paper, a novel tilted homeotropic alignment by the rubbing method (abbreviated as THR method) is proposed and the rubbing effect on the molecular alignment is investigated.

2. EXPERIMENTAL

In order to investigate the effect of rubbing, a cell consisting of a combination of three layers, homeotropic surfactant, undercoated layer and glass substrate, was examined, as shown in Figure 1. The surface coupling agent for homeotropic alignment is N,N-dimetyl-N-octadecyl-3-aminopropyltrimethoxysilyl chloride (DMOAP)[9] marketed under the name of SRX-679 by Toray Silicone Co., Ltd. As the undercoated layers, indium tin oxide, evaporated silicon monoxide, polyvinyl alcohol and coat diffusion source layers were used. Indium tin oxide (In_2O_3) layer on the glass was produced by Matsuzaki Shinku Co., Ltd. Silicon monoxide (SiO)

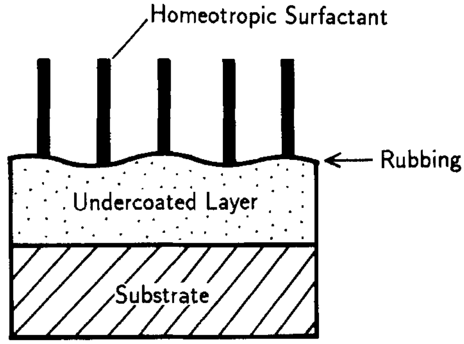

FIGURE 1 Structure of examined cell to obtain tilted homeotropic alignment.

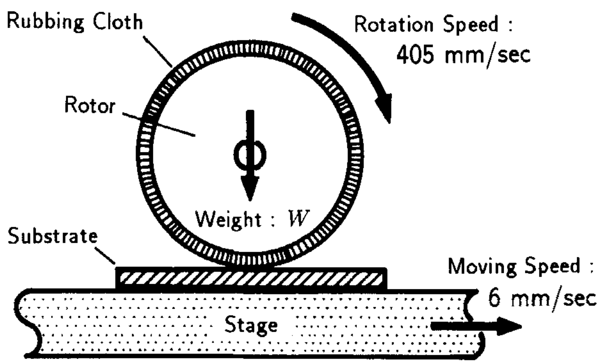

FIGURE 2 Arrangement of rubbing system. Substrate is rubbed by the rubbing cloth at the relative speed 411 mm/sec.

produced by Mitsuwa Pure Chemical Ltd. was evaporated from normal direction of the substrate. Polyvinyl alcohol (PVA) produced by Tokyo Kasei Kogyo Co., Ltd. and OCD Si-8000 (Ohka Coat Diffusion Source) supplied from Tokyo Ohka Kogyo Co., Ltd. were also used. OCD is silicon chemical compound dissolved in organic solvent OCD was spincoated on the glass substrate at 2840 rpm and heated at 200°C for 30 minutes.

The condition for a rubbing apparatus is shown in Figure 2. Weight of rubbing load *W* was measured by a tubular scale and controlled by the weight of metal blocks. A polishing cloth was used for rubbing. The rotor was rotated at a constant speed of 146 rpm, while moving the substrate in one direction with the speed of 405 mm/sec. The contact area of the cloth with the substrate surface was 100 mm × 12 mm. The surface was examined by a scanning electron micrograph (JSM-25SIII, JEOL Ltd.).

The liquid crystal used in the experiment was an N_n-type nematic liquid-crystal mixture EN-38 supplied from Chisso Co., Ltd. which has large negative dielectric anisotropy $\Delta\varepsilon = -7.5$ and a threshold voltage of 1.3V.

3. RESULTS AND DISCUSSION

Figure 3 shows electron micrographs of the surface of the In_2O_3 layer measured by a SEM. The weight of rubbing load was 2.7 kg in this substrate. This picture shows that micro-grooves have been formed along the rubbing direction with separation of some 5 μm to 30 μm on the rubbed surface. It is confirmed that the rubbed surface is deformed strongly. It is easily considerable that the surface in fine region also changes and it affects the alignment of liquid crystals. Then, it is predicted in Figure 1 that the surface without rubbing process produces homeotropic alignment and that with rubbing induces pretilt alignment.

The liquid-crystal orientation can be defined by a tilt angle θ as shown in Figure 4, where the substrate is on the x-y plane. Rubbing was done in the direction of y-axis. The tilt angle θ is defined as the angle between the normal to the substrate (z-axis) and the director of a liquid-crystal molecule. The tilt angle θ was measured by the conoscopic method.

Figure 5 shows the weight of rubbing load dependence of the tilt angle θ on the In_2O_3, evaporated SiO and OCD surfaces. The cumulative number of rubbing was one. It can be seen that the value θ on each surface can be adjusted to arbitrary value between 0 and 10 degrees. This is because that the anisotropic surface structure induced by rubbing inclines the director of liquid crystal from normal of the substrate. In this case, a tilt angle on the mechanically weak surface such as In_2O_3 became larger. OCD is stronger than other surfaces and it is desirable to control

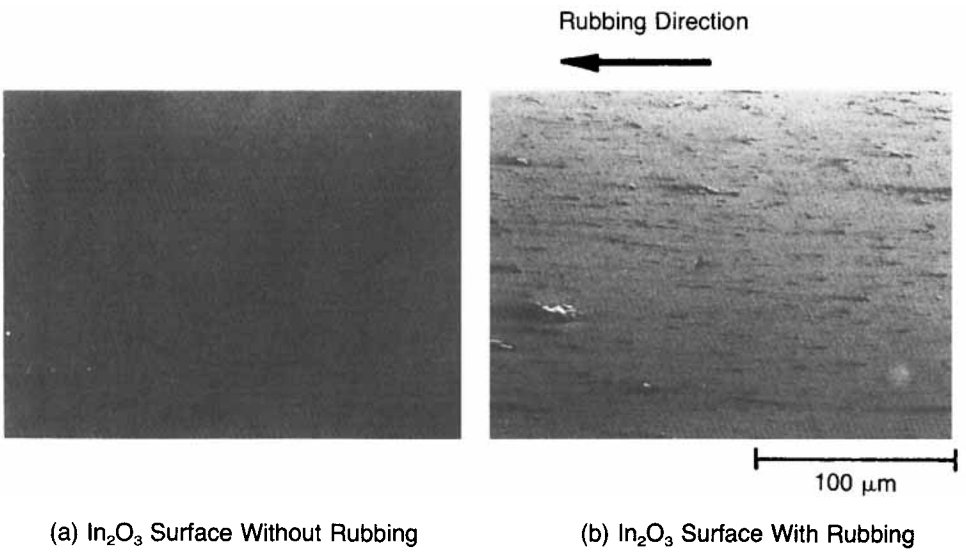

FIGURE 3 SEM observation of the surface on the rubbed In_2O_3 layer. The cumulative number of rubbing is 30.

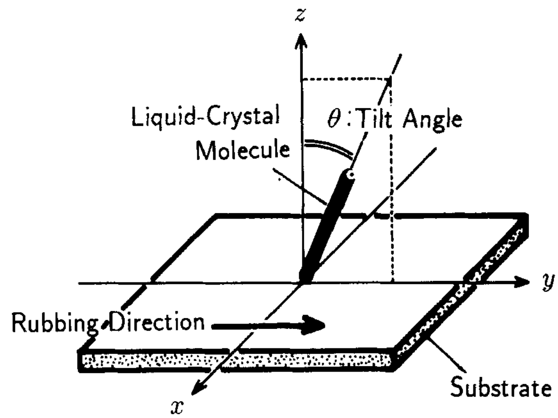

FIGURE 4 Definition of tilt angle θ.

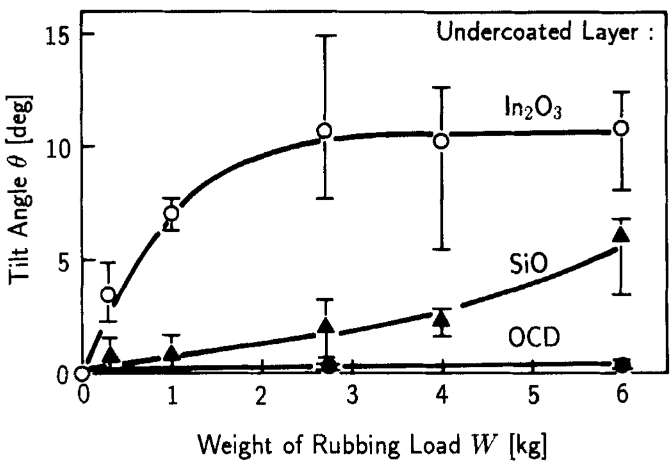

FIGURE 5 Weight of rubbing load dependence of the tilt angle θ on In_2O_3, evaporated SiO and OCD surfaces.

on the small tilt angle. The deviation of the tilt angle originates for the condition of the contact between the rubbing cloth and the undercoated layer.

Nakamura[10] explained the existence of the pretilt angle by assuming a "phonograph record" model where the bottoms of the rubbing grooves are modulated by a asymmetric sawtooth shape having a steep rise followed by a gentle fall in the rubbing direction, presumably generated through unit linkage of microscopic sticking and slipping events. Assuming this model, the homeotropic alignment agents makes liquid-crystal molecules align perpendicular to the surface. As the results, the director inclines according to the surface of substrate and uniform tilt alignment from normal of the microscopic surface of the substrate is generated in the bulk of the liquid crystal as shown in Figure 6.

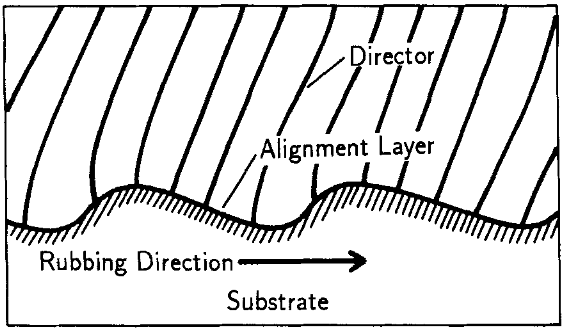

FIGURE 6 Alignment model of liquid-crystal molecule on rubbed surface followed by homeotropic treatment.

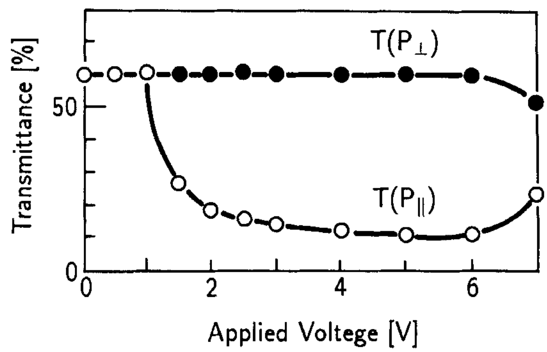

FIGURE 7 Voltage dependence of the transmittance of the THR cell applied to positive type guest-host mode. The surface is rubbed SiO.

4. APPLICATION TO POSITIVE TYPE GUEST-HOST CELL

Figure 7 shows the voltage dependence of the transmittance of the polarized light for the cell with the rubbed SiO layer under the homeotropic surfactant. G355 produced by Nippon Kankoh-Shikiso Kenkyusho Co., Ltd. was used as a guest whose maximum absorption wavelength was 494 nm. In this figure, $T(P_{\parallel})$ and $T(P_{\perp})$ show the properties for the normal incident light whose polarized plane are parallel and perpendicular to the tilt direction of the liquid-crystal molecule, respectively (abbreviated as $P_{\parallel}$ and $P_{\perp}$, respectively). As $T(P_{\perp})$ is independent of voltage, as shown in Figure 7, the direction of the liquid-crystal molecules is found to always be perpendicular to the polarization plane of the incident light, which indicates uniform alignment under application of voltage. The increases of transmittance at higher voltage caused by disturbance by electrohydrodynamic instability.

In the case of the PVA-cell, the transmittance became independent to applied voltage in a few weeks after fabrication.[11] This fact indicates that the direction of the liquid-crystal molecules is always parallel to the substrate. It is considered that the homeotropic surfactant dissolved into the liquid crystal and the rubbed PVA layer becomes bare, and hence the liquid-crystal alignment changes to homoge-

(a) OFF State (b) ON State

FIGURE 8 One example of the THR cells applied to positive-type guest-host mode. In on-state, applied voltage is 3V (100 Hz).

neous. Hence the combination of homeotropic surfactant and undercoated layer is important in the THR method. In the case of In_2O_3, SiO and OCD, the problem of degradation mentioned above was not observed.

One example of application of the THR method is shown in Figure 8, which is a positive-type guest-host color device with one polarizer.[6] The polarizing direction coincides with the rubbing direction. In the off state, no pattern can be seen and uniform alignment is recognized. In the on state, the pattern appears clearly. Hence the director in the voltage-applied region changes uniformly to the rubbing direction.

5. CONCLUSION

In conclusion, it was shown that a new alignment technique of slightly tilted homeotropic alignment using the rubbing method (THR method) is useful for display devices such as positive-type guest-host LCDs, ECB-type LCDs and so on. Tilted homeotropic alignment has recently become important because it is necessary for the positive-type guest-host LCDs and highly multiplexed ECB-type LCDs which is proposed by the name of Super Homeotropic LCDs[12] and Vertically-Aligned-Nematic LCDs.[13] The THR method reported here gives the slightly tilted homeotropic alignment of liquid-crystal molecules. This method does not require the oblique evaporation, and hence it is suitable for large-area display and mass production.

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