3J5-4

Optical characteristics of a variable-focus lens using ultrasound and a thixotropic gel

チキソトロピーゲルを用いた超音波式可変焦点レンズの光学特性

Daiko Sakata[1†], Takahiro Iwase[1], Daisuke Koyama[1], and Mami Matsukawa[1] ([1]Faculty of Science and Engineering, Doshisha Univ.)
坂田　大昂[1†]，岩瀬　貴大[1]，小山　大介[1]，松川　真美[1] ([1]同志社大・理工)

1. Introduction

The human eyes control the focal position by changing the shape of a crystalline lens. We have developed a variable focus lens using a viscoelastic transparent gel film and ultrasound[1]. However, continuous ultrasound excitation was required to maintain the deformation of the lens. Thixotropic materials have unique rheological property where the viscosity changes with shear stress, and the viscosity can be decreased temporarily by ultrasound excitation[2]. We employed a thixotropic gel as the lens material so that the deformation of the lens profile can be maintained with no electric consumption[3]. In this paper, we developed a variable focus lens using a thixotropic gel and ultrasound vibration, and the optical characteristics of the lens were investigated.

2. Methods

Hydrophobic fumed silica (AEROSIL, Evonik) and silicone oil (KF-96, Shin-Etsu Chemical) were mixed and used as the thixotropic gel for the lens. The viscoelastic characteristics of the gel depend on the mixture ratio of oil and silica and the gel with the mass ratio of 7% was prepared. An annular piezoelectric ultrasonic transducer (PZT, C-213, Fuji Ceramics, outer diameter: 30 mm; inner diameter: 20 mm; thickness: 1 mm) polarized in the thickness direction was bonded to a circular glass substrate (diameter: 30 mm; thickness: 0.7 mm). A gel film with the thickness of approximately 0.5 mm was formed on the center of the glass substrate to act as a variable focus lens (**Fig. 1**). When a continuous sinusoidal electric signal at the resonance frequencies of the lens was input to the transducer, the flexural vibration mode was excited on the glass substrate, and the surface of the gel was deformed by the acoustic radiation force acting to the boundary between the gel surface and the surrounding air. The incident light is refracted at the gel surface with a convex shape and the transmitted light is focused.

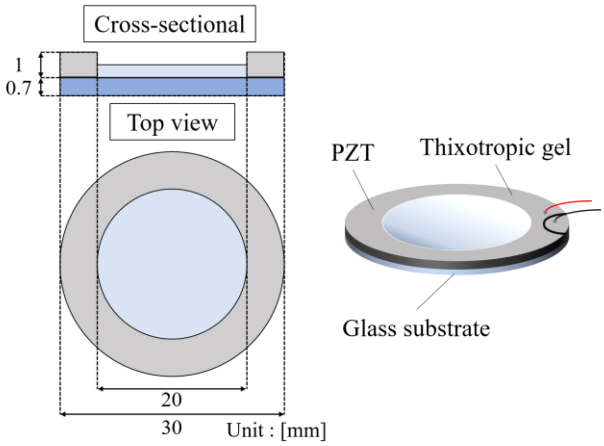

Fig. 1 Ultrasound variable focus optical lens using a thixotropic gel.

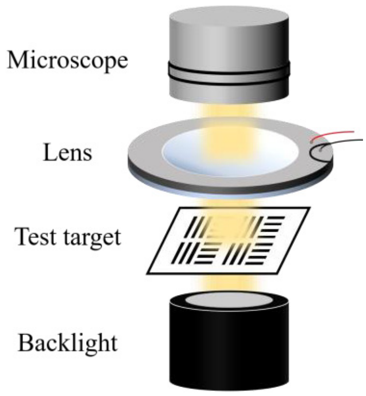

Fig. 2 Experimental setup for the observation of the focus change.

Figure 2 shows the experimental setup for the observation of the focus change. The gel lens was arranged parallel to a test target and the object lens of an optical microscope (VW-300C, Keyence) along the optical axis. We defined the lens shape in the case with 1 V as the default profile where the distances between the object lens and the target was 15.6 mm. The focal length under ultrasonic excitation was measured from the optical images of a test target with changing the driving voltage amplitude to the lens and the position of the test target on the optical axis. The same experiments were conducted five times by reforming the gel. The light transmittance spectra of the lens were measured using a UV-VIS spectrophotometer (UV-2450, SHIMADZU) at the wavelength of 190 to 900 nm. All the experiments were conducted under a room temperature at 25 °C.

3. Results and discussion

Figure 3 shows the vibration distribution of the glass substrate of the lens at the resonance frequency of 71 kHz. The vibrational amplitude was normalized by the maximum value. When the input voltage was 10 V, the maximum displacement amplitude at the center was 1.99 μm. **Figure 4** shows the representative photographs through the lens without and with ultrasound excitation. By exciting the lens, the surface profile of the lens was deformed, and the focal position of the lens was changed. **Figure 5** shows the relationship between the input voltage to the transducer and the focal length of the lens. Plots and error bars indicate the average value and the standard deviation for five measurements. Larger input voltage gave larger displacement on the lens surface and shorter focal length; the maximum displacement on the lens surface was 48.3 μm and the change in the focal length was 15.1 mm in the case with the input voltage of 4.0 V.

Figure 6 shows the light transmittance spectra of the lens. The transmittance was 70 to 80% in the visible light range (380 to 780 nm). Considering the practical applications in electric devices, the transmittance over 90% is required.

4. Conclusion

The variable-focus gel lens using ultrasound and a thixotropic gel was developed. The optical characteristics of the lens were investigated. The focal point could be controlled by changing the input voltage. In future research, we intend to investigate the response speed of the focusing on the lens.

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.

References

1. D. Koyama, et al: Appl. Phys. Lett. **100** (2012) 091102.
2. K. Masuda, et al: IEEE, **118** (2018) 353 pp.11–14.
3. D. Sakata, et al: Proc. 40th Symp. Ultrasonic Electronics, (2019) 1P4-8.

dkoyama@mail.doshisha.ac.jp

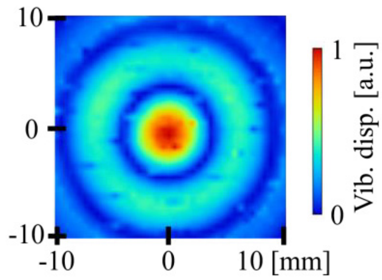

Fig. 3 Vibration distribution of the glass substrate at 71.1 kHz.

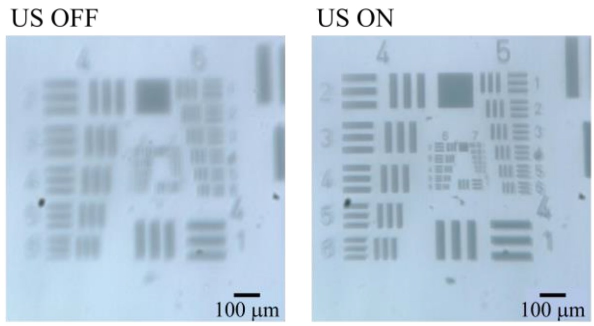

Fig. 4 Optical images captured through the lens (L) without and (R) with ultrasound excitation.

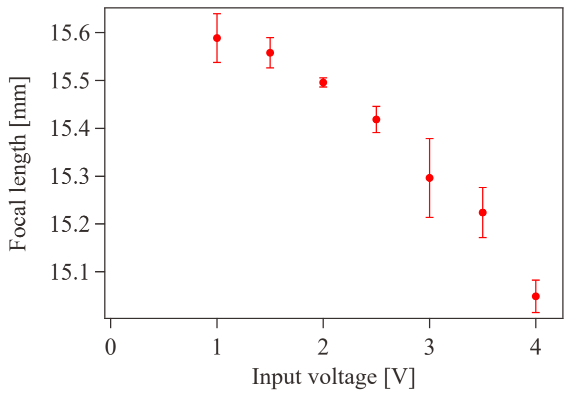

Fig. 5 Relationship between the focal length of lens and the input voltage to the lens.

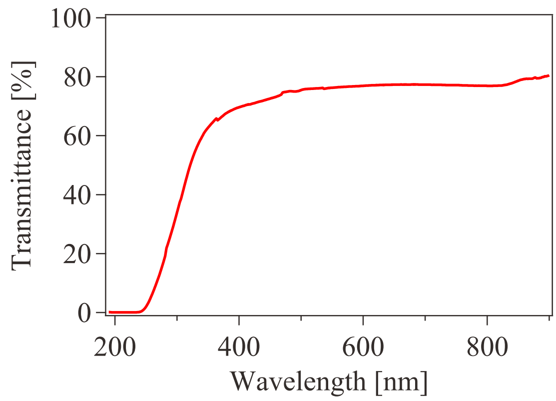

Fig. 6 Light transmittance spectra of the lens.