

## Development of miniature hydrophone with PZT flim deposited by hydrothermal method

Hiroshi KITSUNAI<sup>1</sup>, Takahiro SUZUKI<sup>1,2</sup>, Mutsuo ISHIKAWA<sup>2,4</sup>,  
Norimichi KAWASHIMA<sup>1,2</sup>, Etsuzo OHDAIRA<sup>2,3</sup>, Minorui KUROSAWA<sup>4</sup> and Shinichi TAKEUCHI<sup>1,2</sup>  
<sup>1</sup>Toin University of Yokohama, Faculty of Engineering, Yokohama 225-8502, Japan  
<sup>2</sup>Toin University of Yokohama, BME Center, Yokohama 225-8502, Japan  
<sup>3</sup>Musashi Institute of Tchnology, Tokyo 158-8557, Japan  
<sup>4</sup>Tokyo Institute of Technology, Yokohama 226-8503, Japan

*Abstract* - A needle type miniature hydrophone was developed by hydrothermally depositing PZT poly-crystal film with thickness of about 10 $\mu$ m on an end of a titanium wire with diameter of 0.3mm in this study. It is desirable that hydrophone should have as small shape as possible in order to avoid from disturbance in acoustic field by itself. Since the body of hydrophone developed in this study is a titanium wire with diameter of 0.3mm, disturbance in acoustic field measurement by our hydrophone can be reduced remarkably. It was confirmed that receiving sensitivity of our hydrophone was about -280 dB (0dB=1V/ $\mu$ Pa) in frequency range from 1 MHz to 10 MHz.

### I. Introduction

We are studying on the hydrothermally synthesizing technology of piezoelectric poly-crystal films for fabrication of piezoelectric actuators or ultrasound sensors[1],[2]. The hydrothermally synthesized PZT poly-crystal films have features of possibility of deposition to the curved, complex shaped or tiny titanium substrates, no need for post-treatment like annealing or polarization etc.[3],[4]. Developments of micro-actuators or micro-sensors have been accomplished taking advantage of the features [5]-[9]. The ultrasound sensors for under water applications were developed using hydrothermally synthesized PZT

in our laboratory [2]. We have developed the needle type miniature hydrophone with the hydrothermally synthesized PZT poly-crystal film on an end of titanium wire. It is important for the hydrophone to have tiny body to minimize disturbance in acoustic field measurement by themselves and to have wide frequency characteristics and wide directivity [10], [11]. Therefore, it is thought that the features of hydrothermally synthesized PZT poly-crystal films are effective to develop the needle type miniature hydrophone. We accomplished trial fabrication of the needle type miniature hydrophone by depositing PZT poly-crystal film hydrothermally on an end of titanium wire with diameter of 0.3 mm. Furthermore, we measured the received waveform by the hydrophone and its frequency characteristics of receiving sensitivity.

### II. Methods

#### *Apparatus for hydrothermal synthesis*

Hydrothermal method is the method of material synthesis or crystal growth in water under high temperature and pressure. Water exists as liquid under high pressure even if the temperature is above the boiling point of water at atmospheric condition. The reaction impossible to be occurred in atmospheric pressure can be occurred under the above hydrothermal

situation. Although it is known that hydrothermally deposited PZT piezoelectric films have various merits, this method is not commonly used because of instability and low yield rate. Therefore, we modified the apparatus and synthesizing procedure to allow stable deposition of PZT films [1].

Figure 1 shows an our apparatus for hydrothermal method.

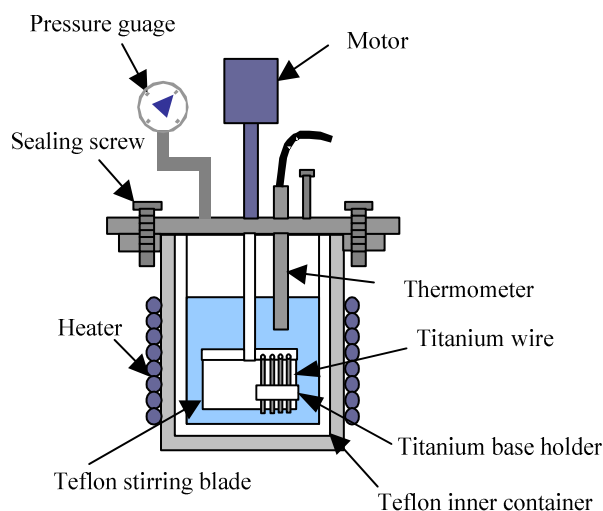


Fig. 1 Apparatus for hydrothermal method used in this study

Aqueous solutions with precursor materials including metal ions of  $Ti^{4+}$ ,  $Zr^{4+}$ ,  $Pb^{2+}$  are mixed with a mineralizer of KOH solution in a Teflon coated tank of the apparatus. They are stirred with rotating Teflon blade. The titanium substrates on which PZT poly-crystal films to be deposited are held directly on the rotating Teflon stirrer blade. The PZT poly-crystal films can be deposited on the titanium substrates by stirring aqueous solution with precursor materials and mineralizer using the rotating Teflon blade under high temperature (120-160 degree centigrade) and high pressure (about 400 kPa). Stirring aqueous solutions and mineralizer using the rotating blade with the

titanium substrate is typical feature of our hydrothermal apparatus. With this apparatus, we can deposit more stable PZT piezoelectric films within much shorter time than the conventional apparatus.

#### *Deposition of PZT poly-crystal film on titanium wire*

PZT poly-crystal films were deposited hydrothermally on an end of titanium wire with diameter of 0.3 mm for the fabrication of hydrophones. The deposition conditions are shown in Table 1. Each once for crystal nucleation process and crystal growth process are accomplished. After deposition, the deposited surface was observed with a scanning electronic microscope (SEM; JSM-5500LV) and it was confirmed that the deposited PZT poly-crystal film was formed on the titanium wire.

Table 1 Hydrothermal synthesis condition of PZT on titanium wire with diameter of 0.3 mm

	Nucleation process	Crystal growth process
Temperature	160°C	140°C
Time	24 h	24 h
Stirring speed	245 rpm	245 rpm

#### *Trial fabrication of hydrophone*

Our hydrophone has the coaxial basic structure shown in Fig. 2 taking account of electrostatic shield. After hydrothermal deposition of PZT poly-crystal film on the titanium wire, insulating resin was coated on the lateral side of the titanium wire. The titanium wire is used as backing material for the PZT poly-crystal film and as electric signal line. The conductive resin was coated all over the titanium wire coated with insulating

resin. After that, the signal line of the coaxial cable was connected to the titanium wire, and the GND line was connected to the coated conductive resin. Since electrical interference from outside is shielded with this coaxial structure, improvement of S/N ratio can be expected.

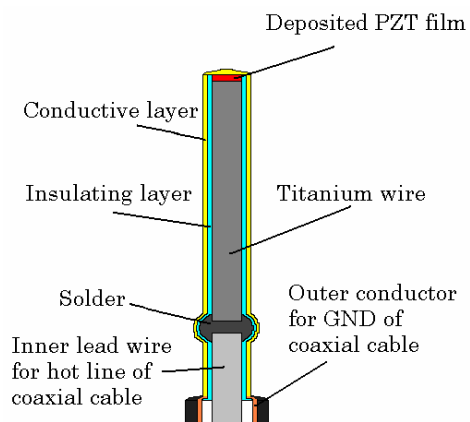


Fig. 2 Schematic diagram of needle-type miniature hydrophone with hydrothermally synthesized PZT film on titanium wire with diameter of 0.3 mm.

*Measurement of received waveform and receiving sensitivity*

The received ultrasound waveform and frequency characteristics of receiving sensitivity of our fabricated hydrophone are measured using the system shown in Fig. 3. A commercial water immerse type ultrasound probe with nominal frequency of 10 MHz (I3-1008-R Staveley Sensors Inc.) was used as transmitter for observation of received ultrasound waveforms by the fabricated hydrophone. The burst pulse voltage wave with amplitude voltage of 170 V, 10 cycles of burst was applied to the commercial ultrasound probe used for transmission at 10 MHz. The distance between the commercial ultrasound probe and our fabricated hydrophone was 10 mm. Frequency characteristics of

receiving sensitivity were measured at frequencies from 1 MHz to 10 MHz. Five commercial ultrasound probes with each nominal frequency of 2.25 MHz, 3.5 MHz, 5 MHz, 7.5 MHz and 10 MHz were employed as the transmitters. The sound pressures in water transmitted with the commercial ultrasound probes were measured by calibrated commercial standard hydrophone (NP-1000 ; NTR Systems Inc.). Frequency characteristics of the fabricated hydrophone were measured by replacing the commercial standard hydrophone with the fabricated.

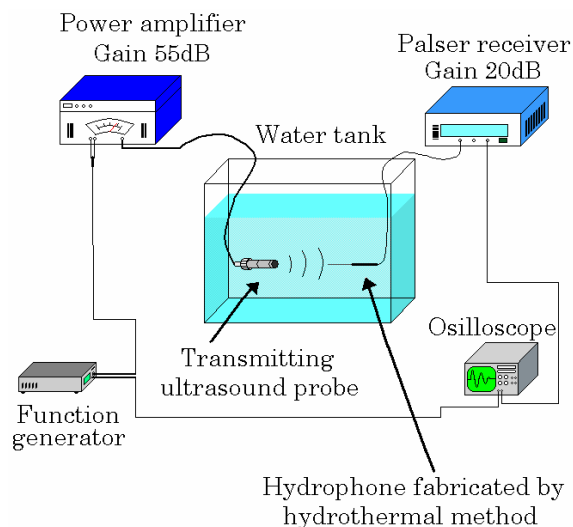


Fig.3 Measurement system of received ultrasound waveform and receiving sensitivity of fabricated needle-type miniature hydrophone by hydrothermal method.

**III. Results and discussion**

*Deposition of PZT poly-crystal film on titanium wire*

The PZT poly-crystal film was deposited hydrothermally on an end of the titanium wire with diameter of 0.3 mm using the apparatus shown in Fig. 1. SEM images of the poly-crystals deposited on an end of titanium wire are shown in Fig. 4. Large number of cubic poly-crystals to be thought as PZT can be

observed. Therefore, it can be expected that these PZT poly-crystals have piezoelectricity.

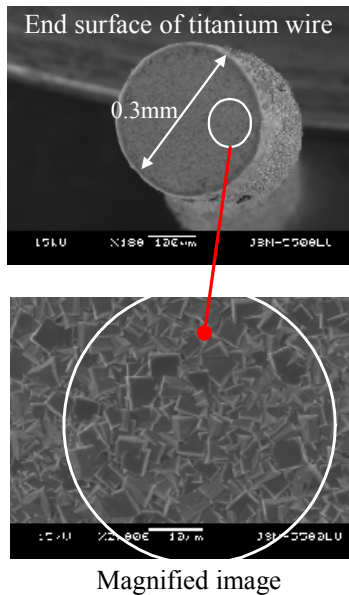


Fig. 4 SEM images of hydrothermally synthesized PZT film on the end surface of titanium wire with diameter of 0.3 mm

*Trial fabrication of hydrophone*

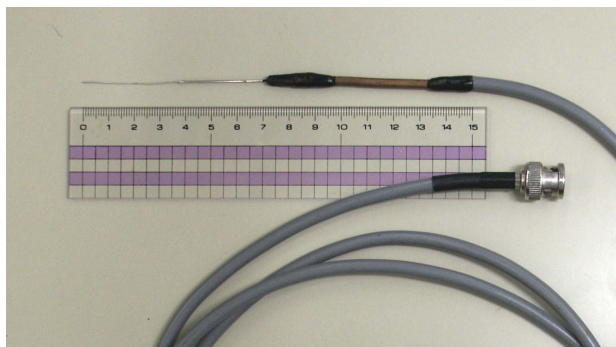


Fig. 5 Photograph of a trially fabricated needle type miniature hydrophone with hydrothermally synthesized PZT poly-crystal film

Since it could be thought that the hydrothermally deposited PZT poly-crystal film on an end of titanium

wire with diameter of 0.3 mm is expected to have enough piezoelectricity, we fabricated the needle type miniature hydrophone with the structure shown in Fig. 2. The photograph of fabricated hydrophone is shown in Fig. 5.

*Measurement of received waveform and receiving sensitivity*

The transmitted ultrasound pulse into water with the commercial water immerse type ultrasound probe with frequency of 10 MHz was received with the fabricated hydrophone shown in Fig. 3. The measured result is shown in Fig. 6. The received ultrasound waveform could be observed at about 10  $\mu$ s after rise of trigger pulse for transmission.

Frequency characteristics of sensitivity of the fabricated hydrophone were measured at frequencies from 1MHz to 10 MHz with the measurement system shown in Fig. 3. The measured frequency characteristics are shown in Fig. 7. It was found that the measured receiving sensitivity was in the range of  $\pm$  5d B with the center value of -281.3 dB.

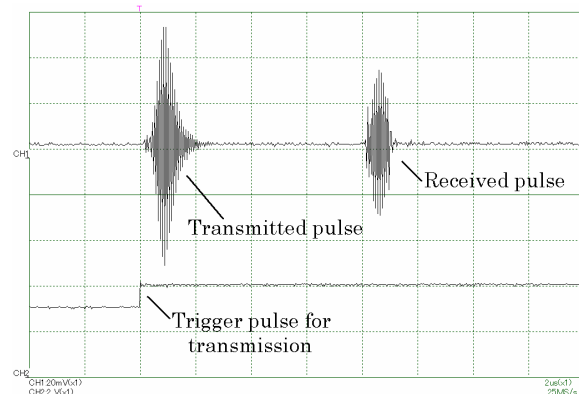


Fig. 6 An example of received ultrasound waveform with trial fabricated hydrophone by hydrothermal method

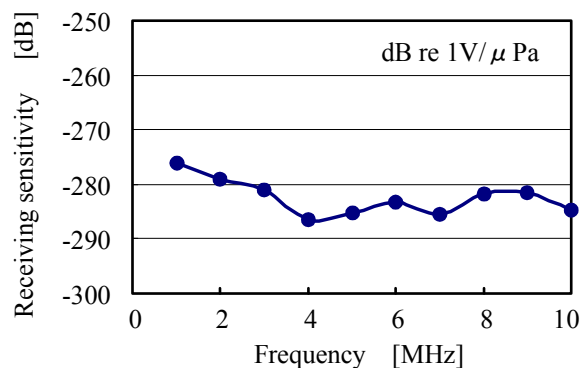


Fig. 7 Frequency characteristic of receiving sensitivity of trial fabricated hydrophone with deposited PZT film by hydrothermal method

#### IV. Conclusions

The needle type miniature hydrophone was fabricated by hydrothermally deposition of PZT poly-crystal film on an end of titanium wire with diameter of 0.3 mm. The ultrasound burst pulse irradiated into water with the commercial water immerse type ultrasound probe could be received by trially fabricated hydrophone. The commercial water immerse type ultrasound probe was driven by applied electric burst pulse with 10 cycles at frequency of 10 MHz. Furthermore, the frequency characteristics of receiving sensitivity of our fabricated hydrophone were measured at frequencies from 1 MHz to 10 MHz. It was found that the measured receiving sensitivities were in the range of  $\pm 5$  dB with the center value of -281.3 dB.

We will fabricate the hydrophone using titanium wire with smaller diameter in the future work. The effect of the PZT deposited surface of titanium wire on the frequency characteristics of receiving sensitivity and the directivity will be considered. Furthermore, since new calibration methods for the sensitivity of

hydrophone were proposed [12],[13], we will consider the proposals in calibration for fabrication of hydrophone using hydrothermal method.

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