1P4-8

Control of surface profile of a vari-focal 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表面形状制御

Daiko Sakata[1†], Daisuke Koyama[1], and Mami Matsukawa[1] ([1]Faculty of Science and Engineering, Doshisha Univ.)

坂田　大昂 [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. We employed a thixotropic gel as the lens material so that the deformation of the lens profile can be maintained with no electric consumption[2]. In this paper, we examined a variable focus lens using a thixotropic gel and ultrasound vibration.

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 gels with the mass ratio of 6, 7, and 8% were 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 is 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 and the surrounding air. The temporal change of the gel deformation under ultrasound excitation was observed in the range of ± 4 mm from the center of the lens by a laser displacement meter (LT-9000, Keyence). The vibration distribution of the glass substrate was measured by a laser Doppler vibrometer.

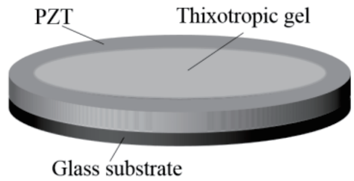

Fig. 1 Ultrasound variable focus optical lens using a thixotropic gel.

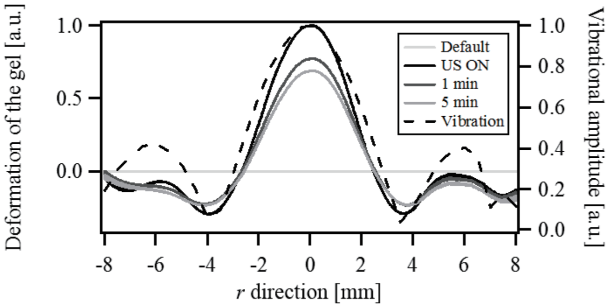

Fig. 2 Surface profiles of the thixotropic gel and the vibrational amplitude distribution.

3. Results and discussion

There were several resonance frequencies of the lens over 20 kHz, and the resonance mode at 70.6 kHz where the concentric flexural vibration with two nodal circles appeared on the glass substrate was used. By applying the input voltage to the transducer, the surface of the gel was deformed statically by the acoustic radiation force. **Fig. 2** shows the temporal change of the surface profile of the gel in the radial direction after switching off the ultrasound excitation in the case of the mass ratio of 7 % and the input voltage of 10 V_{pp}. The maximum displacement of the gel and the maximum vibrational amplitude of the glass substrate at the center were 94.2 μm and 20.3 μm, respectively. The dotted line shows the vibrational distribution of the glass substrate, indicating that there is a correlation between the deformation on the gel surface ("US ON") and the vibrational distribution of the glass substrate. When the ultrasound excitation was switched off, the displacement of the gel surface decreased gradually, but the gel surface did not return to the default position (0 mm) after 5 min. This result implies that the viscosity of the thixotropic gel was decreased temporarily by ultrasound excitation and increased again after switching off the ultrasound. **Fig. 3** shows the surface profiles of the gel in the steady state under ultrasound excitation when changing the input voltage. Larger input voltage gave larger displacement of the gel. The relationship between the input voltage and the maximum displacement at the center of the lens (r = 0) was shown in **Fig. 4**. Considering the practical application as a variable-focus lens, the fact that the displacement of the gel surface increases with the input voltage up to 10 V_{pp} and saturated over 10 V_{pp} means that the focus point can be controlled by the input voltage. The surface profile of the gel was determined by the balance among the elasticity, density, and the thickness of the gel and the acoustic radiation force.

The temporal change in the deformation displacement of the gel at the center was observed by switching on (t = 0 s) and off (t = 900 s). **Fig. 5** shows the representative result in the case of the gel with a mass ratio of 8 % and 20 V_{pp}. If we term the deformation displacements at t = 900 and 1700 s with and without ultrasound excitation A and B, respectively, the preservation rate R can be defined as $R = B/A$. **Table 1** shows the preservation rates for the lens with the mass ratios of 6, 7, and 8%. The input voltage of 20 V_{pp} was applied to the lenses. As the mass ratio of the gel increased, the deformation displacement A decreased since the elasticity and viscosity of the gel increased with the mass ratio. On the other hand, the preservation rate R also increased with the mass ratio of the gel. This is because the thixotropic of the gel is based on the hydrogen bonds between the silica and the number of hydrogen bonds contained per unit volume increased with the mass ratio. By increasing the mass ratio of the gel, the recovery of the viscosity was accelerated after switching off the ultrasound excitation.

Table 1 Mass ratio and the preservation rate.

Mass ratio	6 %	7 %	8 %
R	57 %	62 %	67 %
A [µm]	389	275	163
B [µm]	222	170	110

4. Conclusion

The variable-focus gel lens using ultrasound and thixotropic gel was developed. The lens can maintain its deformation without electric power supply. In future research, we intend to investigate the optical characteristics of 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: IEICE, **118** (2018) 353 pp.11-14.

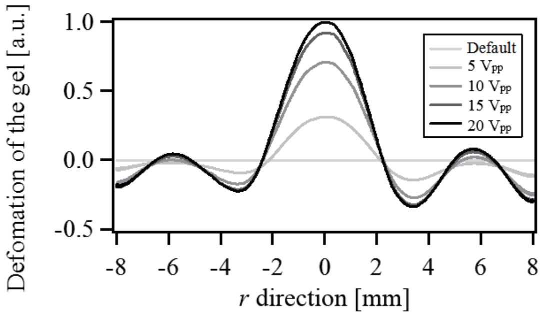

Fig. 3 Relationship between the input voltage and the displacement of the gel.

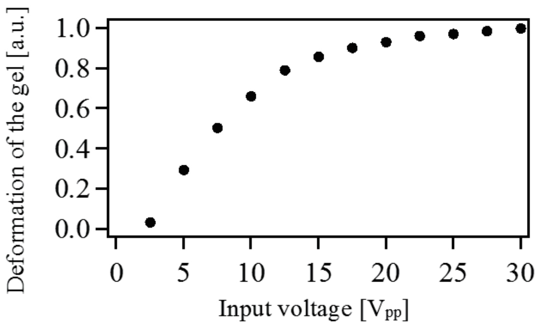

Fig. 4 Relationship between the input voltage and the maximum displacement of the gel at the center.

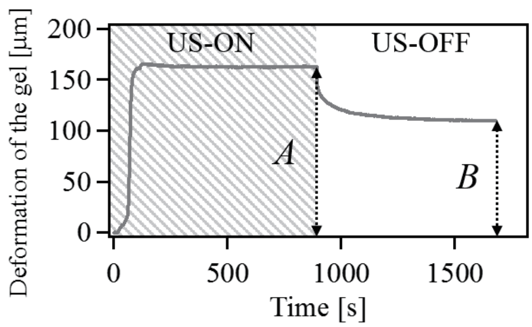

Fig. 5 Temporal change in the displacement of the gel with the mass ratio of 8 %.

dkoyama@mail.doshisha.ac.jp