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Measurements of acoustically stimulated electromagnetic response from piezoelectric materials
圧電材料からの超音波誘起電磁応答の測定

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1. Introduction

Ultrasonic waves are capable of propagating through opaque substances such as human bodies, metals, and concrete blocks, in which light does not propagate. Owing to the significant difference between sound and light velocities, elastic ultrasound waves are featured by remarkably short wave lengths, being by about five digits smaller than those of electromagnetic waves. Therefore sharp ultrasonic focusing on a millimeter/micrometer scale is achievable in the MHz/GHz range where real-time waveform analysis is performed in commercially available equipments. However, the majority of existing applications is restricted to inspection of mechanical properties resulting from elasticity or mass density of the target. Recently, a new type of ultrasonic methods for imaging electromagnetic properties is reported [1]. In this method, acoustically stimulated electromagnetic response (ASEM) is detected by a narrowband loop antenna tuned to a center frequency of incident ultrasonic waves.

Piezoelectric is one of interesting objects from which ASEM response is expected. In this paper, we show experimental results of the ASEM response from a single crystal of GaAs(100) and amorphous plastics materials (methacrylate, polypropylene (PP), and polystyrene (PS)).

2. Experiments

The measurement setup is shown in Fig.1. Rectangular 50ns wide pulses are applied at a repetition rate of 100-500 Hz by a pulser/receiver (Panametrics-NDT, 5077PR). To distinguish ASEM response from transducer noise, a target sample is placed in a focused zone at a distance (40mm) from 10 MHz transducer. The ASEM signals are thus temporally separated at a half of the echo delay time (τ_{echo}) as shown in Fig.2. The signals are detected through a tuned loop antenna (A or D) and amplified by 80 dB with low-noise preamplifiers (NF, SA-230F5). Two-dimensional (2D) images of ASEM response are obtained by mechanically scanning the focused ultrasonic beam.

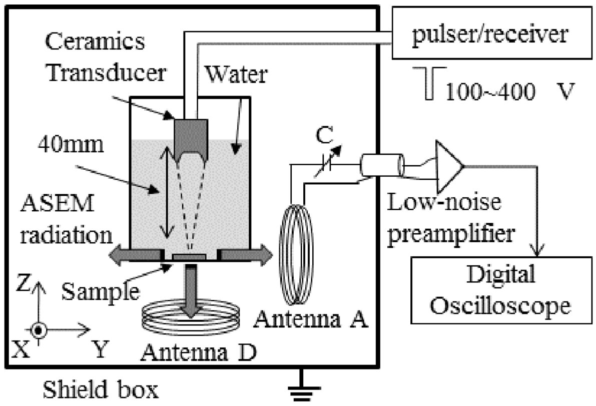

Fig. 1. Schematic of the mesurement set up. Two loop antennas (A and D) are used for the detection of ASEM signals.

Square plates of 10 mm width are prepared for all samples. The thickness is 0.45 mm, 1.1 mm, 0.65 mm, and 0.9 mm for GaAs(100), methacrylate, PP, and PS, respectively.

3. Results and discussion

Figure 2 shows ASEM response form a variety of piezoelectric materials. The Antenna tuned at 9.25 MHz is used. The signal intensity of GaAs(100) is about 250 times larger than those of plastics materials. Polymer crystals generally show piezoelectricity of which the coefficient is one order of magnitude smaller than that of GaAs [2, 3]. The reason why the observed signals are more reduced by a factor of 250 is that these plastic samples are not crystalline. Since net ASEM response is not expected in amorphous plastics, the observed small signals suggest the presence of crystallized grains.

We have also performed 2D imaging for a single-crystal GaAs(100) with antennas A and D (Fig.3). The tuned frequency is set into a mechanical resonance condition (10.5 MHz). The maximum peak-to-peak voltages (V_{max}), as shown in Fig.2, are plotted in the images. A stripe pattern of ASEM response is obtained in the configuration of antenna A (Fig.3(a)), but a more complex pattern

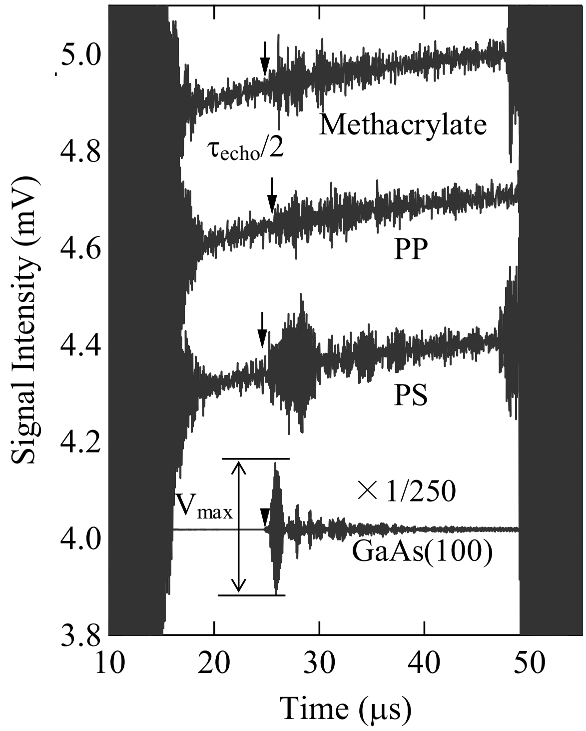

Fig.2. Real-time waveform of ASEM response in a variety of piezoelectric materials. The arrows represent a half of the echo delay time. The signal intensity of GaAs is scaled down by a factor of 1/250.

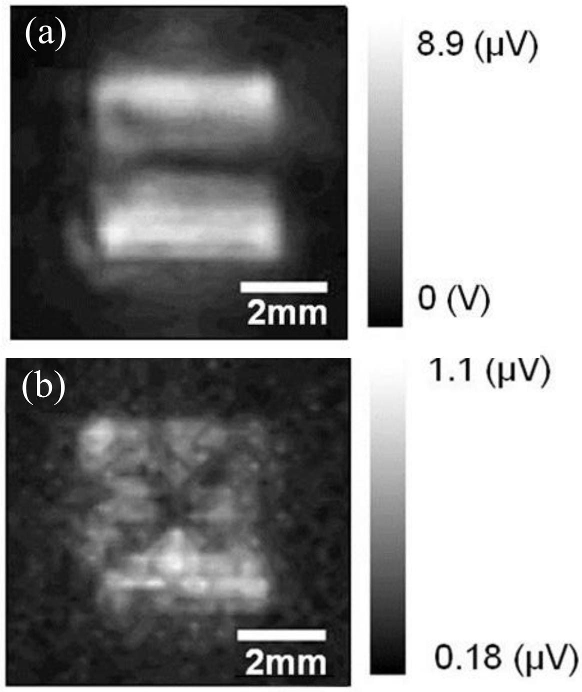

Fig.3 ASEM imaging of GaAs(100) with Antenna A (a) and Antenna D (b).

is obtained in the configuration of antenna D (Fig.3(b)). Here, the signal intensity detected by antenna D is roughly of one tenth of that by antenna A. It should be noted that the signal intensities and imaging profiles strongly depend on the configuration of antennas despite the same condition on ultrasound irradiation.

From real-time waveform analysis, it turns out that the delay time of the observed V_{max} corresponds to the time required for the ultrasonic pulse to travel to a free edge of the sample. i.e., it does not exactly correspond to $\tau_{echo}/2$. This indicates that the imaging profiles provide with the intensity of standing waves confined to the GaAs(100) substrate as a function of the position of the focused beam spot. We also measured the 2D imaging of GaAs(100) in an off-resonance condition (8.25 MHz). The imaging profile measured by antenna A in the off-resonance condition becomes very similar to that shown in Fig.3(b). It strongly suggests that a primary acoustic mode excited by mechanical resonance is detected by antenna A but only the higher modes are obtained by antenna D.

4. Conclusion

We have demonstrated ASEM measurements for a variety of piezoelectric materials. The ASEM signals are found in amorphous plastics, suggesting that our method is capable of non-uniformity evaluation of plastics. By studying relationship of ASEM response to piezoelectricity and uniformity of crystalline, the method will open up new possibilities for ultrasonic nondestructive inspection.

In addition, it turned out that the imaging pattern of ASEM response in a single crystal GaAs(100) largely depends on the antenna configuration. Selective acoustic-mode detection might be allowed by our method, leading to an interesting application to mode determination of plate waves or the related acoustic waves confined to the piezoelectric substrates.

Acknowledgment

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