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Ultrasonic Optical Lens Array with Variable Focal Length and Pitch

焦点位置及びレンズピッチを制御可能な超音波式レンズアレイ

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1. Introduction

In most of camera modules, a plastic camera lens, actuators, and gearing system are required to move the position of the lens and focus on objects. Crystalline lens in human eyes can change in shape and control the focal point. We have been investigating a variable-focus optical lens using acoustic radiation force [1,2]. In the lens, the focal point could be controlled by the input voltage. In this report, a lens array with variable focal length and pitch was investigated.

2. Configuration

Fig. 1 shows the configuration of lens array. The lens array consists of four rectangular ultrasonic transducers (PZT, 10×10×1 mm^3), a glass plate (50×50×1 mm^3), and silicone gel (KE-1052(A/B), Shin-Etsu Silicone, refractive index: 1.4, the real part of complex elastic modulus: 2×10^4 N/m^2). The transducers were attached to the glass plate by epoxy and a silicone gel film of 300 μm thick was formed on the glass.

3. Lens profile

By exciting the PZT transducers, the lattice flexural vibration modes can be generated on the glass plate. **Fig. 2** shows the vibration modes of the glass plate at 91 and 183 kHz calculated by finite element analysis (FEA, ANSYS 11.0, ANSYS Inc.). The flexural vibration of the glass plate induces the acoustic radiation force and the surface of the silicone gel is deformed. The deformation pattern of the gel corresponds to the vibrational distribution of the glass, and the gel acts as a lens array. **Fig. 3** shows the surface profiles of the silicone gel at 90 and 170 kHz measured by a confocal laser microscope (LT-9000, KEYENCE). The measurement area was 40×40 mm^2. The numbers of lenses among four PZT transducers were 21 at 90 kHz and 37 at 170 kHz, respectively. The bottom figures show the cross-sectional views at lines A-A' when the input voltages were switched on and off. The lens pitches correspond to half wavelength of the lattice flexural vibrations, and the flexural vibration with the shorter wavelength at higher frequency produces the lens array with the smaller pitch: the lens pitches were 10 mm at 90 kHz and 7.4 mm at 170 kHz, respectively. There are

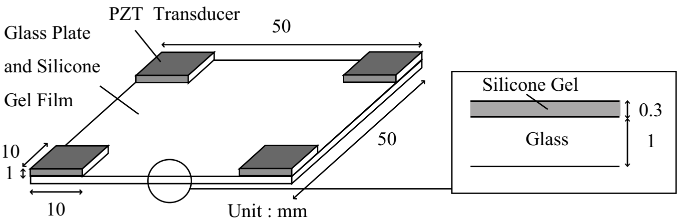
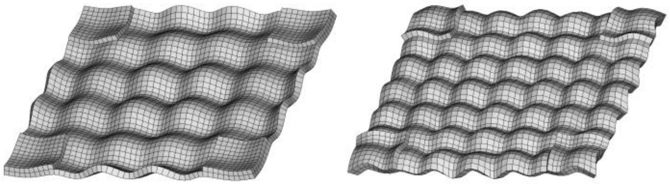
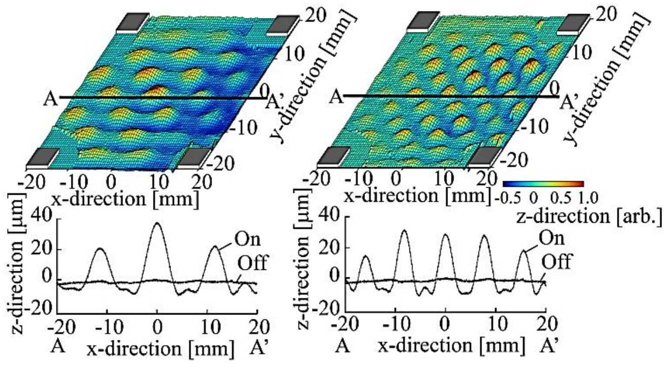


Fig. 1 Configuration of the lens array.



(a) 91 kHz (b) 183 kHz

Fig. 2 Vibration modes of the glass plate (FEA).



(a) 90 kHz (b) 170 kHz

Fig. 3 Surface profiles of the silicone gel.

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several resonance frequencies of the lattice modes of the glass plate over 200 kHz. Because lens array can be formed only at the resonance frequencies, the lens pitch can change discretely by varying the driving frequency.

Fig. 4 shows the average values and the standard deviation of the lens height in lens array when the input voltages were 24 V_{pp} at 90 kHz and 53 V_{pp} at 170 kHz, respectively. The horizontal axis indicates the number of lenses counted from the center of the lens array (For example, ″five lenses″ correspond to a group of lens which consists of the center lens and surrounding four lenses as shown in **Fig. 4**). The circles are the average values and the error bar indicates the standard deviation. The variation of the lens height increased and the average values decreased with the number of lenses at 90 kHz: the lens height gradually decreased with distance from the center. This variation of the lens height is attributed to that the vibration amplitude at the center of the plate is larger than that at the edge.

The transmitted light profile was calculated by ray tracing. **Fig. 5** shows the calculated results for the lens array excited with 0, 32 and 62 V_{pp} at 90 kHz. The profiles of the lens were imported from the experimental values in **Fig. 3**. The incident lights with a beam width of 3.9 mm passed through the lens from left to right. When the input voltages were 32 and 62 V_{pp}, the transmitted lights were focused and the focal points of the lens array were approximately 164 and 76 mm from the lens surface, respectively. **Fig. 6** shows the relationship between the input voltage and the focal length. The shorter focal length could be obtained with the larger input voltage since the displacement amplitude of the gel increased. The focal point of the lens array could be controlled by the input voltage.

4. Conclusions

An ultrasonic optical lens array with variable focal length and pitch was proposed. The lens array has a simple and thin structure which consists of four PZT transducers, a glass plate, and silicone gel. The surface and optical profiles of the lens array were investigated. The lens pitch could be controlled by the driving frequency. The focal point could be controlled by the input voltage and the lens array acted as a variable-focus lens array.

Acknowledgement

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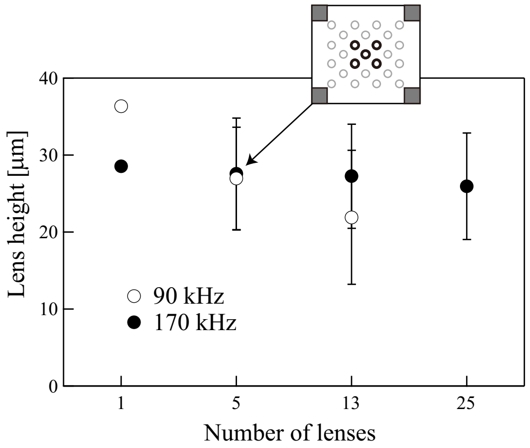

Fig. 4 The average values and the standard deviation of the lens height in the lens array.

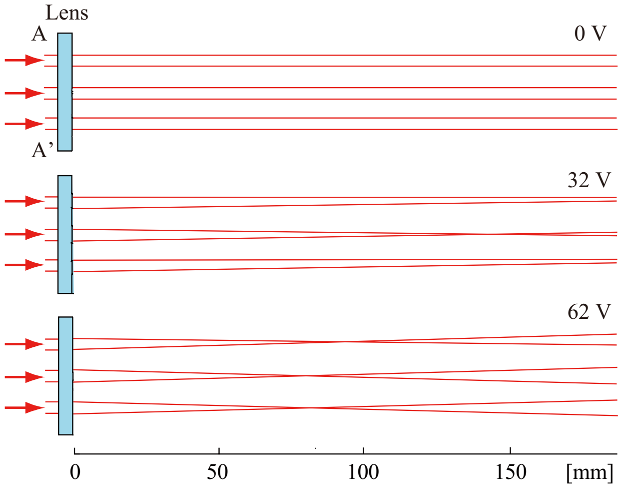

Fig. 5 Ray-trace simulation results for the lens arrays excited by the input voltages of 0, 32 and 62 V_{pp} at 90 kHz.

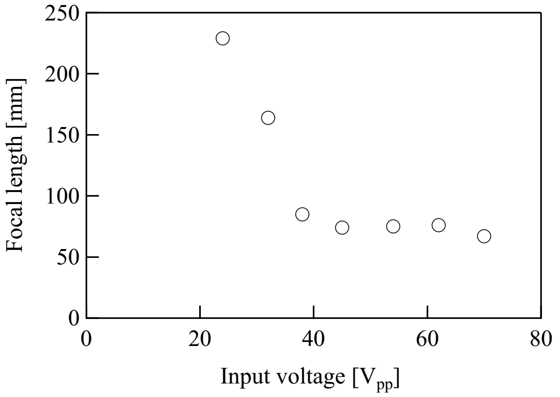

Fig. 6 Relationship between the input voltage and the focal length of the center lens at 90 kHz.