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Ultrasonic Variable-Focus Optical Lens Using Viscoelastic Material

粘弾性材料を用いた超音波駆動式可変焦点レンズ

Daisuke Koyama†, Ryoichi Isago, and Kentaro Nakamura (Precision and Intelligence Lab., Tokyo Tech)
小山 大介†，井砂 亮一，中村 健太郎（東工大・精研）

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. Crystaline lens in human eyes can change in shape and control the focal point. We have been investigating the liquid optical lens with no mechanical moving parts utilizing the difference of refraction indices of two immiscible liquids and acoustic radiation force [1,2]. The profile of the interface of the two liquids could change and the lens acted as a variable-focus lens. In this report, a variable-focus lens using viscoelastic material has been investigated.

2. Configuration

Fig. 1 shows the configuration of the lens. The lens has a simple and thin structure: the center of a PZT ring (inner diameter: 15 mm, outer diameter: 30 mm, thickness: 2 mm) polarized in thickness direction was filled with viscoelastic material, silicone gel (KE-1052(A/B), refractive index: 1.4, Shin-Etsu Silicone). An acrylic cylindrical case was attached to the PZT ring. The viscoelastic property of the silicone gel can be controlled by the mixture ratio of KE-1502-A and -B, and in our experiment, it was 1:0.7. A 0.1-mm-thick PET film was attached on the one side of the PZT to form the silicone gel, and the gel does not flow out and the lens profile changed little when the lens was inverted. By exciting the radial vibration mode on the PZT ring, the acoustic standing wave is generated in the silicone gel at the center of the ring and the lens profile changes by the acoustic radiation force. The computed result by finite element analysis (FEA) predicted one of the radial vibration modes of the PZT ring is generated at 219 kHz as shown in **Fig. 2**.

3. Lens profile

When the acoustic standing wave is excited in the silicone gel, the difference of the acoustic energy density between the gel and air layers is generated at the boundary of the lens surface. This fact induces the acoustic radiation force acting from the medium with the larger energy density (gel) to that with the smaller energy density (air), and the

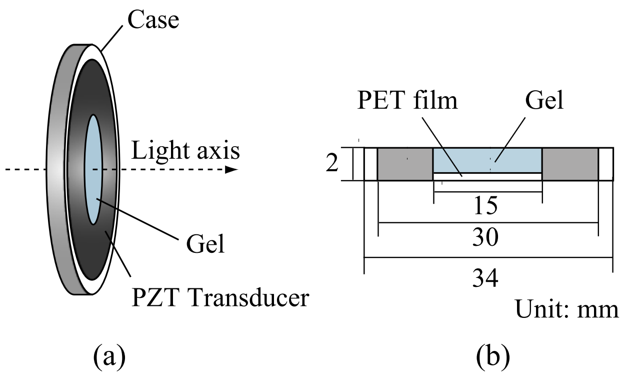

Fig. 1 Configuration of the lens.

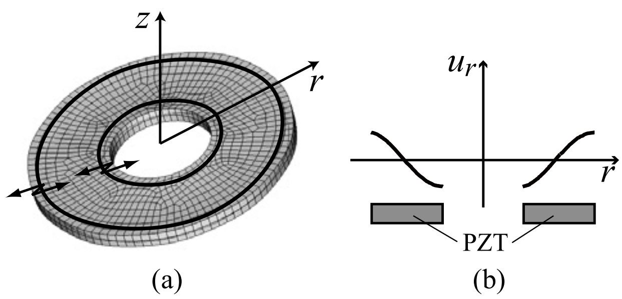

Fig. 2 Vibration mode of the PZT ring at 219 kHz predicted by FEA.

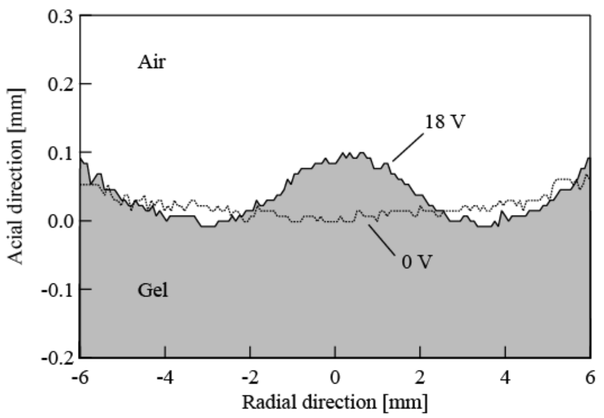

Fig. 3 Radial profiles of the lens excited with the input voltages of 0 and 18 V at 226 kHz.

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†dkoyama@sonic.pi.titech.ac.jp

lens surface is statically deformed toward air. **Fig. 3** shows the radial profile of the lens observed by optical coherence tomography (OCT) with the input voltages of 0 and 18 V at 226 kHz. The center of the lens surface was statically deformed outward with the displacement amplitude of approximately 100 μm due to the acoustic radiation force.

The transmitted light profile was calculated by ray tracing. **Fig. 4** shows the calculated results for the lens excited with 0 and 18 V. Considering the lens aperture acting as a variable focus lens, the incident light with the beam width of 3 mm passed through the lens to the right-hand side. A two-dimensional model was employed in the computation and the experimental results of the lens profile obtained by OCT shown in Fig. 3 were imported to the simulation model. When applying no input voltage, the lens worked as a concave lens, and the transmitted light was diffused at the lens surface and no focal point exists. When the input voltage was 18 V, the transmitted light was focused and the focal point of the lens was 55 mm from the lens surface. The shorter focal length could be obtained with the larger input voltage, and the focal point of the lens could be controlled by the input voltage. **Fig. 5** shows the representative optical images of a resolution test target (1951 USAF) captured by a CCD camera through the lens with the input voltages of 0 and 18 V. By applying the input voltage, the focal point could be changed and the clear image could be obtained.

The dynamic response of the lens was investigated. The transient response at the lens surface on the center axis was observed by the M-mode of OCT (**Fig. 6**). The lens was excited at t<0 and the input voltage was switched off at t =0. After switching off, the lens surface began to move to the default position. The response time of the lens which corresponds to the duration of the transient state was 0.1 ms. The lens response depends on the viscoelastic property of the gel and the faster response will be obtained in our future works.

4. Conclusions

A variable-focus optical lens using viscoelastic material and the acoustic radiation force was proposed. The lens has a simple and thin structure which consists of a PZT ring and silicone gel. The optical profile of the lens was investigated. The focal point could be controlled by the input voltage and the lens acted as a variable-focus lens.

Acknowledgment

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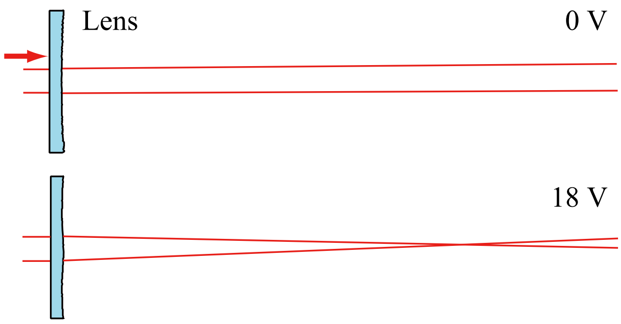

Fig. 4 Ray-trace simulation results for the lenses excited by the input voltages of 0 and 18 V at 226 kHz.

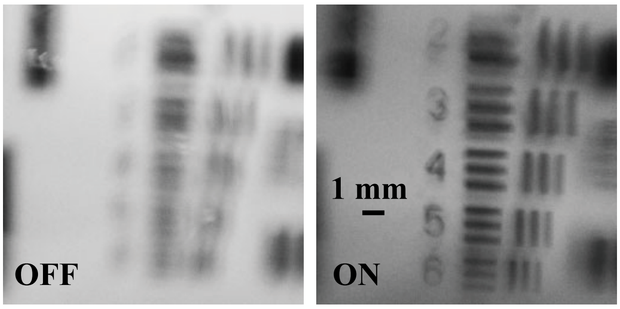

Fig. 5 Captured image of a resolution test target through the lens when input voltage is switched on and off.

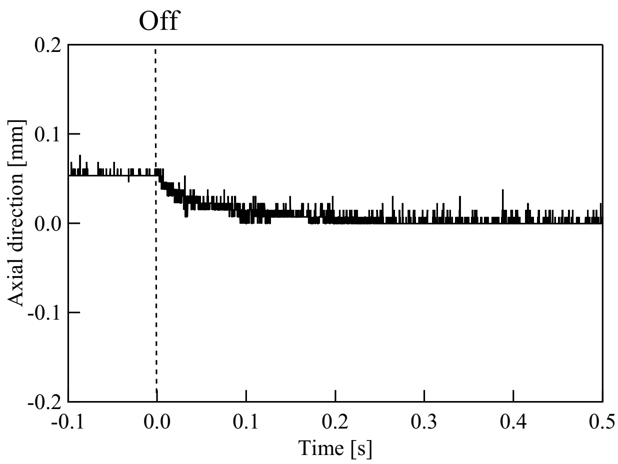

Fig. 6 Transient responses of the lens when input voltage is switched off at t=0.