1Pb3-4

Underwater Characteristics of a Lead-free BNBT15-BNM Transducer

Yimeng Wang[1†], Deqing Kong[1], Yutaka Doshida[2], Minoru Kuribayashi Kurosawa[3], Manabu Aoyagi[1] ([1]Muroran Institute of Technology; [2]Ashikaga Univ.; [3]Tokyo Institute of Technology)

1. Introduction

Nowadays piezoelectric ceramics are widely used in various applications including the underwater propulsion system[1], due to their high power density and electromechanical coupling properties. A novel type of lead-free piezoelectric material, $(Bi_{0.5}Na_{0.5})_{0.85}Ba_{0.15}TiO_3$-$(Bi_{0.5}Na_{0.5}Mn)O_3$ (BNBT15-BNM), was proposed since it is not harmful to the human body[2,3]. To determine that BNBT15-BNM could be used in the fabrication of miniature underwater propulsion systems, it's essential to obtain its underwater characteristics.

In this study, underwater characteristics of the ultrasonic transducer made of BNBT15-BNM, which mainly included sound pressure and particle velocity in water, were investigated and discussed.

2. Principles of BNBT15-BNM Transducer

The appearance of the BNBT15-BNM transducer used in this study is shown in **Fig. 1**. The diameter is 5.3 mm, the thickness is 0.5 mm, and the electrode area is 15.9 mm^2. To facilitate the measurement, the transducer was fixed in the 3D-printed cylindrical cavity, so that one side of the transducer was placed in the cavity and the other side was exposed to the outside.

The admittance characteristics were first measured with air on both sides of the transducer. Then the cavity with the transducer was fixed in the tank where the water could completely submerge the transducer. The admittance characteristics were measured again in this case where one side of the transducer was air in the cavity and the other side was water in the tank. The results of two measurements are shown in **Fig. 2**. When the driving frequency was 4.3 MHz, there was a peak value of measured conductance both in air and water. However, the peak in water was only 12.6 mS, which was much smaller than the peak in air 28.7 mS. At the same time, the measured susceptance in air and water were 3.4 mS and 4.5 mS separately.

Fig. 1 Photograph of the BNBT15-BNM transducer.

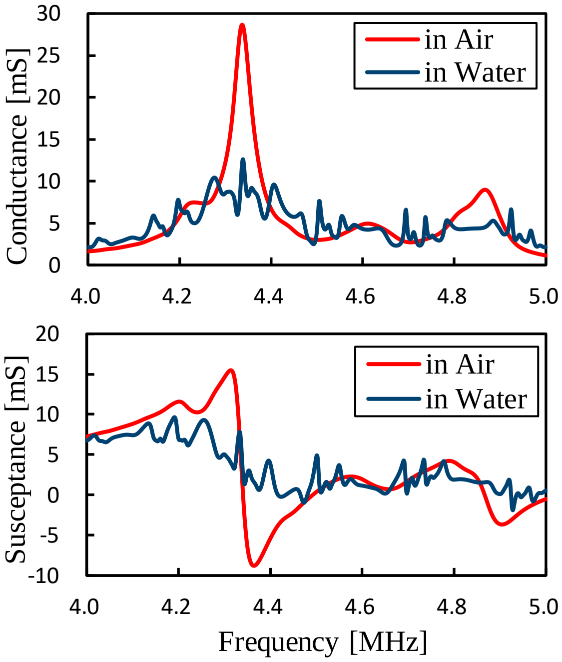


Fig. 2 Admittance characteristics of BNBT15-BNM transducer

3. Measurements and Results

3.1 Sound pressure

The hydrophone was used to measure sound pressure mainly in two lines, and both of them started from the position very close to the center of the transducer. One extended along the radial direction and ended at 6 mm. The other extended along the axial direction and ended at 20 mm. The interval between every two spots on both lines was 0.4 mm.

The results of sound pressure distribution

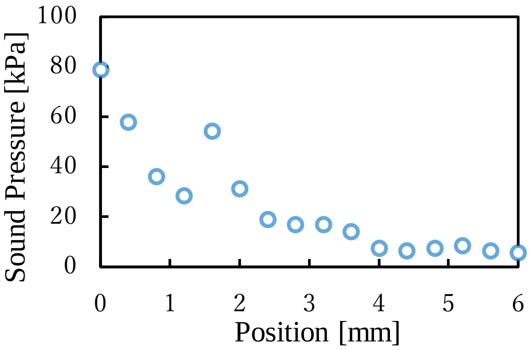
21043075@mmm.muroran-it.ac.jp

along both directions with 5 V_{pp} driving voltage were shown in **Fig. 3**. In the radial direction, the general tendency of sound pressure was to decrease with the increasing distance from the center. At the center of the transducer, there was the largest value of about 79 kPa. In the axial direction, the general tendency of sound pressure was to decrease rapidly at the beginning, and with the increase of distance from the center by about 5 mm, it started to increase and could reach 81 kPa at 11.6 mm. This means that there was a high sound intensity area generated by the transducer

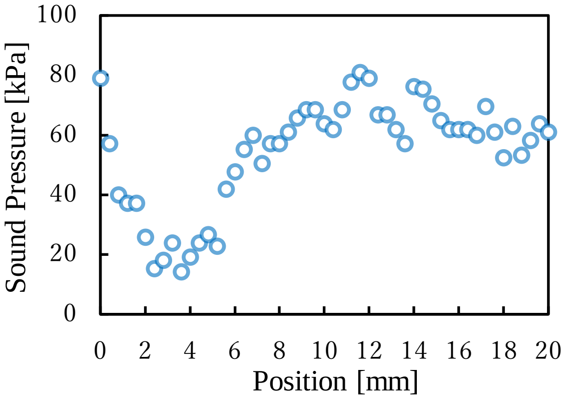
Sound pressure under different driving voltages was also measured. **Fig. 4** shows the relationship between the sound pressure close to the center of the transducer and the driving voltage. The sound pressure is almost proportional to the driving voltage.

3.2 Particle velocity

By using particle image velocimetry (PIV) analysis, the relationship between the maximum particle velocity and driving voltage can be obtained, as shown in **Fig. 5**. When the driving voltage was 10 V_{pp}, the maximum particle velocity was about 4.5 mm/s. With the increase of driving voltage, the maximum particle velocity also increased. When the driving voltage increased to 55 V_{pp}, the maximum particle velocity could reach about 16 mm/s.



(a) Radial direction



(b) Axial direction

Fig. 3 Distributions of sound pressure in radial and axial directions at 5 V_{pp}.

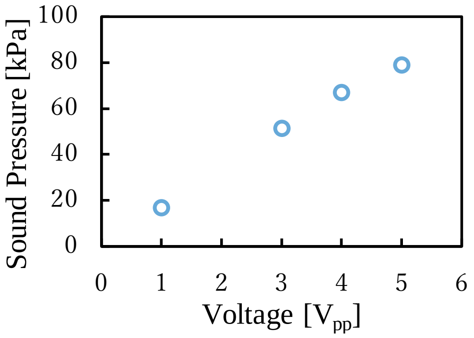


Fig. 4 The relationship between sound pressure close to the center of the transducer and driving voltage.

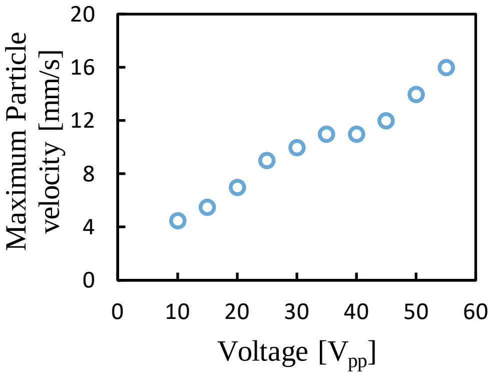


Fig. 5 The relationship between maximum particle velocity and driving voltage.

4. Conclusion

The underwater characteristics of BNBT15-BNM with a driving frequency of 4.3 MHz were investigated. In terms of sound pressure, the position close to the center of the transducer was the highest. It would keep decreasing along the radial direction, but along the axial direction would first decrease and then increase. Furthermore, the relationship between the sound pressure near the center of the transducer and the driving voltage was approximately proportional. In terms of acoustic streaming, the maximum velocity of particles in water increased along with the driving voltage.

Acknowledgment

This work was supported by Japan Society for the Promotion of Science (JSPS) KAKENHI Grant No. 20K20217.

References

1. Deqing Kong, Yuan Qian, Minoru Kuribayashi Kurosawa, and Manabu Aoyagi: J. Acoust. Soc. Am. **150**, 1157 (2021).
2. Yutaka Doshida, Kosuke Hayakawa, Hideki Tamura, and Satoshi Tanaka: Jpn. J. Appl. Phys. **61** (2022) SG1058.
3. Yuan Qian, Deqing Kong, Yutaka Doshida, Manabu Aoyagi, and Minoru Kuribayashi Kurosawa: Jpn. J. Appl. Phys. **60** (2021) SDDD11.