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High-temperature flexible ultrasonic sensors using $Bi_4Ti_3O_{12}/TiO_2+SrCO_3$

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1. Introduction

Nondestructive testing is considered important in industry to prevent accidents before they occur [1)]. The use of ultrasonic transducers for nondestructive testing is effective. because of the subsurface inspection capability and cost-effectiveness. Among ultrasonic transducer fabrication methods, the sol-gel composite method is good at high temperature durability, broadband characteristics, and signal-to-noise ratio.

In a previous study, $Bi_4Ti_3O_{12}$(BiT)/ TiO_2+SrCO_3(TO+Sr) could be fabricated at a low firing temperature of 200°C when the piezoelectric film was fabricated directly on the object to be measured, and a clear ultrasonic response was obtained[2)]. When a sol-gel composite piezoelectric film is made directly on the measurement object, a low-humidity environment must be created, and since the piezoelectric film is made at the measurement site, it must be worked on for a long time, making the fabrication process more difficult. In this respect, flexible sensors are relatively easy to fabricate in the laboratory and have the advantage of short working hours at the measurement site.

In this study, we fabricated a high-temperature flexible ultrasonic sensor using BiT/TO+Sr. We conducted two sets of measurements using the fabricated flexible sensor. First, the ultrasonic response was measured at room temperature using an Alnico magnet on a flat steel object. Second, the flexible sensor was mounted on a substrate that imitated a stainless steel pipe, and the ultrasonic response was measured at room temperature to verify whether the sensor could handle curved surfaces.

2. Sample Fabrication

We fabricated a BiT/TO+Sr sol-gel composite film on an aluminum foil using the sol-gel complex method. First, we mixed the BiT piezoelectric powder, with the TO+Sr sol-gel solution, and subjected it to rotation in a ball milling machine for approximately one day to grind and blend the piezoelectric powder. After that, BiT/TO+Sr was sprayed on an aluminum foil using an automatic sprayer at humidity below 20%. The dimensions of the aluminum foil were 30mm × 30mm × 0.1mm. Then, drying at 150°C for 5 min and firing at 200°C for 5 minutes were performed. The procedure of spraying, drying and firing is repeated until the film thickness reaches 50μm. The dimensions of Piezoelectric film were 20mm × 20mm. The next step is to add piezoelectricity to the piezoelectric film by polarizing it using corona discharge. Finally, a flexible sensor can be fabricated by creating a platinum top electrode using a sputtering system. **Figure 1** shows the Optical image of the fabricated flexible sensor sample using BiT/TO+Sr. The decrease in fabrication temperature has enabled the fabrication of flat flexible sensors.

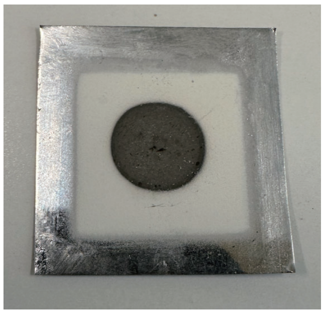

Fig.1 Optical image of fabricated flexible sensor using BiT/TO+Sr

3. Experiment Results

The fabricated flexible sensor was fixed with an alnico magnet and attached to a 3.5mm thick steel substrate to be measured. At this time, couplant for room temperature was used. An oscilloscope and pulsar receiver were then connected to measure the ultrasonic response at room temperature. In order not to damage the thin film, an aluminum foil was used to connect the wire to the top electrode. Optical image of the flexible sensor fixed with an Alnico magnet is shown in **Figure 2**, and the ultrasonic response obtained from the sensor is shown in **Figure 3**. The experimental results show that the fabricated flexible sensor can measure a clear ultrasonic response even at the strength of an alnico magnet.

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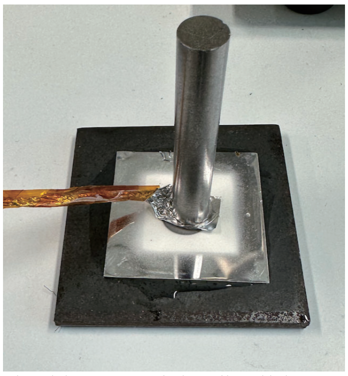

Fig.2 Optical image of the flexible sensor on flat substrate fixed with an Alnico magnet

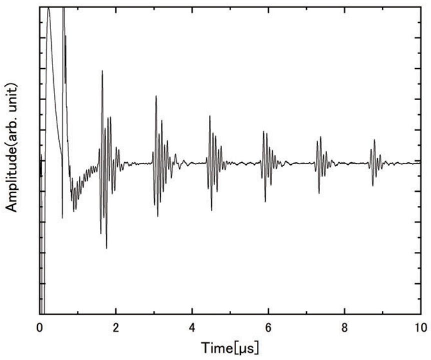

Fig.3 Ultrasonic response when clamped with an alnico magnet on steel substrate

Then we attached a flexible sensor to a stainless steel pipe-shaped mold, which was formed to have a thickness of 4mm and a diameter of 40mm. At this time, couplant for room temperature was used. The flexible sensor was fixed to the mold using a hose clamp, and ultrasonic response was measured. the optical image of the flexible sensor attached to the curved surface resembling the pipe is shown in **Figure 4** and the obtained ultrasonic response is shown in **Figure 5.** The experimental results show that the fabricated flexible sensor can be used on curved surfaces, and a clear ultrasonic response can be obtained.

Fig.4 Optical image of flexible sensor fixed with curved surface using hose clamp

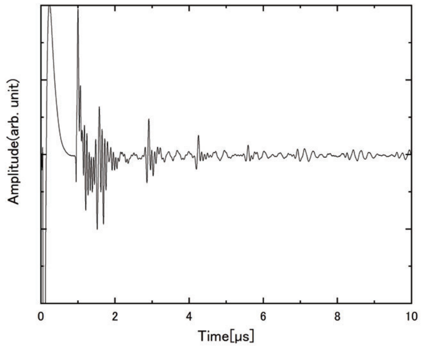

Fig.5 Ultrasonic response when clamped curved surface

The frequency response was analyzed using FFT from the first reflected echo of the ultrasonic response obtained from two measurement targets: the flat measurement target shown in Fig.3 and the curved measurement target in Fig.5. The gain of the pulsar receiver during the measurements was 35dB for the flat measurement target and 45dB for the curved measurement target. The results of the frequency analysis are shown in **Table** I. BW is 6dB bandwidth and Fc is the center frequency. The frequency response results indicate that both are broadband.

Table I Frequency analysis

	BW[MHz]	F_C[MHz]
Flat substrate	11.2	11.4
Curved surface	9.8	9.5

4. Conclusions

In this study, we succeeded in fabricating a high-temperature flexible ultrasonic sensor using BiT/TO+Sr sol-gel composite. In the fabricated high-temperature flexible ultrasonic sensor, a flat steel substrate was fixed using an Alnico magnet, and a clear ultrasonic response was obtained in the measurement. The high-temperature flexible ultrasonic sensor was also able to measure curved surfaces using a pipe-shaped stainless steel substrate, and the ultrasonic response was also obtained. Future research will include measurement of ultrasonic response at high temperatures.

References

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2) Naoki Kambayashi, Naoki Zaito, and Makiko Kobayashi, Proc. 43nd Symp. Ultrasonic Electronics, 2022, 2Pb1-4