Articles

Proposal of Structure of Adhesive Layer-free Hydrophone

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I. Introduction

In recent years, the use of high intensity ultrasound has spread in medical field, industrial field, and other fields. For example, in medical field, high intensity focused ultrasound therapy is used for treatment of brain cancer and pancreatic cancer[1–2], and diagnosis of ultrasound elastography is based on acoustic radiation force which are used for evaluating and diagnosing various conditions based on the hardness of organs. In these methods, the patient's body is exposed to ultrasound; therefore, the ultrasound waves must be safe in humans. In industrial field, devices such as ultrasound cleaners and ultrasound dispersing machines use high intensity ultrasound. Industrial ultrasound instruments must have the constant performance when they are mass-produced. Therefore, it is important to evaluate the performance of ultrasound waves emitted by these instruments[3].

The safety and performance of the ultrasound waves are evaluated by measuring the sound field by using a hydrophone[4]. However, exposure of commercially available hydrophones to high intensity ultrasound waves damages the surface electrode, and ultrasound measurement becomes impossible. Therefore, our laboratory is developing a tough hydrophone that does not break even when it is exposed to high intensity ultrasound[5–20]. The front plate, backing of our tough hydrophone are made of titanium, and a PZT polycrystalline film is deposited on the back face of the titanium front plate by hydrothermal synthesis. In this research, we investigated the structure and manufacturing method of a tough hydrophone without adhesive layer.

II. Conventional tough hydrophone

The tough hydrophone that we have developed in our laboratory is shown in ***Fig. 1***. The titanium front plate is a thin plate with 50 μm thick and a hydrothermally synthesized PZT polycrystalline film is deposited on the back surface of the front

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plate. An electrically conductive adhesive is used to bond the front plate and the backing. Between the insulated conductor and the backing, there is a heat shrinkable tube and a nonconductive adhesive.

Figure 2 shows the frequency response of the receiving sensitivity of the conventional tough hydrophone. The upper line shows the receiving sensitivity of the commercial hydrophone (HNR-1000, ONDA) used for comparison and the lower line shows the receiving sensitivity of our conventional tough hydrophone.

There was no change in the receiving sensitivity even when the conventional tough hydrophone was exposed to the ultrasound cleaner for 3 h. However, between 3 and 4 h, the front plate was peeled off because the adhesive layer was damaged by the energy of the high intensity ultrasounds (***Fig. 3***).

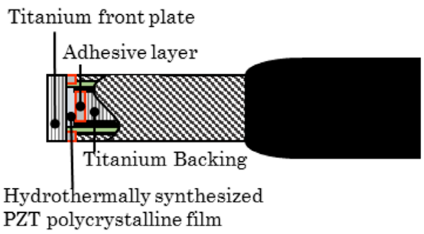

Fig. 1 Structure of our conventional tough hydrophone.

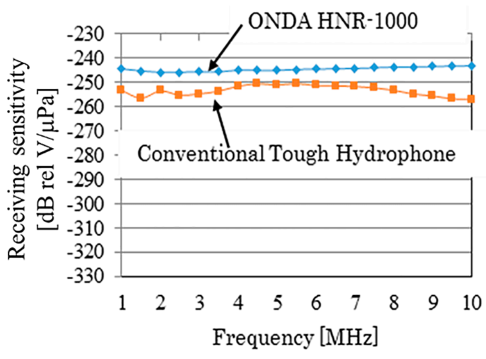

Fig. 2 Receiving sensitivity of the conventional tough hydrophone

Fig. 3 Photograph of conventional tough hydrophone front plate and main body

III. Adhesive layer-free hydrophone

To solve the problem with the adhesive layer breaking in the conventional tough hydrophone, we investigated an adhesive layer-free hydrophone. The proposed structure of the acoustic signal propagation part of our adhesive layer-free hydrophone is shown in ***Fig. 4***. Titanium is used for the front plabe and backing, similar to conventional tough hydrophone. The front plate is a 20 mm-long rod, which is thicker than the thin plate in the conventional tough hydrophone. The front plate and backing are bonded together with a hydrothermally synthesized PZT polycrystalline film without electrically conductive adhesive. We expect that this adhesive layer-free structure will produce a tougher hydrophone with excellent frequency characteristics.

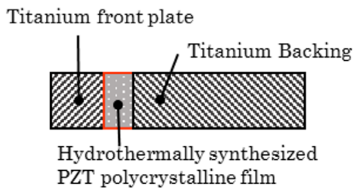

Fig. 4 Basic structure concept of our proposed adhesive layer-free hydrophone.

IV. Advantages of the adhesive layer-free hydrophone

The adhesive layer-free hydrophone differs from the conventional tough hydrophone in terms of the front plate shape and the absence of adhesive between hydrothermally doposited PZT polycrystalline film and Ti backing. The acoustic properties of the materials used for each part of the tough hydrophone are shown in ***Table 1***.

The difference in specific acoustic impedance between titanium and the PZT polycrystalline film is small. However, there are large differences in acoustic impedance between titanium and the conductive adhesive and between the hydrothermally synthesized PZT polycrystalline film and the conductive adhesive. The reflection coefficient ρ at the boundary surface between materials with specific acoustic impedances Z_1 and Z_2 is

$$\rho = (Z_2 - Z_1)/(Z_2 + Z_1)$$

The reflection coefficients at each interface are shown in ***Table 2***.

In the conventional tough hydrophone structure, the electrically conductive adhesive causes a large reflection from the interface among the PZT polycrystalline film and the electrically conductive adhesive and the titanium backing. Thus, multiple reflections of the ultrasound waves occur in the adhesive layer, which concentrates the acoustic energy in the adhesive layer and eventually breaks the adhesive layer. Furthermore, the multiple reflections attenuate the transmission of ultrasound waves, affecting the receiving sensitivity. However, in the structure of the adhesive layer-free hydrophone, there is no adhesive layer-free causing multiple reflections. In addition, there is no difference in the acoustic impedance of the titanium front plate, the PZT polycrystalline film, and the titanium backing, which suppresses reflections at each boundary surface. Accordingly, no acoustic energy is produced in the materials, and the transmitted ultrasound waves are not attenuated. We expect that this construction will be suitable for developing a tough hydrophone that is tougher and more sensitive than a conventional tough hydrophone.

Table 1 Acoustic impedances of tough hydrophone materials

	Density (kg/cm^3)	Sound Velocity (m/s)	Specific acoustic impedance [Z] (10^6 kg/m^{2}s)
Titanium	4.5	6000	27.5
PZT	7.1	3000	21.3
Adhesive layer	1.7	3000	5.1

Table 2 Reflection coefficients at each interface of the conventional tough hydrophone

Material 1	Material 2	Reflection coefficient
Titanium	PZT	-0.13
PZT	Adhesive layer	-0.61
Adhesive layer	Titanium	0.69

V. Fabrication method of making adhesive layer-free hydrophone

To prepare the adhesive layer-free hydrophone, a jig for fixing the titanium parts during hydrothermal synthesis was prepared. The jig was made of Teflon and it was designed not to melt in the aqueous solution for hydrothermal synthesis. The titanium parts were fixed in the jig groove and immersed in the hydrothermal synthesis solution, and PZT polycrystalline film was deposited in hydrothermally synthesizing apparatus.

We attempted to join the front plate and backing by depositing a PZT polycrystalline film by hydrothermal synthesis. However, microscope observations of the joint revealed that an air gap was deposited between the front plate and backing and the two titanium parts were not bonded. In addition, the size of the gap between the two titanium parts varied during synthesis.

VI. Discussion

In this fabrication method, front plate and backing could not be joined by using hydrothermally synthesized PZT polycrystalline film. . This was because the Teflon jig thermally expanded due to the high temperature during hydrothermal synthesis. In addition, the two titanium parts were pulled and separated apart by the thermal contraction of the jig upon cooling.

To fabricate the adhesive layer-free hydrophone, it is necessary to redesign the jig to prevent the thermal expansion from affecting the fixing of the titanium parts.

VII. Summary

Our conventional tough hydrophone suffered from the front plate peeling off because of the damage to the adhesive layer. Therefore, in this research, we proposed an adhesive layer-free hydrophone. By abolishing the adhesiv layer, we expected to suppress the reflection inside the hydrophone and the concentration of sound energy. However, we could not fabricate an adhesive layer-free hydrophone using our fabrication method. The jig for fixing the titanium parts during hydrothermal synthesis was not suitable because of its large thermal expansion. In future work, we will redesign the jig and develop an alternative method for manufacturing the hydrophone without an adhesive layer.

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