Novel Oblique Photoalignment Technique for Multi-Domain Control in VA Cells Filled with Monomer-Doped Nematic LCs

Taiju Takahashi[1], Yukihiro Kudoh[1], Satomi Suzuki[2], Yasuo Toko[2]

ct12326@ns.kogakuin.ac.jp
[1]Dept. of Information and Communication Eng, Kogakuin Univ, 2665-1 Nakano-cho, Hachioji, Tokyo 192-0015, Japan
[2]Stanley Electric Co., Ltd., 400 Soya, Hadano-shi, Kanagawa 257-8555, Japan

Keywords: Photoalignment, Pretilt angle, VA-LCDs, Monomer, Polymer stabilization

ABSTRACT

A nematic LCs doped with an acrylate-based monomer was injected into Vertical Alignment (VA) cells. Oblique UV irradiation for the polymer stabilization to the cell induced a pretilt angle. This method is proposed as a new photoalignment method to pretilt angle control for VA-LCDs. Multi-domain alignment will be realized.

1 Introduction

In general, photoalignment [1-5] in liquid crystal (LC) cells involves inducing some form of anisotropy in the alignment layer by irradiating it with polarized UV light after the alignment film has been formed. After the photoalignment treatment, the cell is assembled and LC material is injected. However, in many cases, it is difficult to generate a pretilt angle using photoalignment methods. For example, in the case of a photo-dissociation-based photoalignment technique, it is necessary to irradiate the alignment layer twice, changing both the direction of illumination and the polarization direction. [6]

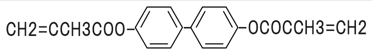
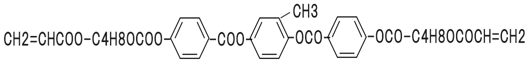
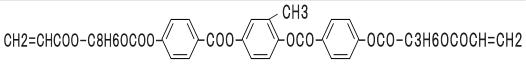
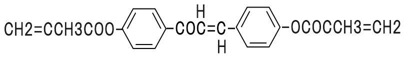
In this study, we propose a photoalignment method that enables pretilt angle control by performing a polymer stabilization process through UV irradiation after LC material injection, using a conventional polyimide-based vertical alignment layer. Specifically, an empty cell is fabricated using a standard polyimide vertical alignment film, which exhibits a perfectly vertical alignment at this stage, with no pretilt angle introduced. In this empty cell, an LC material containing a UV-curable monomer is injected, and collimated UV light is irradiated obliquely onto the LC cell to induce polymer stabilization. Polarized light is not required for this irradiation. Through this process, a small pretilt angle can be introduced from the initial vertical alignment, which is sufficient for driving the cell as a VA-LCD.

2 Experiments

2.1 Types of Monomers Used for Addition

After cleaning the glass substrates, a vertical alignment layer was formed using SE-4811 (4 wt%, Nissan Chemical), and cells with a cell gap of 4 μm were fabricated. Four types of monomers, RM-A to RM-D, as listed in Table 1, were each mixed at a concentration of 0.3 wt% into a nematic mixture ZLI-4415 (Merck) with negative dielectric anisotropy ($\Delta\varepsilon = -3.5$), and the resulting mixtures were injected into the cells. For comparison, a reference cell without any monomer was also prepared.

Table 1 Molecular structure of RM materials doped into nematic LCs.

	Molecular structure of RM materials
RM-A	
RM-B	
RM-C	
RM-D	

Subsequently, as shown in Fig. 1, the cell was tilted and irradiated for 10 minutes with collimated UV light (ultra-high-pressure mercury lamp, intensity: 15 mW/cm² at λ=365 nm). The UV light was unpolarized. The tilt angle of the cell during irradiation was defined as the irradiation angle α, which was set to α = 45° in this experiment.

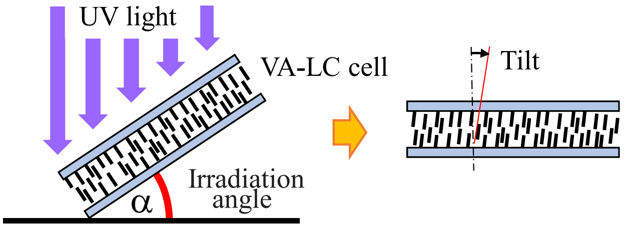
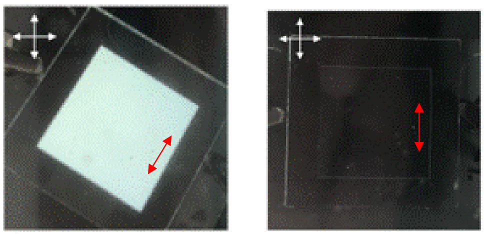


Fig. 1 Schematic diagram of UV irradiation to generate pretilt angle.

As a result, visual observation of each cell under crossed polarizers revealed that all cells remained dark without the applied voltage. However, upon voltage application, only the cell containing RM-D exhibited uniform alignment, indicating successful pretilt angle induction. The direction of the pretilt was parallel to the incident UV light. In contrast, the cells containing RM-B, RM-C, or no monomer showed disordered molecular tilt directions.

Although RM-A exhibited some degree of anisotropic alignment, it did not achieve the same level of uniformity as RM-D. In the cells containing RM-B, RM-C, or no reactive monomer, the liquid crystal molecules exhibited randomly tilted orientations, indicating the absence of controlled pretilt alignment. In the case of RM-A, partial anisotropic alignment was observed; however, it lacked the uniform and well-defined molecular orientation achieved with RM-D.

Figure 2 shows the overall view of a VA cell fabricated using RM-D under applied voltage. The images were taken under crossed polarizers while rotating the cell. Fig. 2(a) corresponds to a non-extinction state, while Fig. 2(b) shows the extinction state. These results indicate that the LC directors are uniformly aligned.



(a) (b)

Fig. 2 Photos of VA cells aligned using our photo-alignment method, observed under applied voltage.
(a) non-extinction state, and (b) extinction state.

At present, the mechanism by which the pretilt is induced remains unclear; however, we speculate as follows. The monomer that did not exhibit photoalignment possesses three cyclic structures connected by flexible segments (ester linkages), which are considered to form a bendable and flexible backbone. Therefore, it is assumed that bending occurs at these flexible segments during polymerization, leading to a nearly random overall arrangement of the polymer chains. In contrast, the monomer that exhibited photoalignment contains only two cyclic structures and is considered to possess a relatively rigid molecular backbone. During polymerization, this backbone is presumed to align in accordance with the anisotropy induced by the direction of UV irradiation. Owing to this rigidity, when one of the acrylate groups undergoes polymerization, the molecular backbone proceeds without bending, thereby preserving the influence of the UV-induced anisotropy in the resulting polymer structure. Moreover, in RM-D, a highly rigid reactive group is located between the two cyclic structures, which is considered to contribute in some way to the mechanism inducing a larger pretilt angle compared to RM-A. Therefore, for RM materials employed in this photoalignment method, a highly rigid molecular backbone is preferable, and the presence of two cyclic structures is considered desirable. Based on these considerations, the following experiments focus exclusively on the LC materials containing RM-D.

2.2 Control of Pretilt Angles

The concentration of RM-D added to the LC mixture was varied to 0.1 wt%, 0.2 wt%, 0.5 wt%, and 1.0 wt%. Additionally, the cell tilt angle α during UV irradiation was adjusted to 30°, 45°, and 60°. The effective UV irradiation energy, 8.6 J/cm^2, delivered to the cell was calibrated such that it remained equivalent to that at $\alpha = 45°$, regardless of the tilt angle. The pretilt angle was measured using the crystal rotation method. [7] The results are shown in Fig. 3. When the concentration of RM-D is 0.5 wt% or higher, a pretilt angle sufficient for vertical alignment LCD operation is induced. Furthermore, a clear dependence on the irradiation angle is observed. In particular, at an RM-D concentration of 1.0 wt%, the pretilt angle was controllable over a wide range from 89.6° to 88°, depending on the irradiation angle.

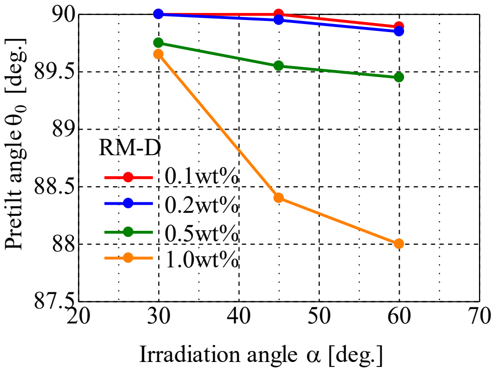


Fig. 3 Dependence of pretilt angle θ_0 on irradiation angle α and RM concentration.

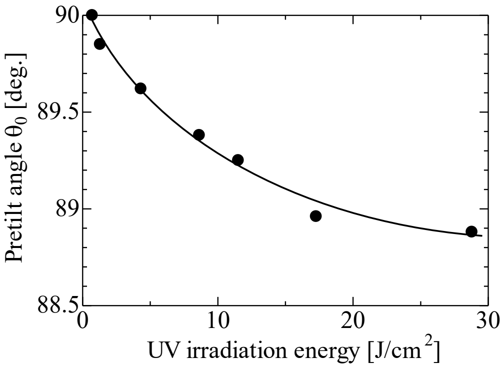


Fig. 4 Dependence of the pretilt angle θ_0 on UV irradiation energy.

Figure 4 presents the change in the pretilt angle obtained with RM-D (0.5 wt%) under a fixed irradiation angle of $\alpha = 45°$, as the irradiation energy (irradiation time) was varied. An increase in irradiation energy leads to a larger induced pretilt angle. (Decreased from 90°.)

As saturation was not attained within the experimental range investigated, it is inferred that residual monomers remain under these conditions. However, in practical use as an LCD, polarizers are applied, preventing UV transmission. Therefore, polymerization that would significantly alter the properties does not occur, and this is not considered a practical issue.

Furthermore, partial UV exposure was performed using a mask to shield specific regions, and cells with different irradiation angles α were observed from an oblique direction. Figure 5 shows the viewing angle characteristics of a single VA cell that was partially masked and photoaligned with UV irradiation angles of −30°, 60°, and 45° in different regions, and a close-up view of the alignment boundary is shown in Fig. 6. At α = −30° and 60°, the tilt direction of the cell with respect to the incident UV light is reversed. In the microscope images of these regions, disclination lines were observed, indicating discontinuities in the alignment. In contrast, at the boundary between α = 60° and 45°, no disclination lines were observed, suggesting that the pretilt angle changes continuously across this region. The use of a fine-patterned photomask during exposure may enable the control of multi-domain alignment, allowing the tilt directions to be adjusted for the enhancement of viewing-angle characteristics

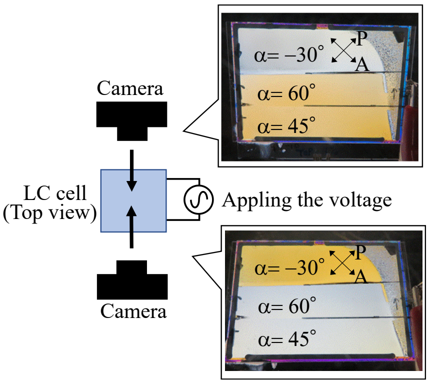


Fig. 5 Example of viewing angle characteristics of a VA cell with varying UV irradiation angle α.

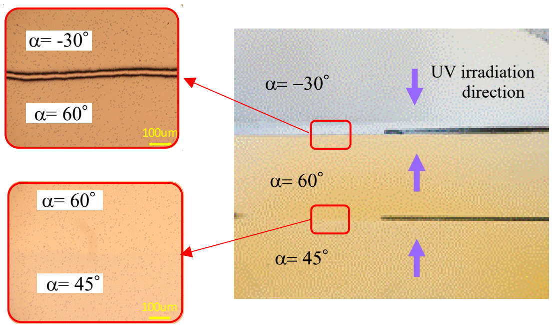


Fig. 6 Photos of alignment conditions in the VA cell under applying the applied voltage with fabricated our proposed photoalignment method.

2.3 Two-Step Exposure Method

2.3.1 Inducing a Larger Pretilt Angle

A method for enhancing the pretilt angle by employing a two-step exposure process is proposed. As illustrated in Fig. 7, during the first exposure, the cell is tilted, leaving a significant portion of unreacted monomer.

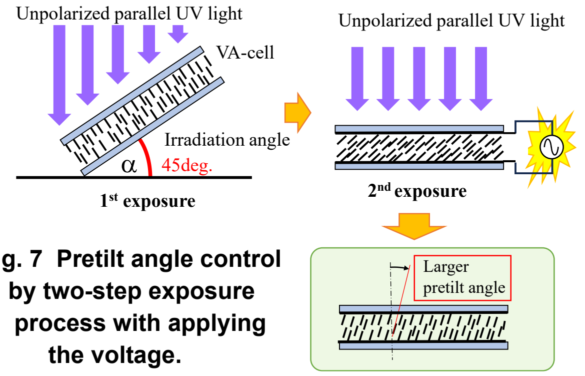


Fig. 7 Pretilt angle control by two-step exposure process with applying the voltage.

To achieve this, the UV irradiation energy is adjusted to roughly half of that employed under the previously described conditions. Thereafter, application of a voltage to the cell causes the LC directors to tilt in a single direction, with the tilt angle being controllable through the magnitude of the applied voltage. Under these conditions, the second UV exposure is carried out without tilting the cell, thereby achieving an increased pretilt angle.

For the experiment, an LC material doped with 0.5 wt% RM-D was employed. The first exposure was conducted at an irradiation angle of α=45°, with an irradiation energy of 4.3 J/cm². Subsequently, the necessary AC voltage was applied to the cell, and the second exposure was carried out without tilting the cell (α=0°). The irradiation energy in this step was 8.6 J/cm². The results, presented in Fig. 8, indicate that a larger pretilt angle can be obtained than with a single exposure, suggesting the potential to reduce the monomer concentration.

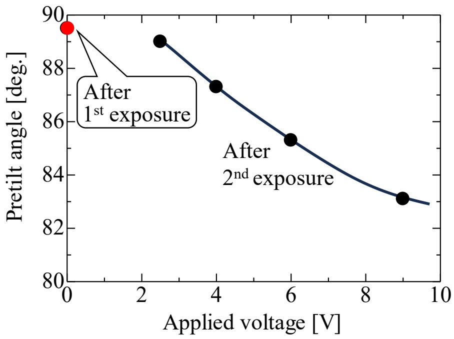


Fig. 8 Pretilt angles after two-step exposure.

2.3.2 Variation of the Alignment Azimuthal Angle

Next, an experiment was conducted to investigate how the alignment direction changes when the UV exposure is performed twice with different irradiation directions. The tilt angle α of the cell during both the first and second exposures was set to 45°. The first UV exposure with an energy of 8.6 J/cm^2 was performed. For the second exposure, the cell was rotated by 90°, and the irradiation energy was varied to examine its effect. As a result, it was found that the azimuthal direction of the easy axis after two UV irradiations corresponds to a synthesized orientation derived from both exposure directions, as shown in Fig. 9. The azimuthal direction of the easy axis was defined relative to the second irradiation direction as the resultant azimuthal angle ϕ. The measurements were conducted by visually determining the extinction position under crossed polarizers while rotating the cell. The results are shown in Fig. 10. Even with a smaller exposure energy of half of the first time (4.3 J/cm^2) compared to the first, the final alignment direction is strongly biased toward the second irradiation direction.

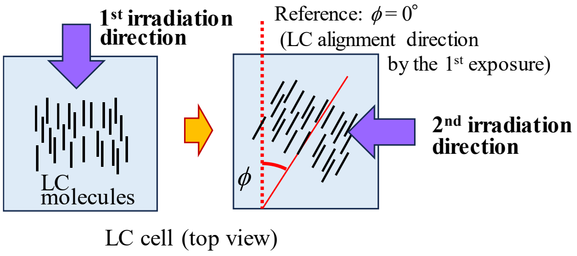


Fig. 9 Schematic illustration of LC alignment when the irradiation azimuthal angles are changed between the 1st and 2nd exposures.

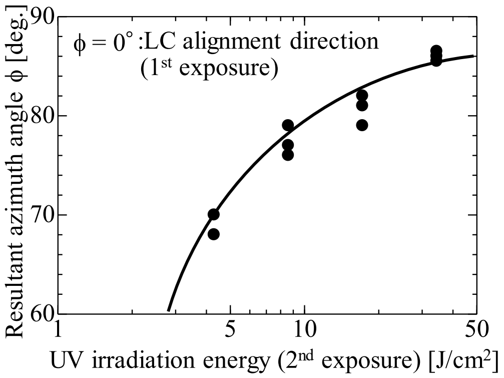


Fig. 10 Dependence of the resultant azimuth angle on the second UV irradiation energy.

In addition, a preliminary experiment was performed to explore the feasibility of achieving patterned alignment by applying a photomask during the second UV irradiation. The photomask featured a polka-dot design, with circular regions shielded from UV light. A vertically aligned cell was first exposed to UV light at an irradiation angle of α = 45° for 10 minutes. The cell was then rotated by 90°, and the photomask was applied to the surface, followed by a second UV exposure at the same angle (α = 45°) for an appropriate duration. The polarized optical microscope image of the resulting cell is shown in Fig. 11. The cell orientation was adjusted so that the region exposed during the first irradiation appears in the extinction position. It can be seen that the alignment direction has been successfully patterned. These results suggest that multi-domain VA alignment can be achieved.

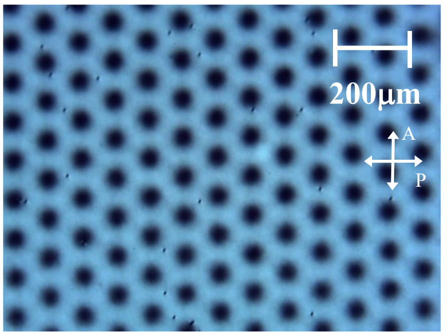


Fig. 11 POM image of multi-domain alignment using a photomask during the second UV exposure.

3 Conclusions

A novel photoalignment method was proposed in which UV light is irradiated obliquely onto a VA-LC cell filled with monomer-doped LCs to induce a pretilt angle, and the resulting alignment characteristics were evaluated. It was confirmed that the induced pretilt angle can be controlled by varying the concentration of monomer added to the LC and the UV irradiation angle. These results demonstrate that the proposed photoalignment technique allows precise control of the desired pretilt angle. Furthermore, it was demonstrated that multi-domain VA alignment can be realized by selectively irradiating UV light through a photomask.

References

[1] Y. Iimura, S. Kobayashi, T. Sugiyama, Y. Toko, T. Hashimoto and K. Kotoh: Proc. SID 35, 915(1994).
[2] T. Hashimoto, T. Sugiyama, K. Katoh, T. Saitoh, H. Suzuki, Y. Iimura and S. Kobayashi: Proc. SID 36, 877(1995).
[3] Y. Iimura, T. Saitoh, S. Kobayashi and T. Hashimoto: J. Photopolym. Sci. Technol, 8, 257(1995).
[4] M. Hasegawa and Y. Taira: J. Photopolym. Sci. Technol. 8, 241(1995).
[5] J. L. West, X. Wang, Y. Ji, J. R. Kelly: Proc. SID 36, 703 (1995).
[6] Jae-Hoon Kim, Bharat R. Acharya, and Satyendra Kumar, Appl.Phys.Lett. 73, 3372 (1998).
[7] T. J. Scheffer, T. Nehering: J. Apple. Phys. 48 (1977).