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High-speed variable-focus small liquid lens using acoustic radiation force

音響放射力を用いた高速可変集束液体レンズ

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1. Introduction

Most of built-in cameras in many mobile electronic devices are bulky because they have a camera lens, and its actuator and gearing system, which move the lens in the axial direction. The response time of these lenses are relatively long, approximately tens of milliseconds. The authors have been investigating liquid lenses using acoustic radiation force. Acoustic radiation force is a static force generated from a difference in the acoustic energy densities of different media [1]. The shape of the lens can be transformed by acoustic radiation force. In this report, a high-speed variable-focus small liquid lens with no mechanical moving parts have been investigated.

2. Configuration

The variable-focus liquid lens utilizes the difference in the refractive indices of two immiscible liquids, and the focal point can be controlled in the light axis by deforming the interface of two liquids. **Fig. 1** shows the configuration of a liquid lens. The lens consists of an aluminum cylindrical cell (inner diameter of 3 mm, outer diameter of 6 mm, thickness of 3 mm) filled with two immiscible liquids (water and silicone oil) and a PZT ring (outer diameter of 4 mm, inner diameter of 2 mm, thickness of 1 mm). Two circular quartz plates were installed to the center of the PZT ring and the top of the lens to seal the liquids and allow light to propagate through the lens in the axial direction. Silicone oils with different kinematic viscosities (KF-96-2cs to KF-96-1,000cs, Shin-Etsu Silicone) were used.

3. Lens Performance

The profile of the oil-water interface could be changed by controlling the acoustic radiation force from the transducer. The variation of the shape of the oil-water interface while varying the transducer driving voltage at 1.62 MHz was observed by optical coherence tomography (OCT), and the distribution of the transmitted light was calculated by a ray-tracing simulation (**Fig. 2**). The kinematic viscosity of the silicone oil was 200 cSt. With the

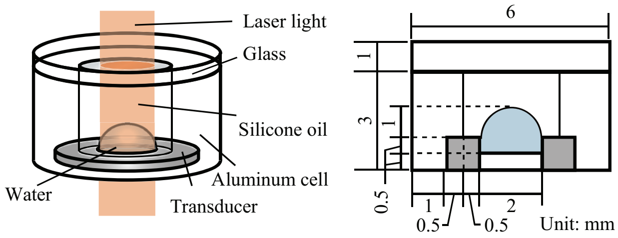

Fig. 1 Configuration of the liquid lens.

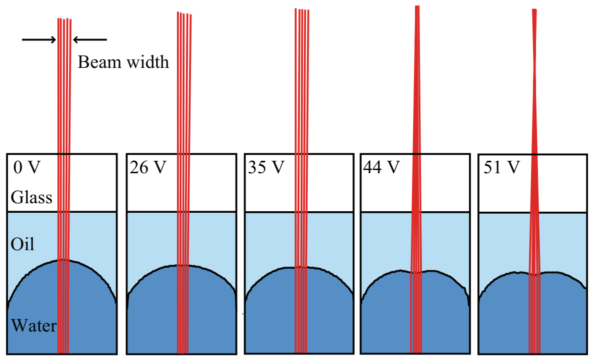

Fig. 2 Ray-trace simulation results for the liquid lenses excited by several input voltages at 1.62 MHz.

increase of the driving voltage of the transducer, the oil-water interface on the center axis proceeded toward the water side by the acoustic radiation force. The moving direction of the interface is from the oil side with a higher acoustic energy density (with a smaller density and a lower speed of sound) to the water side with lower acoustic energy density (with a larger density and a higher speed of sound). The profiles of the transmitted light were changed with the deformation of the oil-water interface, and the beam was focused with the input voltages of 44 and 51 V. **Fig. 3** shows the distributions of the beam width in the axial direction with several input voltages. The axial position of 0 mm corresponds to the lens surface. With the input voltages of 44 and 51 V, the beam widths have the minimum values at 4.1 and 1.7 mm from the lens surface, respectively, and these positions correspond to the focal points of the lens. With the input voltages of 0, 26 and 35 V, the transmitted light was diffused due to the convex surface of the lens, and the focal point does not exist. A He-Ne laser with the beam width of 0.2 mm

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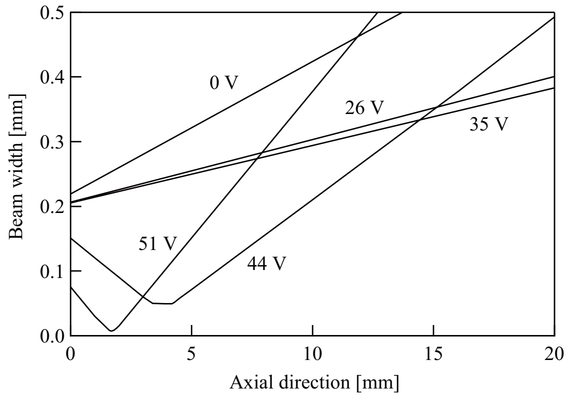

Fig. 3 Computed beam widths in the axial direction of the lens driven by several input voltages.

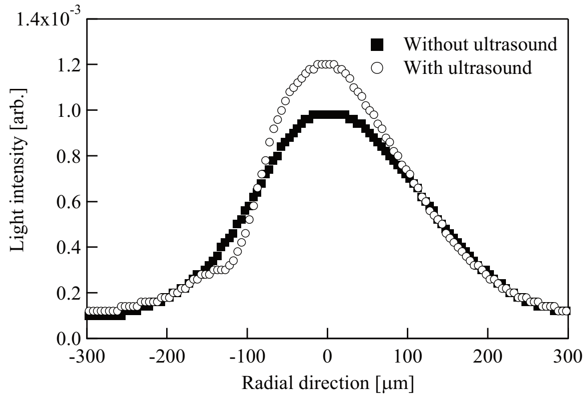

Fig. 4 Intensity distributions of the transmitted laser beam in the radial direction produced by a liquid lens for input voltages of 0 and 35 V.

was penetrated to the lens perpendicularly, and the incident light was focused by exciting the lens. The light signal was measured by scanning a photodetector in the radial direction at a distance of 3 mm from the lens surface when the lens was excited with 0 and 35 V (**Fig. 4**). The profile of the laser beam was changed by applying the input voltage and the full widths at half maximum were calculated to be 0.255 and 0.215 mm with 0 and 35 V, respectively.

4. Dynamic Response of the Lens

The response time of the lens depends on not only the interfacial tension but also the kinematic viscosity of the liquids. **Fig. 5** shows the transient response of the oil-water interface measured by the OCT. The kinematic viscosities of the oil were 10, 100, and 1000 cSt. The input voltage was switched off at t=0, and the interface began to move almost simultaneously. After the transient state of approximately tens-milliseconds, the interface reached to the steady state. The shorter time constant of the transient response could be obtained with the smaller viscosity of the oil although the damped oscillation was observed with 10 cSt. If we determine the duration of the transient response as the response time of the lens, these results reveal the kinematic viscosity of the oil has the optimal value to reduce the response time. **Fig. 6** shows the relationship between the viscosity and the response time. The optimal kinematic viscosity to shorten the response time was 100 cSt, and the shortest response time of 6.7 ms was achieved: this result means the focal point of the lens can be varied from infinity to 4.1 mm within 6.7 ms.

5. Conclusions

A small-sized and high-speed liquid lens using acoustic radiation force was developed. The oil-water interface can be deformed by the acoustic radiation force and acts as the surface of a variable-focus lens. The beam profile of the transmitted laser light could be changed rapidly and focused by applying an input voltage. The shortest response time was 6.7 ms for a kinematic viscosity of 100 cSt.

References

1. G. Hertz and H. Mende: Zeits. Phys.**114** (1939) 354.

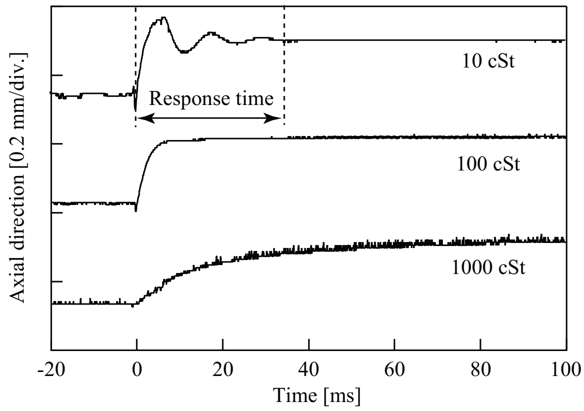

Fig. 5 Transient responses of the oil-water interface for the kinematic viscosities of 10, 100 and 1000 cSt.

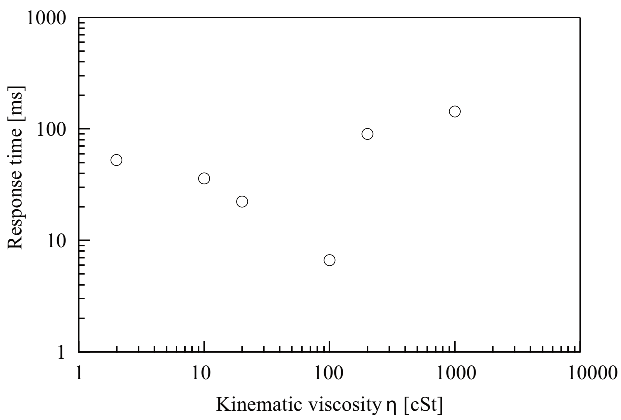

Fig. 6 Relationship between the kinematic viscosity of the silicone oil and the response time of the lens.