DEVELOPMENT OF MINIATURE HYDROPHONE WITH HYDRO-THERMALLY SYNTHESIZED PZT POLY-CRYSTALLINE FILM

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Abstract
A needle type miniature hydrophone was developed by hydro-thermally synthesized PZT poly-crystalline film with thickness of about 10µm on an end of a titanium wire with diameter of 0.3mm in this study. It is desirable that the needle type hydrophone should have as small size 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 itself can be reduced extremely. It was confirmed that receiving sensitivity of our hydrophone was about higher than about –280 dB (0dB=1V/µPa) in frequency range from 1 MHz to 20 MHz.
INTRODUCTION

We are studying on the hydrothermally synthesizing technology of piezoelectric poly-crystalline films[1] for fabrication of piezoelectric actuators or ultrasound sensors[2]. The hydrothermally synthesized PZT poly-crystalline films have features of possibility of deposition to the curved, complex shaped or tiny sized titanium substrates, needless of 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 poly-crystalline film in our laboratory. We have developed the needle type miniature hydrophone with the hydrothermally synthesized PZT poly-crystalline film on an end of titanium wire. It is important for the hydrophone to have tiny sized 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-crystalline films are useful to develop the needle type miniature hydrophone. We accomplished trial fabrication of the needle type miniature hydrophone by synthesizing PZT poly-crystalline film hydrothermally on an end of titanium wire with diameter of 0.3 mm [12]. Furthermore, we measured the received waveform by the hydrophone and its frequency characteristics of receiving sensitivity.

METHODS

Apparatus for hydrothermal synthesis of PZT film

Hydrothermal method is the method of material synthesis or crystal growth in water under high temperature and high pressure. Water exists as liquid under high pressure even if the temperature is higher than 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 hydro-thermally synthesized 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 synthesizing of PZT films [1].

Figure 1 shows our apparatus for hydrothermal method. 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-crystalline films to be synthesized are held directly on the rotating Teflon stirrer blade. The PZT poly-crystalline films can be synthesized on the titanium substrates by stirring aqueous solution with precursor materials and mineralizer using the rotating Teflon blade under high temperature (120-160 °C) 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 synthesize more
stable PZT piezoelectric poly-crystalline films within much shorter time than the conventional apparatus.

Fig. 1 Apparatus for hydrothermal method used in this study

Hydrothermal synthesis of PZT poly-crystalline film on titanium wire

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

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

<table>
<thead>
<tr>
<th></th>
<th>Nucleation process</th>
<th>Crystal growth process</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>160 [°C]</td>
<td>140 [°C]</td>
</tr>
<tr>
<td>Time</td>
<td>24 [hours]</td>
<td>24 [hours]</td>
</tr>
<tr>
<td>Stirring speed</td>
<td>245 [rpm]</td>
<td>245 [rpm]</td>
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</table>
Fabrication of hydrophone

Our hydrophone has the coaxial basic structure shown in Fig. 2 taking account of electrostatic shield. After hydrothermal synthesizing of PZT poly-crystalline 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-crystalline 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.

![Figure 2 Schematic diagram of needle-type miniature hydrophone with hydrothermally synthesized PZT film on titanium wire with diameter of 0.3 mm.](image)

Measurement of waveform and 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 20 MHz. Five commercial ultrasound probes with each nominal frequency of 2.25MHz, 3.5MHz and 5MHz, 7.5MHz and 10MHz 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 receiving sensitivity were measured by replacing the commercial standard hydrophone with the fabricated hydrophone using hydro-thermally synthesized PZT poly-crystalline film.

![Measurement system of received ultrasound waveform and receiving sensitivity of fabricated needle-type miniature hydrophone using hydrothermally synthesized PZT poly-crystalline film on titanium wire](image)

**Figure 3** Measurement system of received ultrasound waveform and receiving sensitivity of fabricated needle-type miniature hydrophone using hydrothermally synthesized PZT poly-crystalline film on titanium wire.

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**RESULTS AND DISCUSSION**

**Hydrothermal synthesis of PZT poly-crystalline film on titanium wire**

The PZT poly-crystalline film was synthesized hydro-thermally 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.
Fabrication of hydrophone

Since it could be thought that the hydrothermally synthesized PZT poly-crystalline 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 using hydrothermally synthesized PZT poly-crystalline film shown in Fig.
3. The measured result is shown in Fig. 6(a). The received ultrasound waveform could be observed at about 10 µs after rise of trigger pulse for transmission.

Frequency characteristics of sensitivity of the fabricated hydrophone were measured at frequencies from 1MHz to 20 MHz with the measurement system shown in Fig. 3. The measured frequency characteristics are shown in Fig. 6(b). It was found that the measured receiving sensitivity was higher than about -280dB (0dB refer to 1V/µPa) in the frequency range from 1MHz to 20MHz.

![Graph](image)

(a) Received ultrasound waveform                                (b) Receiving sensitivity

Fig. 6 An example of received ultrasound waveform and frequency characteristics of receiving sensitivity with trial fabricated hydrophone using hydrothermally synthesized PZT poly-crystalline film

**SUMMARY**

The needle type miniature hydrophone was fabricated by hydrothermally synthesis of PZT poly-crystalline 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 20 MHz. It was found that the measured receiving sensitivities were higher than -280 dB (0dB refer to 1V/µPa).

We will fabricate the hydrophone using titanium wire with smaller diameter in the future work. The effect of the PZT synthesized on the side 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 [13],[14], we will consider the proposals in calibration for fabrication of hydrophone using hydrothermal method.
REFERENCES