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Variable-focus in radial direction in liquid crystal lens using acoustic radiation force

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1. Introduction

The increasing need for miniaturization of electronics, including miniaturized optical systems, has guided liquid crystal research into the development of small size and high performance materials. Due to their physicochemical properties, such as high liquidity and moderate dielectric anisotropy, nematic liquid crystals are widely used for optical devices, i.e. liquid crystal displays, making its downsizing possible.

Several researchers reported the use of electrodes in liquid crystal devices in order to control its molecular orientation. The most common transparent electrode used in liquid crystal experiments has been indium tin oxide (ITO), due to its relatively high conductivity and optical transparency, and compatibility with liquid crystal alignment layers. ITO, however, has some disadvantages, such as high costs from its sputtering deposition fabrication and use of the rare metal indium.

Ultrasound vibration is an alternative for replacing the use of ITO electrodes in liquid crystal devices[1-3]. Therefore, it is possible to have a variable-focus lens with no mechanical moving parts by changing the liquid crystal molecular orientation statically through the acoustic radiation force. The focal point of an ultrasound liquid crystal lens can change only in axial direction due to axisymmetric flexural vibration mode in the lens thickness direction[2]. However, a precise control of liquid crystal molecular orientation is difficult to achieve since ultrasound vibration utilizes the entire resonance vibration modes of the device[3].

This paper describes a liquid crystal lens with variable-focus in radial direction using acoustic radiation force. This lens is based on a PZT element with four channels. Optical image stabilization is one possible application for this lens type.

2. Materials and Methods

2.1 Lens Configuration

A variable-focus lens in radial direction was fabricated as shown in **Fig. 1**. A nematic liquid crystal (RDP85475, DIC) layer with the thickness of 0.05 mm was sandwiched between two circular glass plates with thickness of 0.7 mm (diameters: 15 mm and 30 mm). Initially, liquid crystal molecular orientation is perpendicular to the glass plates due to chemical interaction between liquid crystal molecules and the oriented film formed on the surface of the glass plates[2]. An annular piezoelectric lead zirconate titanate (PZT) ultrasound transducer (C-213, Fuji Ceramics, thickness: 1 mm; inner diameter: 20 mm, outer diameter: 30 mm) was bonded to a glass plate with larger diameter. The PZT electrode was separated electrically in four parts for four-phase drive (CH1 to CH4).

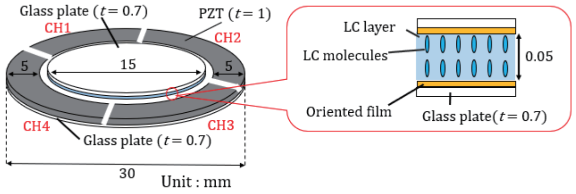
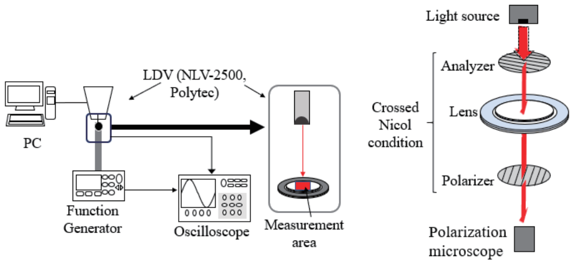


Fig. 1 Configuration of the variable-focus lens in radial direction

2.2 Experimental Setup



(a) (b)

Fig. 2 Experimental setup: measurements using (a) an LDV and (b) a polarization microscope.

Fig. 2 shows a schematic of the experimental setup. The vibrational displacement amplitude on the surface of the glass plate at the center (10×10 mm^2) was measured by using a laser Doppler vibrometer (LDV) (NLV-2500, Polytec). It was possible to control the vibration distribution by controlling the input signals to four channels (CH1 to CH4). By exciting the four transducers simultaneously at its resonance frequency (45.6 kHz) or just one transducer (CH1) under the same driving frequency, the vibration distributions were

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compared. In addition, the light transmitted through the lens was measured under crossed Nicol conditions to verify the optical characteristics of the lens using a polarization microscope (IX83, Olympus).

3. Results and Discussion

The vibration distribution on the upper glass plate was varied by controlling the driving channels condition. **Fig. 3** shows the vibrational amplitude distributions of the glass plate by driving CH1 to CH4 (Fig. 3(a)) and only CH1 (Fig. 3(b)).

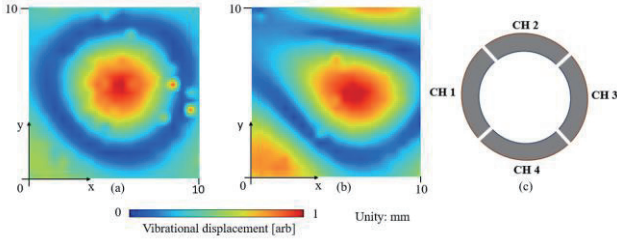

Fig. 3 Vibrational displacement amplitude distributions of the glass plate with driving (a) CH1 to CH4 and (b) only CH1. (c) Position of the PZT channels (superior view).

When all channels were excited in phase with the same voltage amplitude and resonance frequency (45.6 kHz), the axisymmetric flexural vibration mode with one nodal circle was generated in the lens, and the liquid crystal layer was statically deformed by the acoustic radiation force acting on the boundary among the liquid crystal layer, the glass plates, and the surrounding air, as reported in previous studies[1-3]. On the other hand, when the input voltage is applied to only CH1, a non-axisymmetric flexural vibration mode was generated. Thus, the acoustic radiation force changed the liquid crystal molecular orientation in radial direction.

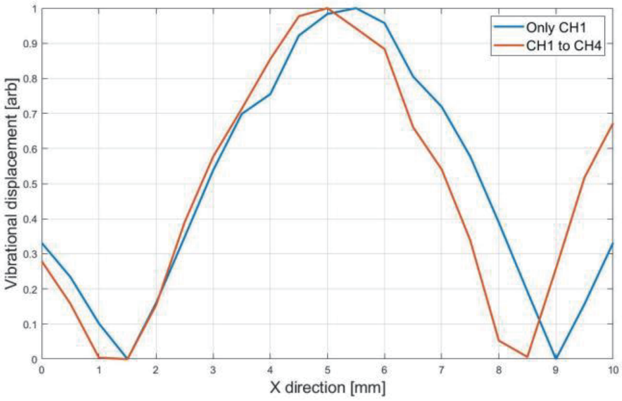

Fig. 4 Comparison of the vibration distributions of the lens driven by all the channels and only one channel.

Fig. 4 shows the comparison of the vibration distributions under two driving conditions. The vibrational amplitude was normalized according to the maximum value for both curves. As shown in Fig. 3 and Fig. 4, it is possible to confirm the vibrational distribution change comparing the two vibration modes. It can be noticed by analysing both vibration displacement figure and graph curves that node and antinode point of the vibration by using only CH1 is slightly different from the vibration mode using CH1 to CH4. Then, it is possible to confirm the change of the focal point.

Fig. 5 shows change in the optical patterns of the lens observed by the microscope. It could be observed by comparing the transmitted light intensity when all channels were excited in phase with the same voltage amplitude with the case that the input voltage was applied to only CH1.

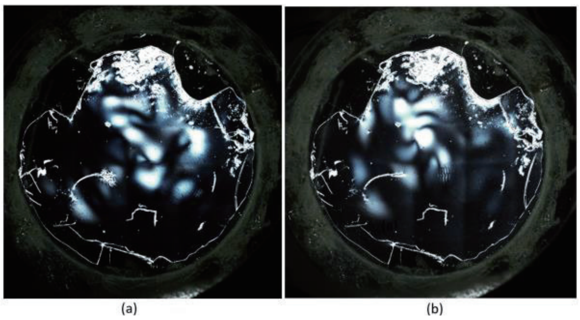

Fig. 5 Comparison of the transmitted light intensity distributions through the lens driven with (a) all the channels and (b) only CH1.

4. Conclusion

In this study, the technique to change the focal point in radial direction, by controlling the orientational direction of a nematic liquid crystal molecules using acoustic radiation force from ultrasound, was investigated using a PZT based on four channels. The results from the LDV and microscope indicate the vibration mode changed due to the number of driving transducers. Also, the optical characteristics changed according to the vibration mode. Therefore, the optical characteristics of the lens depends directly on the vibrational distribution amplitude allowing the focal point to change in radial direction.

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