Needle Type Miniature Hydrophone with PZT Poly-Crystalline Film Deposited by Hydrothermal Method having Wide Directivity

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Abstract - Recently, we have been studied on the deposition technique of piezoelectric poly-crystalline film by hydrothermal synthesizing method in order to develop the piezoelectric actuators and the ultrasound sensors. Hydrophones with diameter of 0.3 mm were fabricated trially by hydrothermal synthesizing method and estimated their performance. However, it was found that there were some problems on their directivities of receiving sensitivities. Hydrophones with modified structure were fabricated trially for improvement of their directivities of receiving sensitivity and estimated their performances.

I. INTRODUCTION

The PZT piezoelectric film deposited by hydrothermal method has been studied actively in our laboratory[1],[2]. The hydrothermally synthesized PZT poly-crystalline 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 feature [5]-[9]. The PZT films can be formed on the Ti substrate in the KOH solution with Pb ion, Ti ion and Zr ion under high temperature about 140 degrees centigrade and high pressure about 400kPa using hydrothermal method. This PZT film has piezoelectricity without polling process and it is easy to form the piezoelectric film on the titanium substrate with extremely small size by hydrothermal method. We reported on the manufacturing of needle type miniature hydrophones using PZT poly-crystalline film with thickness of about 10µm deposited on an end of titanium wire with diameter of 0.3 mm, length of 150 mm by hydrothermal method [10]. 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 [11],[12]. However, it was found that the hydrophones had some significant problems on their directivity. The receiving sensitivity to the side direction was higher than that to the front direction. PZT poly-crystals are synthesized on the all surface of titanium substrate exposed to the source material solution in the apparatus for hydrothermal synthesis. Therefore, PZT piezoelectric poly-crystalline films were deposited not only on an end surface of titanium wire, but also on the side of titanium wire near the end. Consequently, the problems were occurred in the directivity of receiving sensitivity of fabricated hydrophones. Then, we deposited PZT poly-crystalline films on only an end of titanium wire, not on the side of titanium wire by masking on the side of titanium wire using PTFE. We estimated the performance of the fabricated hydrophone using the titanium wire with PZT poly-crystalline film on only its end surface. As a result, we could confirm the improvement of its directivity of receiving sensitivity...
(-6dB; wider than +/-60deg at 5.0 MHz). We will report on the structure of our new hydrophone and considered results like the frequency characteristics of receiving sensitivity, the directivity, etc. in this symposium.

II. METHODS

Hydrothermal method

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 our apparatus for hydrothermal method. The apparatus was used to develop the needle type miniature hydrophone by 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. PZT poly-crystalline films were deposited hydrothermally on an end of titanium wire with diameter of 0.3 mm for the fabrication of hydrophones. The titanium wires are held directly on the rotating teflon stirring blade. The PZT poly-crystalline films can be deposited on the titanium wires 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.

Conventional hydrophone fabricated by hydrothermal method

Our hydrophone has the coaxial basic structure shown in Fig. 2 taking account of electrostatic shield. After hydrothermal deposition 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-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. However there was a problem in the directivity of receiving sensitivity of conventional miniature hydrophone fabricated by hydrothermal method. The receiving sensitivity in the side direction was higher than that in the front direction in the directivity. It is thought that PZT poly-crystalline film deposited on the side...
surface of the titanium wire cause to the problem in the directivity.

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

**New hydrophone fabricated by hydrothermal method**

PZT poly-crystalline film was deposited on all surface of titanium wire exposed to the solution of the source materials in the hydrothermal synthesis. The PZT poly-crystalline film deposited on the side surface of the titanium wire was removed by polishing. However, it is thought that this process was incomplete.

The deposition process for the new hydrophone was modified to deposit only on the end surface of the titanium wire by masking on the side surface of titanium wire. Masking material should not to dissolve to the material solution under the condition of high temperature (160°C), high pressure (0.5Mpa) and with strong alkalinity. Aqueous paint based on PTFE (POLYFLON PTFE enamel, DAIKIN INDUSTRIES LTD.) used as the masking material in this study. The structure of new hydrophone fabricated by hydrothermal method is shown in Fig. 3.

**Measurement of frequency characteristics and directivity of receiving sensitivity**

The received ultrasound waveform and frequency characteristics of receiving sensitivity of our fabricated hydrophone are measured using the system shown in Fig. 4.

Fig. 4 Measurement system of receiving sensitivity of fabricated needle-type miniature hydrophone by hydrothermal method.

A commercial water immerse type ultrasound probe (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
was applied to the commercial ultrasound probe. 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. The sound pressures transmitted with the commercial ultrasound probes in water 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 hydrophone.

Furthermore, directivity of receiving sensitivity of fabricated hydrophone by hydrothermal method was measured by fixing the position and attitude of the commercial water immerse type ultrasound probe (transmitter) and by rotating the fabricated hydrophone. The hydrophone was rotated on the acoustic receiving surface of the hydrophone as the center of rotation.

III. RESULTS AND DISCUSSIONS

Deposition of PZT poly-crystalline film on titanium wire

The PZT poly-crystalline film was deposited hydrothermally on an end of the titanium wire with diameter of 0.3 mm using the apparatus shown in Fig. 1.

Fig. 3 shows the SEM images of the titanium wire with deposited PZT poly-crystalline film by masking the side surface of the titanium wire before deposition. It can be confirmed that the PZT poly-crystalline film was deposited only on the end surface of the titanium wire.

Trial fabrication of new hydrophone

Since it could be thought that the hydrothermally deposited 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 hydrothermally synthesized PZT poly-crystalline film.

Fig. 6 Photograph of a trially fabricated new needle type miniature hydrophone with hydrothermally synthesized PZT poly-crystalline film

Measurement of directivity and frequency characteristics of receiving sensitivity

The directivity of receiving sensitivity of the new hydrophone was improved as result of this study. The receiving sensitivity of the new hydrophone in the front direction was higher than that in the side direction. The measured results at 5MHz were shown in Fig. 7.

Frequency characteristics of sensitivity of the fabricated hydrophone were measured at frequencies from 1MHz to 20 MHz with the measurement system shown in Fig. 4. The measured frequency...
characteristics of new hydrophone are shown together with those of conventional hydrophone fabricated by hydrothermal method and those of commercial PVDF hydrophone in Fig. 8. The receiving sensitivities of the new hydrophone were lower than those of the conventional hydrophone. The average receiving sensitivity of the new hydrophone was about –298 dB. The average receiving sensitivity of the conventional hydrophone was about –273 dB. The directivity of receiving sensitivity of the new hydrophone was improved. The receiving sensitivity of the new hydrophone in the front direction was higher than that in the side direction. The measured results were shown in Fig. 7.

V. CONCLUSIONS

The hydrophones having PZT poly-crystalline film deposited only on the end surface of titanium wire with diameter of 0.3 mm were fabricated trially by masking on the side surface of the titanium wire before deposition for improvement of their directivity. The receiving sensitivities of the new hydrophone were lower than those of the conventional hydrophone in the range from 1 MHz to 20 MHz. The average receiving sensitivity of the new hydrophone was about –298 dB. The average receiving sensitivity of the conventional hydrophone was about –273 dB.

V. REFERENCES