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Evaluation of molecular orientation in the large aperture liquid crystal lens using ultrasound vibration
超音波を用いた大口径液晶レンズの分子配向評価

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1. Introduction

Nematic liquid crystals have low viscosity, high liquidity, and electric dipoles, allowing to be widely used in optical devices such as liquid crystal displays. Generally, transparent electrodes are required for liquid crystal devices to apply electric fields through the liquid crystal layer to control its molecular orientation. Indium tin oxide (ITO) is commonly used as a transparent electrode material because of its high transparency and low power consumption. However, ITO is inorganic material and it is difficult to apply to flexible liquid crystal device such as electronic digital paper. Sato and his colleagues developed liquid crystal lenses using electric fields[1]. Although, in general, molecular orientation of liquid crystals can be controlled by applying electric fields, it is difficult to control the molecular orientation in liquid crystal lenses with a large aperture. Our group has proposed a technique to control the orientation of liquid crystal molecules using ultrasound vibration without using transparent electrodes and developed a variable-focus liquid crystal lens[2]. In this paper, an ultrasound large-aperture liquid crystal lens using tens-kHz-range ultrasound was developed and the molecular orientation of the liquid crystal was evaluated under ultrasound excitation.

2. Methods

The ultrasound large-aperture liquid crystal lens was fabricated; a liquid crystal layer (5CB) with the thickness of 50 μm was sandwiched by two circular glass plates having an annular PZT transducer. The liquid crystal molecules were oriented perpendicular to the glass plates by forming the polyimide films on the glass surface (**Fig. 1(a)**). By exciting the transducer at the resonance frequencies, the flexural vibration modes are generated on the lens, and the acoustic radiation force acts to the liquid crystal layer so that the molecular orientation of liquid crystal can be changed. The optical characteristics of the liquid crystal lens were investigated. The lens was arranged between a polarizer and analyzer under the crossed Nicol

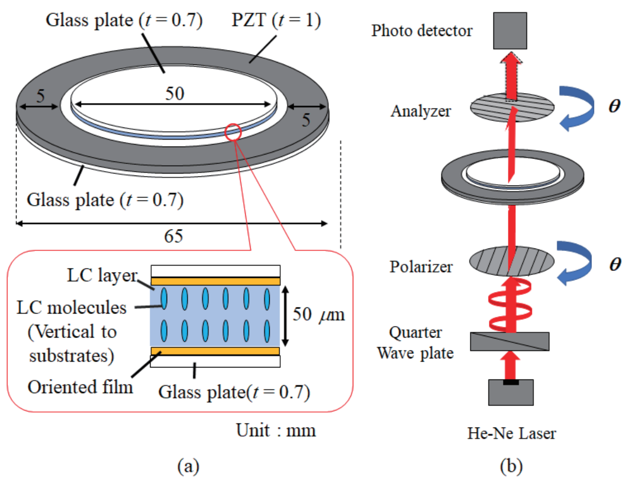

Fig. 1 An ultrasound large-aperture liquid crystal lens. (a) Configuration and (b) experimental setup.

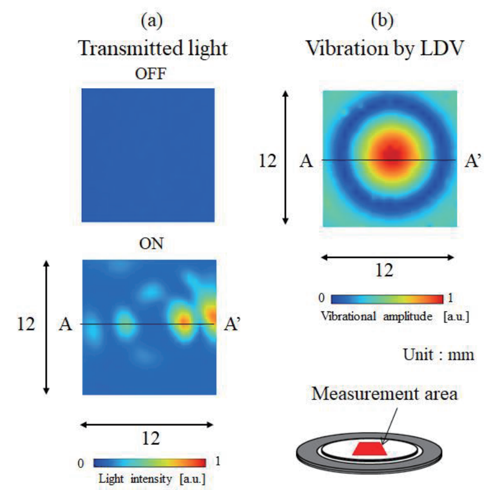

Fig. 2 (a) Distributions of the transmitted light intensity without and with ultrasound excitation at the polarization directions θ of 45° and (b) the distribution of the vibrational amplitude of the glass substrate at 35 kHz.

condition. In order to evaluate the in-plane molecular orientation of the liquid crystal molecules, the transmitted light distributions were measured with rotating two polarizers in the in-plane direction while maintaining the crossed

Nicol conditions (**Fig. 1(b)**). The vibrational distribution of the lens was measured by a laser Doppler vibrometer.

3. Results and Discussion

Fig. 2 shows the transmitted distribution (the polarization angle of the incident light θ = 45°) and vibrational distribution. **Fig. 3** shows the transmitted light distribution when changing θ from 0° to 165° under ultrasound excitation with the voltage of 20 V_{pp} at 35 kHz. The transmitted light distribution corresponded every 90°. These results indicate that the orientation of the liquid crystal molecules is not twisted in the thickness direction of the lens. **Fig. 4** shows the transmitted light distribution and the vibrational amplitude of the glass substrate in the radial direction. The concentric resonance flexural vibration mode with one nodal circle was generated on the lens at 35 kHz. The maximum displace amplitude at the center of the lens was 18 μm. Comparing two distributions, the molecular orientation did not change at the node and antinodal points of the flexural vibration.

From the transmitted light distributions with several polarization angle θ (Fig. 3), it is possible to estimate the in-plane distribution of liquid crystal molecular orientation. **Fig. 5** shows the in-plane distribution of the molecular orientation in the lens. The contour and vectors indicate the vibrational amplitude of the glass plate and the orientation of the liquid crystal molecules, respectively. The orientation directions of the liquid crystal molecules were predicted from the polarization direction of the incident light θ which gives the maximum light intensity of the transmitted light at each measurement point in Fig. 3. It should be noted that the length of the vectors represents the inclination of the molecular orientation against the thickness direction of the lens, which can be calculated from the maximum and minimum transmitted light intensites at each measurement point. As shown in Fig. 5, the change in orientation of the liquid crystal molecules was remarkable between the antinode and node of the ultrasound vibration; the liquid crystal molecules were oriented toward the center of the lens and then it acts as a convex lens.

4. Conclusion

In this paper, the change of liquid crystal molecular orientation of the lens was evaluated. The liquid crystal molecules maintained the initial vertical orientation at the antinode and node of ultrasound vibration and were oriented toward the center of the lens between the antinode and nodal positions.

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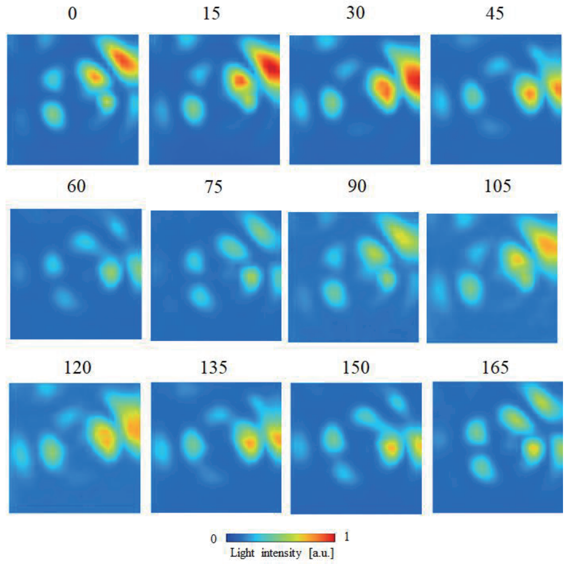

Fig. 3 Distributions of the transmitted light intensity with ultrasound excitation at each polarization directions (θ = 0° to 165°).

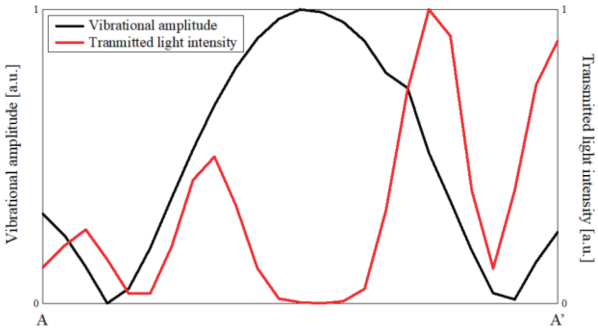

Fig. 4 Distributions of the transmitted light intensity (red) and vibrational amplitude of the glass substrate (black) at 35 kHz along line A–A' in Fig. 2.

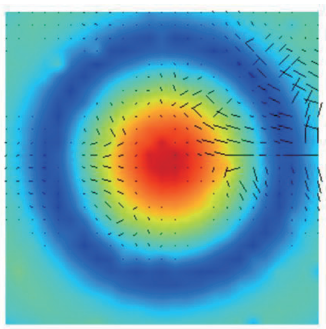

Fig. 5 Distribution of the liquid crystal molecular orientation and the vibrational distribution.

Acknowledgment

This work was partly supported by a KAKENHI Grant-in-Aid (No. 16K14204 and 19H02056) and JKA through its promotion funds from KEIRIN RACE.

5. References

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