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Wide-Band and High-Sensitive Ultrasound Transducer Composed of Very Thick PZT Diaphragm
厚膜 PZT ダイアフラムを用いた
広帯域・高感度超音波トランスデューサ

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1. Introduction

Imaging technology using ultrasound is widely used in the medical field because it is noninvasive. In ultrasonic imaging, it is generally difficult to perform high resolution imaging in the deep part of the body as shown in **Fig. 1**. Transducer must achieve both wide-band and high sensitivity characteristics. They are in a trade-off relationship with each other. Many studies have been done to balance them for a long time.

In the medical field, there is an increasing demand for further applications of ultrasonic imaging such as real-time 3D imaging and in vivo imaging. For that purpose, it is necessary to increase the frequency and miniaturize the transducer [2, 3]. Studies on MUTs (micromachined ultrasonic transducers) manufactured by MEMS (micro electro-mechanical system) technology has been actively conducted in order to cope with microfabrication for expanding the frequency range of the array transducer. One application example of MUTs is PMUT [4] (piezoelectric micromachined ultrasonic transducer). Its piezoelectric performance has been rapidly improved by studies on a method of depositing PZT (lead zirconate titanate) on Si (silicon) substrates using MEMS technology. In addition, a FET (field effect transistor) type pressure sensor using a piezoelectric body as a gate has been proposed, and its high sensitivity has also been confirmed [5].

In this study, we focus on a rectangular diaphragm-type PZT with width of 50 μm formed on a Si substrate. In our previous study, transducers with different combinations of PZT and Si layer thickness have been evaluated [1]. At that time, it was expected that the thickness of the diaphragm had a large influence on the frequency characteristics. The purpose of this study is to confirm the effect of the thickness of diaphragm film on the performance of transducer and to propose optimal design method from its trendency by FEM simulation.

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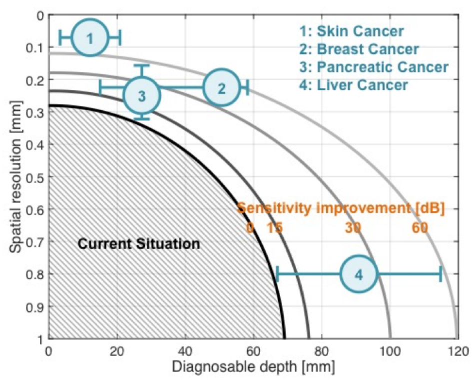

Fig. 1 Spatial resolution versus diagnosable depth for early detection of tumors. Copyright 2017 The Japan Society of Applied Physics. Reprinted with permission from reference [1].

2. Analysis method

A sound pressure of 1 Pa having a shape of an impulse plane wave is applied to the diaphragm composed of a PZT layer polarized in the z-direction and a Si layer (see **Fig. 2**). The PZT layer is sandwiched between electrodes. Received vibration and output voltage are observed, and their frequency characteristics are obtained by DFT

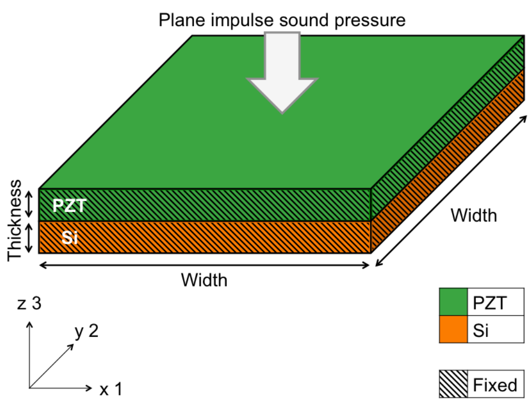

Fig. 2 Evaluation model for analysis.

analysis.

3. Result and discussion

Figure 3 shows the maximum receiving sensitivity and -3 dB specific bandwidth of a 50μm wide diaphragm measured for different thicknesses of PZT and Si layers. First, the influence of PZT layer will be discussed. Under thin PZT conditions, increasing the thickness of the diaphragm decreases the sensitivity and improve the bandwidth. It is a generally known characteristic of diaphragms. When the thickness exceeds 5μm, the specific bandwidth and sensitivity are greatly improved. Although it can be confirmed that there is a trade-off relationship between the sensitivity and the bandwidth, the sensitivity is improved, but the bandwidth reduction is relatively suppressed. Next, the influence of the Si layer will be discussed. The diaphragm thickness of the Si layer does not affect the bandwidth. The sensitivity can be increased by increasing the thickness of the Si layer.

Further investigation is expected to find a reasonable interpretation of the wide-band characteristic for reception. **Figure 4** shows frequencies with maximum amplitudes of received vibrations and frequencies with maximum reception sensitivity. In **Fig. 4**, the blue and red line show the theoretical values of the resonance frequencies of the film vibration f_r and the thickness vibration f_t, respectively, and are calculated by the following equations:

$$f_r = \frac{35.99}{2\pi}\frac{h}{L^2}\sqrt{\frac{Y}{12\rho(1-\nu)^2}}, \quad (1)$$

$$f_t = \frac{v}{2h}, \quad (2)$$

with width L, thickness h, density ρ ,Young's modulus Y, and Poisson's ratio ν. In the range of the narrow-band characteristic, the maximum sensitivity frequencies and the theoretical resonance frequencies of the diaphragm vibration coincide. In the range of the wide-band characteristic, the maximum sensitivity frequency exists between the theoretical resonance frequency of the film vibration and that of the thickness vibration. These phenomena are due to the coexistence of the film vibration and the thickness vibration.

4. Conclusion

In this study, we evaluated a diaphragm-type PZT transducer with a rectangular width of 50μm from the viewpoint of layer thickness dependency of the diaphragm. The bandwidth of the diaphragm transducer can be widened by thickening its diaphragm thickness relatively. By increasing the thickness of the diaphragm, it is considered that

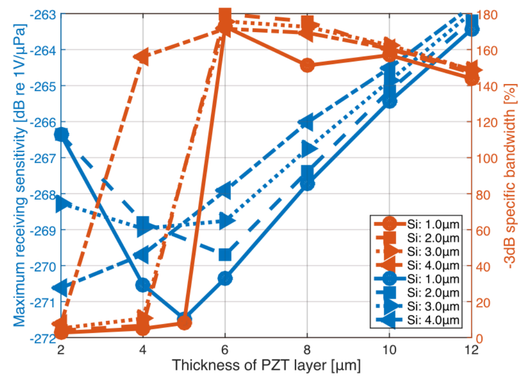

Fig. 3 Maximum receiving sensitivity and -3 dB specific bandwidth of 50 μm-width diaphragm determined for different thicknesses of PZT and Si layers.

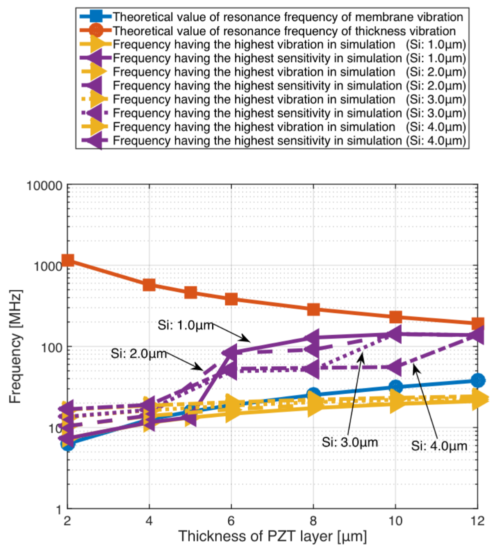

Fig. 4 Frequencies with maximum amplitude of received vibration and frequencies with maximum reception sensitivity of 50μm width diaphragm measured for different thicknesses of PZT and Si layers in simulations.

film vibration and thickness vibration coexist. In the future, it is necessary to optimize the aspect ratio as the design parameter of the diaphragm.

References

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