1P4-6

Rayleigh wave excitation at multiple frequencies by an elliptical reflector focusing structure

Kyohei Yamada[1‡], Shoki Ieiri[1], Shinsuke Itoh[2], Takashi Kasashima[2], Chikahiro Imashiro[1], Jens Twiefel[3], and Takeshi Morita[1*] ([1]The Univ. of Tokyo; [2]Niterra; [3]Leibniz Univ. Hannover)

1. Introduction

Surface acoustic wave (SAW) is an elastic wave propagating on the surface of a solid material. SAW devices are suitable for high-power applications, such as ultrasonic motors (SAW motors),[1)] surface haptics, lab on a chip, cell manipulation, droplet manipulation,[2)] and atomization, for the following two reasons. First, vibration energy is confined to the output surface. Second, deeper parts far from the surface do not vibrate; thus, SAW devices are easily mounted at deeper points and energy leakage from the mounting points can be decreased. In previous studies of high-power applications of SAW devices, piezoelectric single-crystal ($LiNbO_3$, $LiTaO_3$, etc.) substrates with interdigital transducers were usually used as SAW devices. [1,2)] However, these types of SAW devices are not always ideal for high-power applications, which limits the performance and range of applications. Piezoelectric single-crystal substrates have low machinability, anisotropy, and high cost. In addition, the driving frequency is limited to over 10 MHz. Moreover, only one driving frequency is possible for high-power applications. It is true that multiple driving frequencies are possible if the electrode distances of the interdigital transducer vary, but the output would be weakened.

To solve these problems, we have proposed the SAW excitation mechanism with an ELliptical reflector for hIgh-Power ultraSound (ELIPS), which converts the thickness vibration of a piezoelectric plate to the Rayleigh wave, a kind of SAW.[3)] In this study, we realized Rayleigh wave excitation at four frequencies between 1 MHz and 10 MHz by using a single transducer. Multiple-frequency driving would be advantageous for controlling the atomized droplet size, designing the haptic experience, and studying the frequency dependency of the ultrasonic effect on the biological cell.

2. Principle of multiple-frequency driving

Fig.1 shows the proposed mechanism of the Rayleigh wave excitation.[3)] First, alternating voltage is applied to the PZT plate polarized in the thickness direction, and it vibrates in thickness modes. Second, the dilatational wave is emitted into the solid medium and reflected by the ELIPS. Then, it is converted to a focusing shear vertical (SV) wave by mode conversion. At the focal point, it vibrates vertically to the propagation surface. Because vertical vibrations are dominant in Rayleigh wave particle motions, finally, the Rayleigh wave is excited on the propagation surface

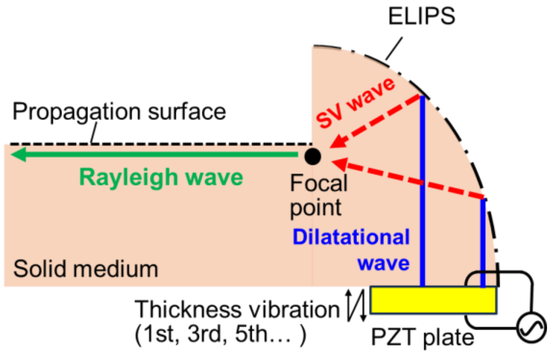

Fig. 1 Principle of the Rayleigh wave excitation at multiple driving frequencies.

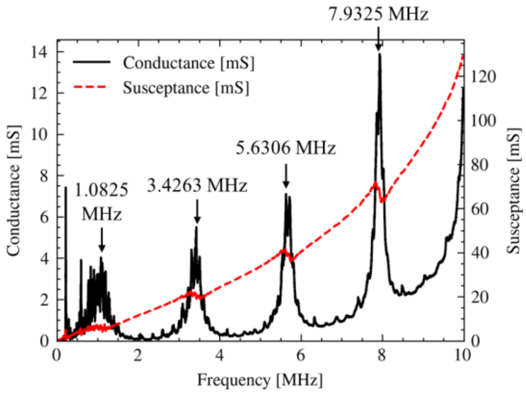

Fig. 2 Admittance characteristics of the prototype.

In the previous study,[3)] we verified that it works at the 1st thickness resonance frequency of the PZT plate. As a next step, higher thickness modes (3rd, 5th, and 7th) of the PZT plate are also utilized to realize the multiple-frequency driving in this study. **Fig. 2** shows the admittance characteristics of the prototype of the proposed structure made of duralumin. Peaks at 1.0825 MHz, 3.4263 MHz, 5.6306 MHz, and 7.9325 MHz correspond to the 1st, 3rd, 5th, and 7th thickness modes of the PZT plate. At these frequencies, we examined Rayleigh wave excitation.

E-mail: ‡yamada-kyohei355@g.ecc.u-tokyo.ac.jp, *morita@pe.t.u-tokyo.ac.jp

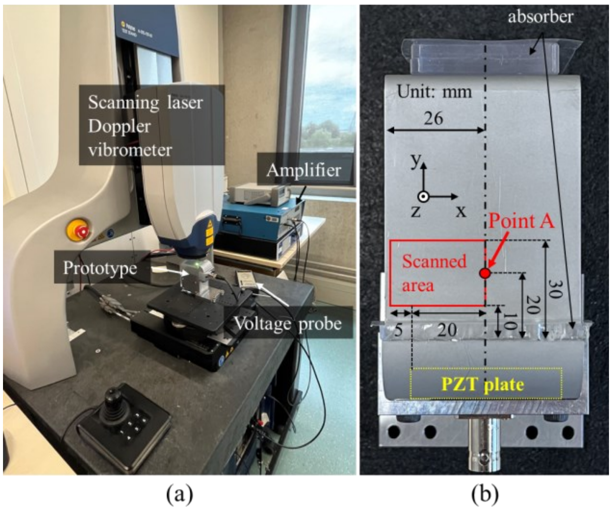

Fig. 3 Experimental setup. (a) measurement system. (b) Scanned area on the prototype.

3. Rayleigh excitation at multiple frequencies

To observe the Rayleigh wave propagation, the vibration velocity was measured with a scanning laser Doppler vibrometer (PSV500, Polytec, Waldbronn, Germany), as shown in **Fig. 3(a)**. First, the vibration velocity trajectory was measured at the point A, shown in Fig.3(b). Second, the distribution of the vibration velocity perpendicular to the surface was measured in the scanned area shown in Fig. 3(b). The measured points step in the y direction was 0.12 mm, and that in the x direction was 1 mm at the part from 0 mm to 20 mm from the right edge and 0.12 mm at the other part.

Fig. 4 shows the comparisons of the particle velocity trajectory between the Rayleigh wave and the measured result. The measured trajectory matches that of the Rayleigh wave at each frequency, though there are slight inclinations between them, which might be because of the overlap of unintended reflected waves.

Fig. 5 shows the scanned results. Parallel wavefronts were observed at the area in front of the PZT plate although some parts are strengthened by interferences at 3.4263 MHz, 5.6306 MHz, and 7.9325 MHz. In the left parts, wave spreading were observed.

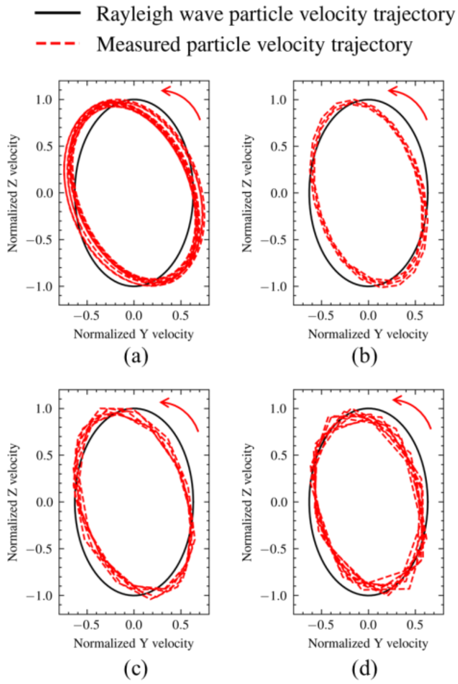

Fig. 4 Comparison between the Rayleigh wave particle velocity trajectory and the measured particle velocity trajectory at (a) 1.0825 MHz, (b) 3.4263 MHz, (c) 5.6306 MHz, and (d) 7.9325 MHz.

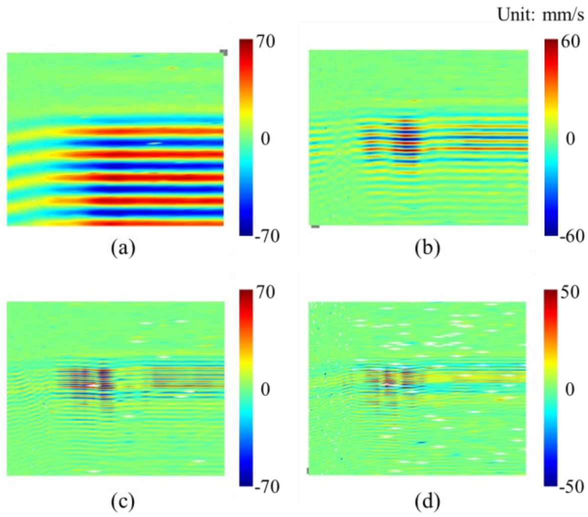

Fig. 5 Vibration velocity distribution at 15 μs from the beginning of applied voltage at (a) 1.0825 MHz, (b) 3.4263 MHz, (c) 5.6306 MHz, and (d) 7.9325 MHz.

4. Conclusion

Rayleigh waves were excited at four frequencies between 1 MHz and 10 MHz by using a single transducer. It would widen the driving frequency of high-power SAW to the megahertz range and multiple driving frequencies would be helpful for the performance improvement of high-power applications of SAW devices.

Acknowledgment

This work was supported by JSPS Overseas Challenge Program for Young Researchers, Satomi Scholarship Foundation, and JSPS KAKENHI Grant Numbers JP23KJ0660 and JP24K00830.

References

1) M. K. Kurosawa, *Ultrasonics*, **38**, pp. 15–19, (2000).
2) J. Kondoh, *Jpn. J. Appl. Phys.* **57**, 07LA01 (2018).
3) K. Yamada, S. Ieiri, S. Ito, T. Kasashima, and T. Morita, *Sens. Actuator A Phys.*, **370**, 115253, (2024).