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Vibration Characteristics of LiNbO3 Single Crystal Ultrasonic Transducer Driven by High Voltage Burst Wave

高電圧バースト波駆動による LiNbO3 単結晶超音波トランスデューサの振動特性

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1. Introduction

Ultrasonic imaging systems are one of the powerful tools to observe a interior in many fields, including a non-destructive inspection (NDI), a medical imaging, and a marine. The systems consist of hardware for transmitting and receiving ultrasonic signals, imaging software, and ultrasonic transducers for converting electrical power into/from ultrasonic power. The piezoelectric type of transducer is more often used than a capacitive micromachined ultrasonic transducer (CMUT) or an electromagnetic type. High SNR or high-intensity transducers can acquire images of interiors of high attenuation and/or thick materials. The methods to increase the intensity of the transducer are selecting a piezoelectric material with a high electromechanical coupling coefficient (k), processing a piezoelectric material in a composite, and/or driving a transducer with high power.

Ultrasonic transducers made of high k piezoelectric materials such as PZT (k_t=0.5 , k_{33}=0.7) and 36°-rotated Y-cut $LiNbO_3$ (k_{33}=0.5) have been developed [1]. Composite PZT transducers for medical imaging have a wide bandwidth. A PMN-PT single crystal composite has been fabricated in a photolithography-based micromachining process [2]. The intensity of PZT signals, however, decreases around 300°C of the Curie point (Tc). This is why PZT is not suitable for NDI using burst waves with a high duty ratio or for high intensity focused ultrasonic (HIFU) treatments. On the other hand, a $LiNbO_3$ single crystal can be used as a transducer up to 1000°C because of its high Tc [3]. There are several reports on single-crystal $LiNbO_3$ transducers, but none on composites.

In this study, we fabricate a 36°-rotated Y-cut $LiNbO_3$ (LN) composite transducer with high-intensity output characteristics and measure vibration properties of its surface when driven by high-voltage burst waves.

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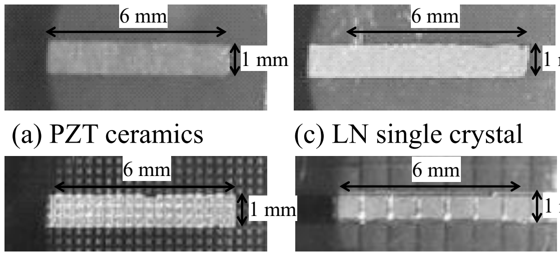

(a) PZT ceramics (c) LN single crystal
(b) PZT composite (d) LN composite

Fig. 1 Photograph of surfaces of prototype transducers.

2. Prototype Transducers

Four ultrasonic transducers used thin plates of (a) a PZT ceramic, (b) a PZT composite, (c) a LN single crystal, and (d) a LN composite were fabricated. The plates were electroplated by sputtering a gold layer. A polyimide film was bonded to a measurement surface as a protection layer that was a 50 µm thickness. The other sides had air boundary conditions. The thicknesses of the piezoelectric material corresponded to a resonant frequency around 1.6 MHz. **Fig. 1** shows the surfaces of the transducers, which measured 1 mm x 6 mm. The electrodes were connected to a BNC. The resonant frequencies calculated from the electrical impedances were respectively (a) 1.57 MHz, (b) 1.60 MHz, (c) 1.45 MHz, and (d) 1.35 MHz as shown in **Fig. 2**.

3. Experiment

Vibration displacements of the transducer surfaces were measured by laser vibrometer (OFV-2700, Polytec). Driving waves of the transducers were 100-cycle tone bursts from a waveform generator (A1493, NF) and a 50-dB fixed amplifier (3100L, NEI). The waveform generator controlled the input voltage in steps of 0.01 V.

4. Results and Discussion

Fig. 3 shows the measured vibration displacements of the transducer surfaces. The PZT ceramics (a) and the LN single crystal (c) show similar tendencies below 220 V. The displacements of (a) rapidly decrease above 220 V and do not increase over the whole input voltage range. The result indicates that the morphotropic phase boundary may exceed by great amplitudes and/or self-heating. In contrast, the LN single crystal (c) vibrates in the amplifier limitation range of 300 V.

The PZT composite (b) has a lower input voltage than the ceramic (a) for the same displacement, while the displacement saturates above 60 V. No vibration displacement is detected above 70 V, similar to the case of (a). On the other hand, the LN composite (d) has an equivalent displacement to that of the single crystal (c) but at a lower input voltage below 100 V as we expected. The vibration displacements of the LN composite (d) saturate above 100 V and do not disappear.

The measured frequency dependences of the LN single crystal (c) and the composite (d) at 190 V are shown in **Fig. 4**. The fundamental resonant frequency is about 1.45 MHz for the LN single crystal and 1.35 MHz (of similar intensity) for the composite. Furthermore, harmonic frequencies occur because of the displacement limitation of the transducer against expectations.

5. Summary

We fabricated a LN composite transducer with high-intensity output characteristics and measured its surface vibration properties driven by tone burst waves. The result of the measured displacement dependence indicated it had a lower input voltage compared with a LN single crystal transducer for an equivalent displacement as we expected. The result of the measured frequency dependence suggested that there was a limitation for the transducer to output high intensity by driving in a high voltage because harmonic frequencies occurred after the vibration displacement saturated.

References

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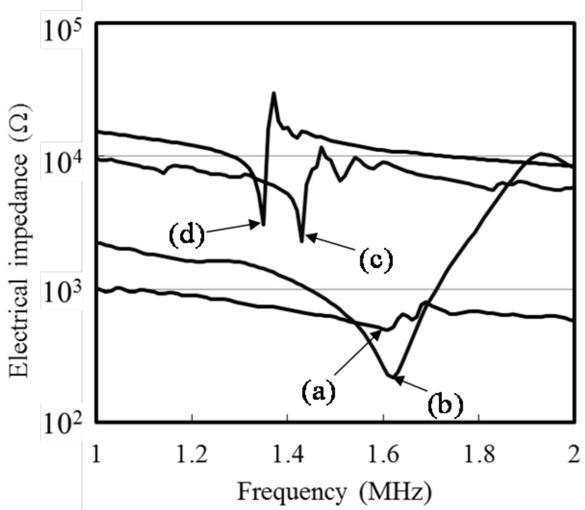

Fig. 2 Measured electrical impedance dependence of prototype transducers.

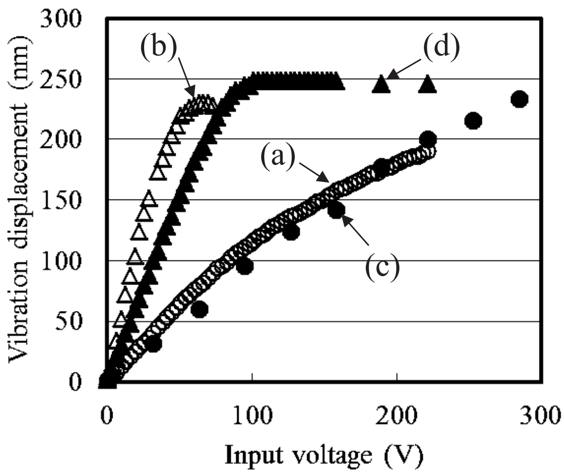

Fig. 3 Measured vibration displacement dependence of transducer surfaces.

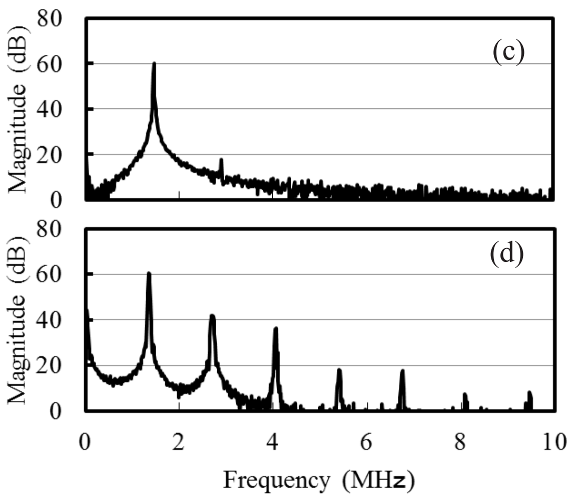

Fig. 4 Measured frequency dependence at 190 V input of (c) the LN single crystal and (d) the LN composite.