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Development of Soft PZT Phased Array Transducer for Large Amplitude Incidence

ソフト系 PZT を用いた大振幅アレイ探触子の開発

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1. Introduction

Ultrasonic phased array (PA) imaging has gradually prevailed for the non-destructive inspection. However, the inspection of welds is still a challenging problem due to strong scattering at the coarse grains. To ensure its reliability, the imaging with high signal-to-noise ratio (SNR) needs to achieved. One of the solutions may be subharmonic phased array for crack evaluation (SPACE), which has been developed as an imaging method for closed cracks.[1)] Note that SPACE may be useful also for open cracks if large amplitude incidence enough to cause nonlinear contact vibration of open crack faces can be realized e.g. by an array transducer. On the other hand, for the inspection of highly attenuation materials, low frequency is often used to reduce the effect of attenuation. However, it causes to lower spatial resolution, which may be insufficient for the inspection of local defects. To solve this problem, large-amplitude incidence with relatively higher frequency (~ hundreds of kHz) will be the solution. Furthermore, even in the PA imaging with the order of MHz, large-amplitude incidence will enhance signal intensity. Thus, the realization of large-amplitude incidence in PA is promising for the imaging with high SNR.

To realize large-amplitude incidence in PA, the structure of array transducer and the performance of each elements needs to be optimized. So far, we proposed a new PA system with individual elements,[2)] where high-voltage excitation (>1 kV) was realized by the individual elements with a high dielectric breakdown voltage and using transformers. For further large-amplitude incidence, it is critical to optimize the internal structure of each element in terms of piezoelectric material and structure.

Soft Lead Zirconate Titanate, Pb(Zr, Ti)O_3 (PZT) is one of the very promising candidates because it has a high piezoelectric strain constant d_{33}. This has lower electrical impedance (EI) than the output impedance of typical pulsar, so that a special pulsar using a SiC transistor with low output impedance is required.[3)] If we use soft PZT as elements of the array transducer, its EI can be heightened because of its small size, resulting in the large-amplitude incidence.

On the other hand, Lead Titanate, $PbTiO_3$ (PT) that was developed to avoid the noise due to lateral vibration has been widely used in industrial inspection. Although it has low d_{33}, it can be easily excited thanks to the high EI. In addition, the high EI of M6 may allow one to fabricate multi-layer structure with higher output.

In this study, to obtain the optimal design of array transducers for large-amplitude incidence, we fabricated the elements of array transducer with two piezoelectric materials (soft PZT, PT) and evaluated them by measuring EI, excitation voltage and displacement.

2. PA system with individual elements for large amplitude incidence

Figure 1(a) shows the schematic of PA system. It has high dielectric breakdown voltage due to air gaps between elements. Moreover, excitation voltage can be increased by a transformer.

Figure 1(b) illustrates the structure of each piezoelectric material for large-amplitude incidence.

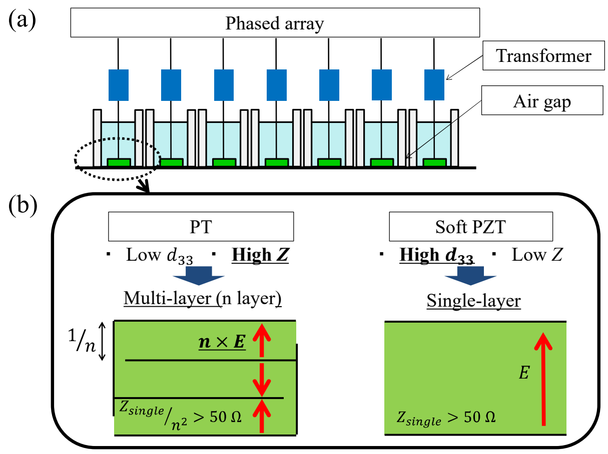

Fig. 1 Phased array system with individual

elements and structure of each element for large amplitude incidence.

For PT, by taking advantage of high EI, n layer structure[4)] can be promising for large-amplitude incidence because the electric field across each layer is n times greater than that across a single layer. However, the EI of multi-layer structure becomes Z_{single} / n^2, where Z_{single} is the EI of single layer. Thus, layer number n must be determined on the basis of the output impedance 50 Ω. On the other hand, soft PZT has a high d_{33} and low EI. It can realize large-amplitude incidence even by simple single-layer structure if it is made with more than 50 Ω.

3. Fabrication and Evaluations of elements with the two piezoelectric elements

We fabricated the element(1) with PT and the element(2) with soft PZT by single-layer structure.

We firstly measured EI of elements(1) and (2), as shown in Fig. 2. As a result, EI of element(1) was 677 Ω. This suggests that element(1) is suitable for two or three layer structure. On the other hand, EI of the element(2) was 81Ω, a little higher than source impedance, which is suitable for single-layer structure.

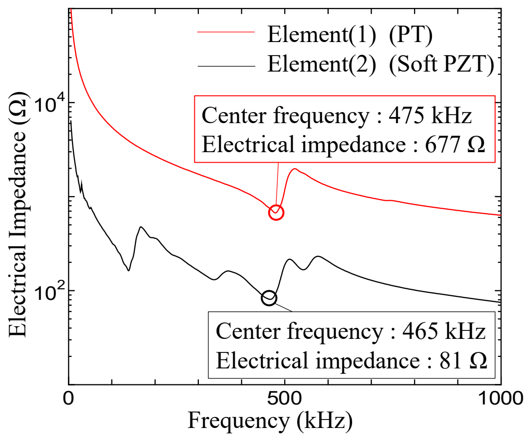

Fig. 2 Electrical impedance of elements (1) and element(2).

Then we confirmed that both elements does not show voltage drop for the excitation voltage of 200 V by a phased array hardware, MultiX LF of which the nominal output impedance is 50 Ω. Subsequently, we measured the out-of-plane displacement of the incident wave propagated through an aluminum-alloy block (200 mm) by a laser vibrometer. As shown in Fig. 3, the displacement of the element(2) was 2.6 times larger than that of the element(1) because of the difference of d_{33}. Thus, in the case of single layer, soft PZT has the advantage of large-amplitude incidence with simple structure, as expected. However, the displacement of element(2) also had the ringing signals, which may cause to make spatial resolution low. This is because of the effect of the lateral vibration due to the property of soft PZT. This kind of ringing may not be avoided when the thickness (4 mm) of the element is close to the width (9 mm). In contrast, the element(1) had a little ringing signal due to very low d_{31}. This is one of the advantages of the piezoelectric material with PT.

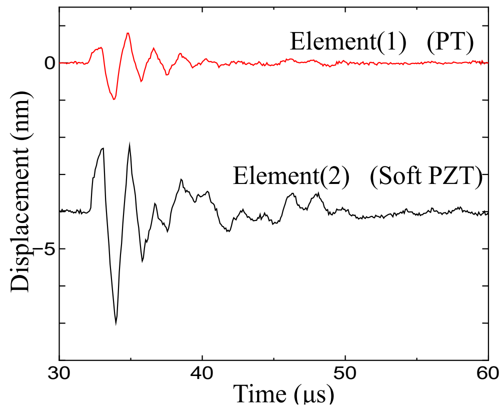

Fig. 3 Specimen surface displacement.

4. Conclusions

In this study, to fabricate the array transducer for large-amplitude incidence, we confirmed that soft PZT and PT are suitable for single-layer structure and for two or three layer structure, respectively. In future, to obtain the optimal design for large amplitude incidence, we will fabricate the elements of array transducers with multi-layer structure and compare each fabricated element.

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References

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