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Development of laminated lithium niobate transducer available at 500°C

500℃で利用可能な積層ニオブ酸リチウムトランスデューサの開発

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1. Introduction

In thermal power plants operated above 500°C, it is important to monitor material defects such as creep voids and wall thinning detected in periodical inspections. Sol-gel piezoelectric thin-film transducer is one of promising candidates for an ultrasonic measurement applicable at high temperature (HT) due to high signal-to-noise (SN) ratio in back-reflection echo measurements and the compliant nature to cope with enormous thermal strain [1,2]. However, it is difficult to be used for the large-amplitude transmission, essential for securing SN ratio in inspecting highly attenuated materials' of power plants[3]. Single crystal lithium niobate ($LiNbO_3$; LN) transducer with high Curie temperature (1210°C) is applicable for HT measurement. However, the piezoelectric constant of thickness vibration is only half of that of typical piezoelectric ceramics for industrial ultrasonic probes even in most efficient 36° rotated Y-cut substrate[4]. In this situation, the laminated transducers bonding the thickness vibrators with opposite polarization facing each other may be useful for enhancing the piezoelectric constant effectively due to increasing electric field. However, bonding method for HT probes has not been established. In this study, we develop laminated LN transducer withstood at 500°C investigating the effectiveness of thermal diffusion bonding with Au thin film.

2. Laminated LN transducer

Figure 1 shows LN vibrators of 36° rotated Y-cut LN substrate. We fabricated 3.2MHz vibrators for future application to highly attenuated materials. **Fig.1(a)** shows a schematic diagram of conventional single-layer vibrator[3]. Au electrode (300nm) on Cr adhesion layer (50nm) typically for room temperature devices was deposited using physical vapor deposition (Sanyu Electron, SVC-700) with circular shape to reduce spurious vibrations. On the other hand, for the laminated vibrator **[Fig.1 (b)]**, Au electrode (500nm) with Ta adhesion layer (20nm) was deposited using magnetron sputtering (Shibaura Mechatronics, CFS-4ESII), and thermal diffusion bonding was performed using a wafer bonding machine (SUSS Micro Tec, SB6e). Note that Cr severely diffuses into Au around 500°C although melting points of all electrode materials are higher than 1000°C.

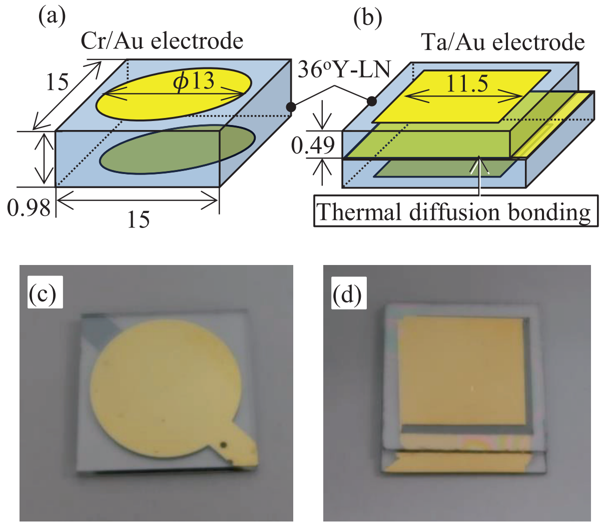

Fig.1 LN vibrators. Schematics of (a)single layer and (b) laminated vibrators. (c, d) Pictures.

3. Experiment

Figure 2 shows the schematics of testing holder to measure electrical impedance at HT. The core wire (Ni) and sheath of HT coaxial cable (Nihon Heat Resistant Wire Industry, nominal upper limit temperature of 500°C) were screwed to the holder, via conductive cushion (Au foil). Each vibrator **[Fig.1(c) and (d)]** was fixed to the holder and installed in electric furnace (Nidec, petit DUA-01), and measured the impedance spectra in the range of 28°C to 500°C (Hioki, IM-7580). After cooling down 28°C, the vibrators were excited with spike signal of -100 V at open circuit using a pulser (ISL, FPRIa), and measured the surface displacement waveforms using a laser vibrometer (Polytec, OVF-2570).

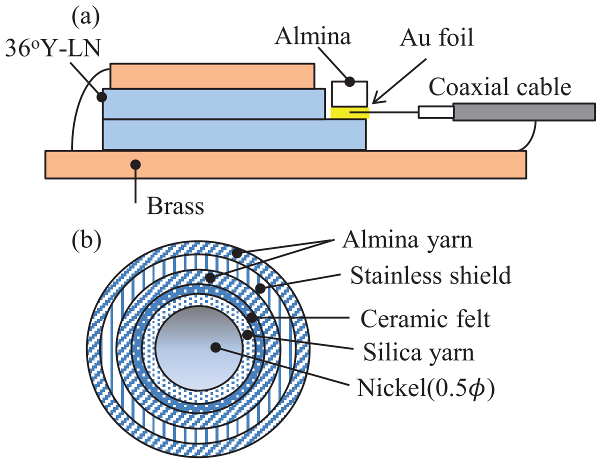

Fig.2 Schematics of test holder for electrical impedance measurement. (a) Connection of laminated LN transducer to HT coaxial cable. (b) Cross section of HT cable.

3. Result

3.1 Variation of impedance spectra

Figure 3 shows typical impedance spectra during increasing up to 500°C. For the single-layer vibrator **[Fig.3(a)]**, the resonance frequency (f_r) decreased 4.5% at 500°C in spite of the spectrum shape changed. On the other hand, for the laminated vibrator **[Fig.3(b)]**, f_r decreased to similar without marked change. The spectra shapes at 500°C returned to their original ones as cooling to 28°C (not shown here).

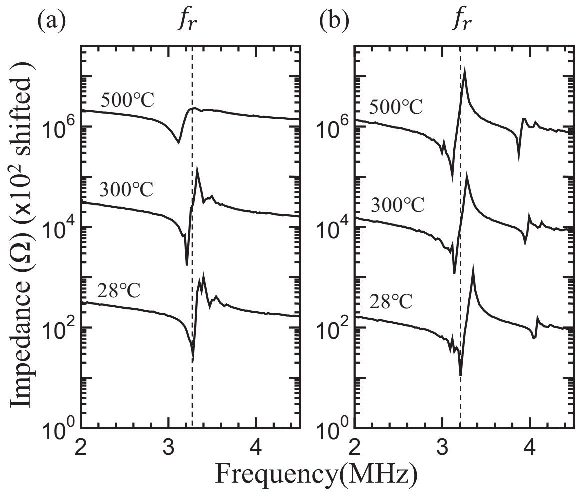

Fig.3 Variation of electrical impedance spectra by increasing temperature. Spectra of (a) single layer and (b) laminated vibrators.

3.2 Degeneration of electrode

Figure 4 shows the vibrators after HT measurement. In the case of Cr adhesion layer **[Fig.4(a)]**, the color of the electrode became dark. Suggesting oxidization of Cr on Au surface. On the other hand, in the case of Ta adhesion layer **[Fig.4(b)]**, there was no change in appearance.

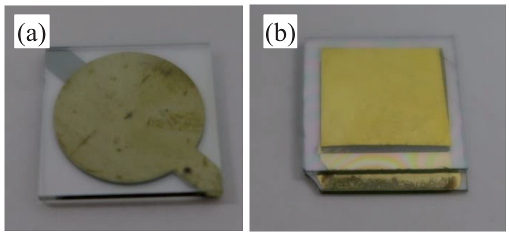

Fig.4 Au electrode of LN vibrators after 500°C. Adhesion layers were (a) Cr and (b) Ta.

3.3 Effect of lamination on displacement waveforms

Figure 5 shows displacement waveforms. The amplitude of the wave front of the laminated vibrator was triple larger than that of single layer one, suggesting the usefulness of thermal diffusion bonding with Au thin film for fabrication of large-amplitude ultrasonic vibrator.

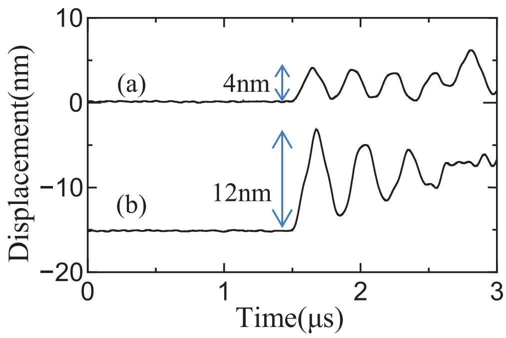

Fig.5 Surface displacement waveforms of (a) single layer (b) laminated vibrators.

4. Conclusion

Thermal diffusion bonding using Au thin film with Ta adhesive layer was useful for fabricating heat-resistant laminated LN vibrator. In the future, we will investigate probe design and heat-resistant couplant and aim to demonstrate transmission and reception of large-amplitude ultrasound at 500°C.

Acknowledgment

A part of this work was supported by Center for Integrated Nanotechnology Support in Tohoku University.

References

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