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Mode-selective excitation of resonance vibration for piezoelectric rectangular parallelepiped using plate antennas
平板アンテナによる圧電直方体の共振モードの選択的励起に関する研究

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1. Introduction

In piezoelectric resonators, surface acoustic wave (SAW) and bulk acoustic wave (BAW) propagating in plate-shape piezoelectric materials are used, and by changing the shape of electrodes attached to the piezoelectric materials, an acoustic wave is selectively excited. However, when the in-plane lengths of the piezoelectric materials decrease and approach the wavelength of acoustic waves, free mechanical vibrations are excited instead of the SAW and BAW, which prevents minimization of the conventional resonators. For making the in-plane scales of oscillators smaller, mechanical free vibrations must be analyzed and a method for exciting a vibrational mode that is close to and can be replaced with the conventional modes is required. In this study, we investigate free resonance vibrations of piezoelectric rectangular parallelepipeds using the Ritz method[1)].

There are various vibrational modes in an oriented rectangular parallelepiped, and they are classified into some groups (A_g, B_g, A_u, and B_u groups for an oriented rectangular parallelepiped quartz). We theoretically and experimentally evaluated excitation efficiency of each mode for various specimen dimensions, and revealed that there is a specific shape to cause a BAW-like resonance mode preferentially.

2. Experimental method

We excited and detected resonance vibrations of piezoelectric materials using the antenna transmission acoustic resonance (ATAR) method[2)]. **Figure 1** shows a schematic of antennas used in the present study. It consists of input, output, and grounding copper plates. By inserting a quartz between the input and output antennas and by applying tone bursts to the input antenna, an oscillating electric field is generated between the input and ground antennas. Then, the quartz vibrates and the output antenna receives the electric field generated by the oscillating quartz. By sweeping the frequency of the input signal, a resonance spectrum is obtained. By using plate antennas larger than the quartz, an uniform oscillating electric field is applied to the quartz. The input voltage is 20 V_{pp}.

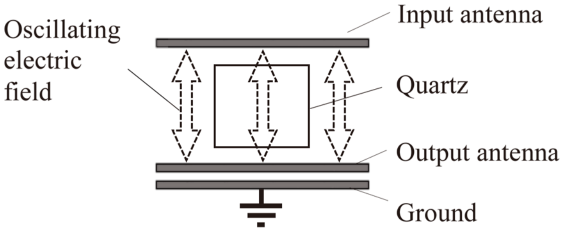

Fig. 1 Schematic of antennas used for the ATAR method.

3. Theoretical calculation

To evaluate excitation efficiency of resonance vibrations, we calculated distributions of electrical potential caused by resonance vibrations. When an applied field matches distribution of potential difference of a resonance mode, the resonance mode is excited efficiently. On the other hand, if the potential difference in the direction of the applied field is expressed as an odd function, the integration over the volume becomes zero, and the resonance mode would not be excited by the uniform field. In this study, we define the absolute value of the integrated potential difference as I. Considering the exciting and receiving processes, square of I, I^2, is defined as the total excitation efficiency.

4. Results and Discussion

We prepared a rectangular parallelepiped of α-quartz (Quartz 1), and measured resonance spectra. Then, the amplitude of each resonance peak is compared with I^2. The edges of the sample are parallel to the X, Y, and Z crystallographic axes. Dimensions of Quartz 1 are 6.0, 5.0, and 4.4 mm in the X, Y, and Z axes, respectively. **Figure 2** shows the resonance spectrum when the field is applied in the X axis. In this case, only resonance modes

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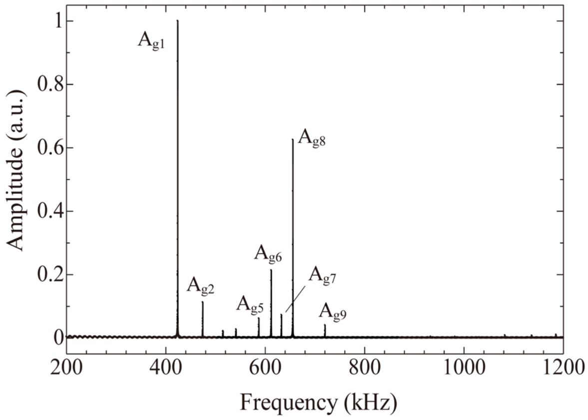

Fig. 2 Resonance spectrum of Quartz 1 measured by applying the oscillating electric field in the *X* axis.

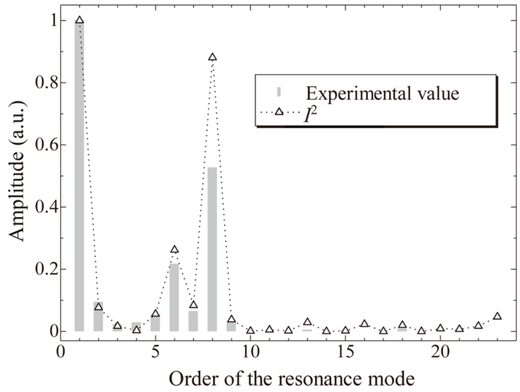

Fig. 3 Comparison between I^2 and average amplitude of the resonance peaks for resonance modes of A_g group for Quartz 1.

belonging to the A_g group were excited. This is because polarization distributions of A_g group match the symmetry of the applied field, and those of the other groups do not. **Figure 3** shows the comparison between I^2 and amplitudes of the measured resonance peaks. Resonance spectra were measured three times, and the averaged values are shown. Both I^2 and the amplitudes are normalized by the maximum values. They show good agreement, confirming that I^2 indicates the excitation efficiency when the uniform electric field is applied.

Next, we looked for sample dimensions that only a specific resonance mode is excited by calculating I^2 for various specimen dimensions. As a result, we found dimensions, measuring 3.6, 9.4, and 5.6 mm in the *X*, *Y*, and *Z* axes, respectively, in which I^2 of 13th mode of A_g group is significantly larger than the others. We prepared a quartz specimen (Quartz 2) that has the above dimensions, and measured the resonance spectrum. The results are shown in **Fig. 4**. The 13th mode of A_g group shows the largest amplitude. **Figure 5** shows the comparison between I^2 and the measured amplitudes. They are in good agreement, and we succeeded in selectively exciting a specific resonance mode by a simple flat antenna.

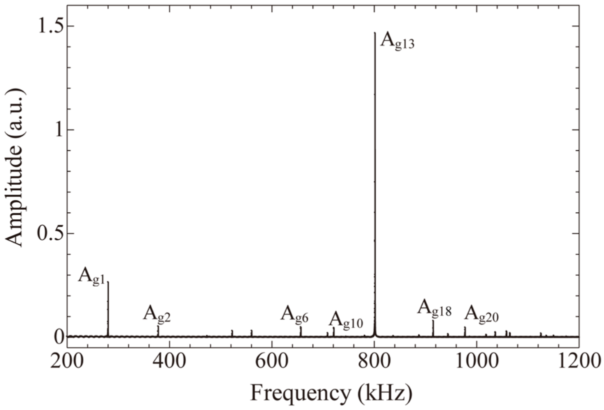

Fig. 4 Resonance spectrum of Quartz 2 measured by applying the oscillating electric field in the *X* axis.

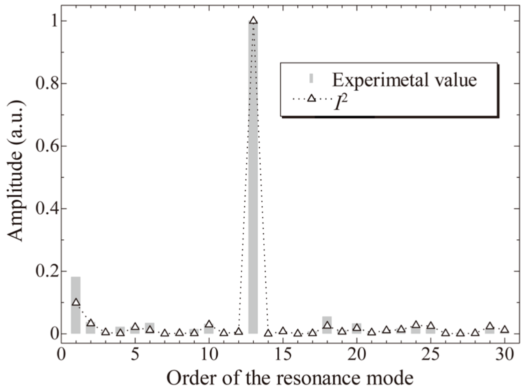

Fig. 5 Comparison between I^2 and average amplitude of the resonance peaks for resonance modes of A_g group for Quartz 2.

We analyzed vibrational behavior of the 13th mode. Its frequency is 801.2 kHz. In a quartz plate of 3.6 mm thick in the *X* axis, the through-thickness resonance frequency is 803.1 kHz, and the frequency of 13th mode is close to this value. Therefore, we consider that the enhancement of amplitude of the 13th mode is caused by the match of the frequencies of a mechanical free resonance vibration and a thickness resonance. In a rectangular parallelepiped, when ratios of the edge lengthes are close to one, thickness resonances do not occur. However, the present results indicate that thickness resonances can be excited by adjusting the specimen dimensions, and it can be used for the oscillators.

Acknowledgement

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3. References

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