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Development of 1-3 ceramic-air composite transducers for air-coupled ultrasonic measurement
空中超音波計測のための 1-3 セラミック-空気コンポジット探触子の開発

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1. Introduction

Air-coupled ultrasonic transducers must have both low acoustic impedance and large electromechanical coupling coefficient to overcome large acoustic impedance mismatch with the propagation media (the air). It's a common problem with medical ultrasonic transducers and 1-3 piezoelectric ceramic-polymer composites were developed[1)]. However, the vertical effect of piezoelectric element pillars partly cancelled by the transverse effect so long as using solid matrix[2)]. Then, 1-3 ceramic-air composites (air composites; AC) were studied for maximising the vertical effect and suppressing the noise between the ceramic pillars[2)], and later applied for air-coupled ultrasonic transducers with acoustic matcing layers[3)]. However, there is demand for improving the transmission efficiency in nondestructive inspection[4)].

Although the variation in local acoustic impedance of the air composite is large, the phase front becomes in phase similar to existing polymer composites when using thick front plate. However, we have studied the usefulness of large-amplitude local vibration of thin front plate for air transmission. In this study, the effectiveness of this principle is verified exprimentally.

2. Principle

Figure 1 shows schematics of AC transducers. Conventional air composites (C-AC) are designed for generating uniform displacement u_a to satisfy element-pillar distance (kerf width) w much shorter than the wavelength of A0 mode Lamb wave λ_{A0}[2)] **[Fig. 1(a)]**. In reference 2, the relation

$$w < \lambda_{A0}/4 \quad \cdots(1)$$

was proposed. On the other hand, **Fig. 1(b)** shows thin-plate air composite (T-AC) with the front plate thickness much smaller than w. Local deflection resonant vibration with amplitude u_b occurs in the plate on the kerf since w may become comparable to λ_{A0}. Since the magnitude is

$$|u_b| \gg |u_a| \cdots (2),$$

effective transmission can be obtained is spite of the pahse opposite to that of the elements (u_a).

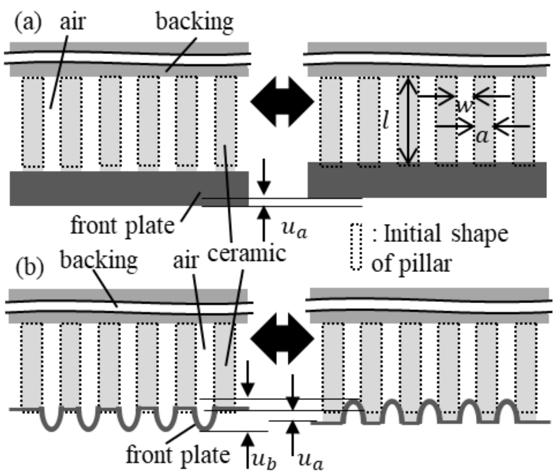

Fig. 1 Schematics of AC transducers with (a) thick and (b) thin front plates, where a, l are the width and length of an element pllar, w is the kerf width, u_a and u_b are the maximum displacement.

3. Experiment

3.1 Design and fabrication of transducers

The transducers were designed for transmiting the tone burst wave at 400 kHz and fabricated by dicing PZT ceramics (Fuji Ceramics, C9). Aluminum tape (Teraoka Seisakusho, No.8303) was laminated as backing (t_B=0.5 mm) to reduce the electrode plate vibration. To obtain similar waveform to the excitation signal, the resonance of element pillars was determined near 600 kHz higher than 400 kHz with a=0.95 mm and l=2.0 mm. Next, the deflection resonance of T-AC was tuned to 400kHz with t_F=0.1 mm and w=0.7 mm (λ_{A0}=0.7 mm). Finally, the thickness of the front plate of C-AC was determined as t_F=0.5 mm (λ_{A0}=3.25 mm) with w common.

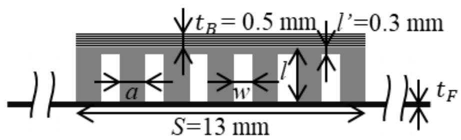

Fig.2 Design parameters for AC transducer.

3.2 Air-transmission measurement

Figure 3 shows shematics of air-transmission mesurement. The excitation signal was sine wave tone burst (30 cycles, 800Vpp). The waveform was recorded by small probe (KGK, 3 mm diameter, 30MHz) at the distance of 50 mm (near-field distance) on the center axis.

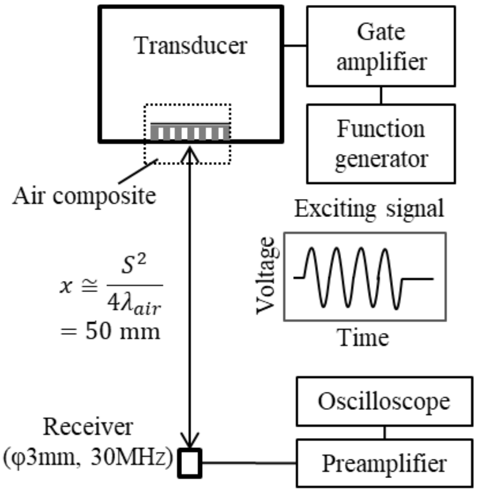

Fig. 3 Schematics of air-transmission measurement.

4. Result

4.1 Resonance characteristics

Figure 4(a) shows impedance spectrum of C-AC transducer. The local minimum was observed at 420 kHz. **Fig.4(b)** shows the result of T-AC one. Local minima appeared and the lowest value of them was judged as the resonance (500 kHz). The increase of the frequency of T-AC transducer may be explained by the decrease of the mass of the front plate.

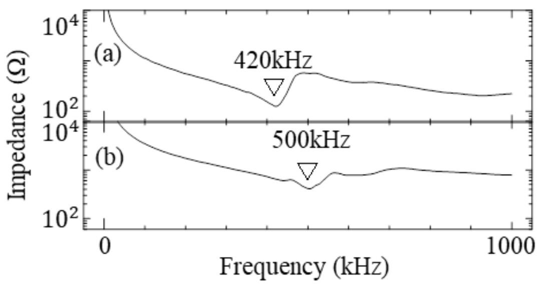

Fig. 4 Impedance spectra of transducers with (a) C-AC and (b)T-AC transducers.

4.2 Air-transmission waveforms

Figure 5 shows air-transmission waveforms at the resonances. Although we expected siginificant waveforms, the waveforms were poorly differenet from the excitation signal. For each case, period (ii) was small amplitude of excitation frequency and periods (i) and (iii) were relatively large amplitude with the center of 370kHz.

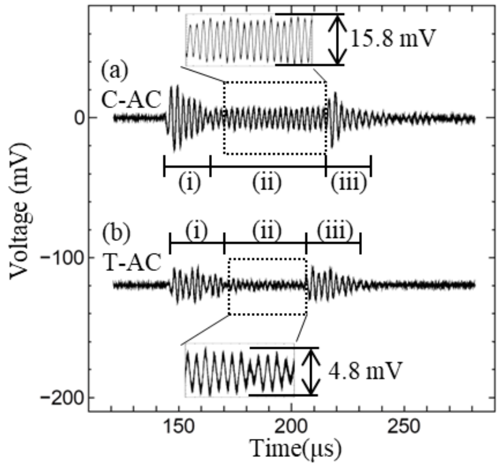

Fig. 5 Air-transmission waveforms at the resonances. (a) C-AC (420 kHz) and (b)T-AC (500 kHz) transducers.

Figure 6 shows air-transmission waveforms at 370kHz. The amplitude of T-AC transduer was 1.25 times larger than that of C-AC one in spite of effective transmission area less than 20%, suggesting the usefulness of the relation (2).

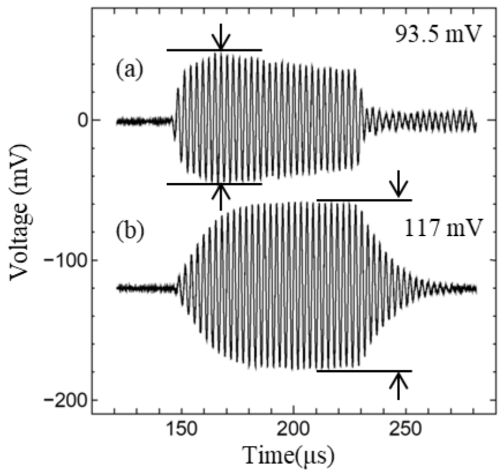

Fig. 6 Air-transmission waveforms at 370kHz. (a)C-AC and (b)T-AC transducers.

5. Conclusion

Large-amplitude vibration of the thin front plate was effective for the air transmission. We will study the relationship between the resonance characteristics and the vibration pattern on the plate, and the expanding method of the transmission area.

Reference

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