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Surface acoustic wave excitation by an elliptical reflector transducer

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1. Introduction

Surface acoustic wave (SAW) devices are essential in various fields, such as electronic components, sensors, and actuators[1)]. In general, interdigital transducers (IDT) or wedge transducers are used to excite SAW. However, for IDT excitation, the piezoelectric materials must be piezoelectric single crystals with low electromechanical coupling coefficients (LiNbO$_3$: 5.5 %, LiTaO$_3$: 0.64 %)[2)]. For wedge transducers, the wedge materials are generally limited to resins with large attenuations since it must have slow phase velocity.

In this study, we propose a novel Rayleigh wave excitation principle by using an elliptical reflector transducer. It enables the propagating media to be high-Q materials like metal, glass, and silica. Moreover, piezoelectric materials, such as PZT, with higher coupling coefficients can be selected as a vibration source. The proposed driving principle would excite Rayleigh waves efficiently, which would widen the application fields, especially high-power applications such as actuators and atomizers in the megahertz range.

2. Rayleigh wave excitation

Rayleigh wave vibration has elliptical orbits with horizontal displacement u and vertical displacement w. Vertical displacement w is larger than horizontal displacement u at the points of any depth, and the phase velocity of Rayleigh wave is similar to that of transverse wave (0.93 times of transverse wave in Duralumin). Based on these similarities between Rayleigh and transverse waves, we expected that the transverse displacements could excite Rayleigh waves as a vibration source.

To verify the Rayleigh wave excitation with transverse wave source, we conducted a finite element method (FEM) simulation with FEMTET (Murata Software) with the simulation model as shown in **Fig. 1**(a). The wave source with a length of 5 mm vibrates with a displacement of 1 μm in vertical direction in 5 cycles at 1 MHz. The length and width of the wave propagation medium (Duralumin) were 100 mm and 50 mm, respectively, which were large enough for no reflection at the boundary in the simulation time of 25 μs. The result is shown in Figs. 1(b) and (c). Figure 1(b) shows a contour plot of the displacement magnitude at 25 μs. In this figure, the surface-concentrated waves with a vertical amplitude of 1.5 μm are indicated. To identify this wave, u and w distributions along the Z1 and Z2 axes shown in Fig. 1(b) were compared with the analytical waveform of Rayleigh wave, as shown in Fig. 1(c). As a result, the u and w distributions in this simulation agreed with the analytical waveform of Rayleigh wave. Thus, Rayleigh wave excitation with transverse vibration is proven possible. Although not shown here, an excitation with horizontally displacing wave sources was also simulated; however, Rayleigh wave were hardly excited.

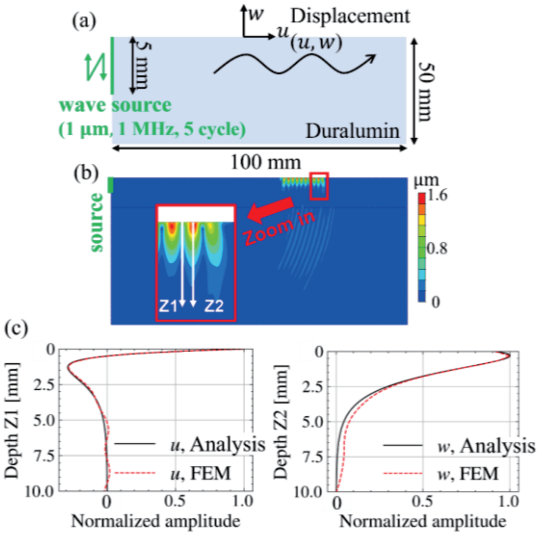

Fig. 1 FEM simulation of Rayleigh wave excitation by transverse vibration. (a) Simulation model, (b) vibration amplitude distribution, and (c) waveform comparison with Rayleigh waveform in analysis.

3. Elliptical reflector

To generate high-power transverse waves, we propose a wave-focusing and mode-conversion (dilatational to transverse) mechanism with an

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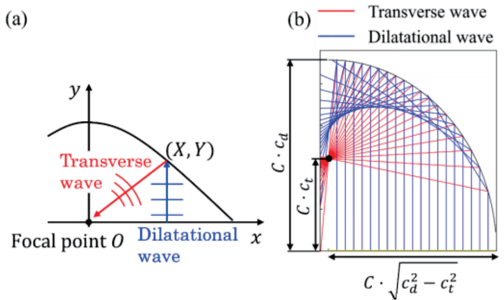

Fig. 2 Reflector design. (a) Reflector characteristics, (b) acoustic path based on Snell' law.

elliptical reflector. Here, the incident waves to the reflector are dilatational waves with plane wavefronts generated by a piezoelectric plate with thickness modes.

To convert the incident plane dilatational waves to the focused transverse waves, as shown in **Fig. 2**(a), the propagation time to the focal point should be constant. Hence, we obtain

$$\frac{Y}{c_d}+\frac{\sqrt{X^2+Y^2}}{c_t}=C_0\ (constant). \qquad (1)$$

Note that c_d and c_t are dilatational and transverse phase velocities. Equation (1) can be transformed to

$$\frac{X^2}{\left(C\cdot\sqrt{c_d^2-c_t^2}\right)^2}+\frac{(Y+C\cdot c_t)^2}{(C\cdot c_d)^2}=1, \qquad (2)$$

where C denotes $\frac{C_0 c_t c_d}{c_d^2-c_t^2}$. Equation (2) means that the reflector shape is ellipse shown in Fig. 2(b).

Figure 2(b) is an acoustic path calculation result based on Snell's law. The incident dilatational wave focuses as a transverse wave as designed.

4. Simulation of elliptical reflector transducer

We designed an elliptical reflector transducer by combining the piezoelectric plate, the elliptical reflector, and the Rayleigh-wave-propagating surface. To verify the proposed SAW exciting principle, FEM simulation was conducted with the simulation model shown in **Fig. 3**(a) with COMSOL Multiphysics. The piezoelectric material was PZT MT-812A (Niterra Co., Ltd.) with an electro-mechanical coupling coefficient k_t of 48%. The thickness, width, and depth were 2 mm, 8 mm, and 40 mm, respectively. The continuous driving signal to PZT was 1 $\mathrm{V_{pp}}$. The driving frequency is swept from 1 kHz to 2 MHz with a step of 0.2 kHz. In this setup, the vibration amplitude at point A and on the Z-axis, shown in Fig. 3(a), is calculated. Point A is on the surface and 40 mm away from the reflector; the Z-axis extends from point A in the depth direction.

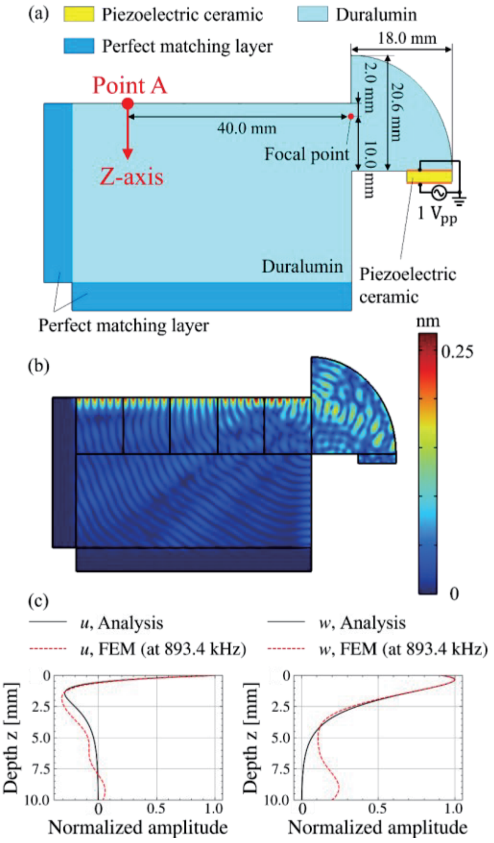

Fig. 3 FEM simulation of elliptical reflector transducer. (a) Simulation model, (b) vibration amplitude distribution, (c), waveform comparison with Rayleigh waveform in analysis.

The simulation result verified that Rayleigh wave could be excited with multiple resonant frequencies (over 10 frequencies) around 1 MHz (the thickness resonant frequency of the piezoelectric plate alone was 1.07 MHz). The maximum vibration amplitude with a driving frequency around 1 MHz was 0.2 nm at 0.893 MHz. A contour plot of the displacement magnitude at 0.893 MHz is shown in Fig. 3(b). The u and w distributions along the Z-axis at 0.893 MHz agreed with the analytical waveform of Rayleigh wave, as shown in Fig. 3(c).

5. Conclusion and future work

The elliptical reflector transducer could excite the Rayleigh wave with an amplitude of 0.2 nm at 0.893 MHz under 1 $\mathrm{V_{pp}}$. In the future, design optimization for high-power output will be studied.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Numbers JP20H02097, JP21KK0065, and JP23KJ0660.

References

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