3Pb4-3

A Underwater Propulsion System with (Bi,Na,Ba)TiO3 Piezoelectric Ceramics

(Bi,Na,Ba)TiO3 基板による液中推進システム

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

銭 源[1†], 孔 徳卿[2], 土信田 豊[3], 青柳 学[2], 黒澤 実[1] ([1]東京工業大学, [2]室蘭工業大学, [3]足利大学)

1. Introduction

Today, piezoelectric ceramics are widely used in robotics and medical fields due to their electromechanical coupling properties. The electromechanical coupling property makes piezoelectric ceramic devices have two advantages compared to electromagnetic devices. The first advantage is that the output power of the piezoelectric ceramics can be directly controlled by the power supply. The second advantage is piezoelectric ceramics have high output power density. The above two advantages also make piezoelectric ceramic devices more suitable for miniaturization than electromagnetic devices. Therefore, the use of piezoelectric ceramics to design miniature underwater actuators that can enter water pipe and even blood vessels is actively being developed. In the past, $Pb(Zr, Ti)O_3$(PZT) piezoelectric ceramics have been proven to be used in miniature underwater propulsion systems. In this study, we used (Bi, Na, Ba)(Ti, Mn)O_3(BNBTM) piezoelectric ceramics instead of PZT to make a small underwater propulsion system and initially proved its feasibility.

2. (Bi, Na, Ba)(Ti, Mn)O3(BNBTM) Piezoelectric Ceramics

The obvious feature of BNBTM piezoelectric ceramics is lead-free. But, the study of BNBTM piezoelectric ceramics is not only from the viewpoint of environmental protection but also because of its stable piezoelectric characteristics at high power. PZT ceramics show nonlinear characteristics under high power conditions in practical applications. Because PZT ceramics heats up significantly at high power, which leads to decrease quality factors and weakened piezoelectric characteristics. But, BNBTM ceramics have high heat resistance, which makes it possible to suppress the decline of quality factors, heat generation, and nonlinear characteristics while the vibration velocity increases. BNBTM ceramics can obtain the faster vibration velocity than PZT ceramics under same power condition. Therefore, we believe that BNBTM ceramics are possible in the application of underwater propulsion systems.

Sen.g.ab@m.titech.ac.jp

3. Principle

In this study, we use the BNBTM transducer in the thickness vibration mode, the diameter is 8.4mm, the thickness is 0.5mm, the electrode area is 38.5mm^2, and the resonance frequency is 4.06MHz. The transducer is shown in Fig 1. We made a simple small underwater actuator by the BNBTM transducer for experiment. The actuator is shown in Fig 2. The small underwater propulsion system is made based on the principle of acoustic radiation force. From the acoustic radiation force principle, the acoustic radiation force will vary with the density of the fluid. Therefore, the difference in the reaction force of the acoustic radiation force between the two sides of the BNBTM transducer is used to provide underwater propulsion, called the acoustic radiation propulsion, as shown in Fig 3.

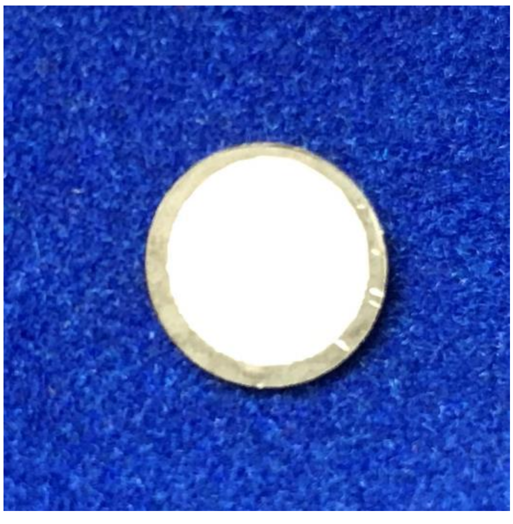

Fig. 1 The BNBTM transducer.(the diameter is 8.4mm, the thickness is 0.5mm, the electrode area is 38.5mm^2)

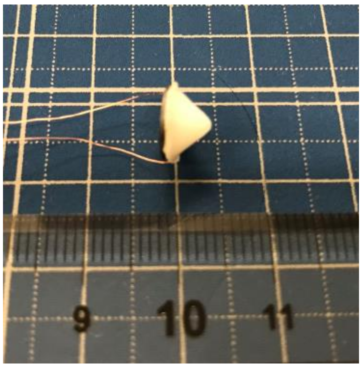

Fig. 2 The small underwater actuator.

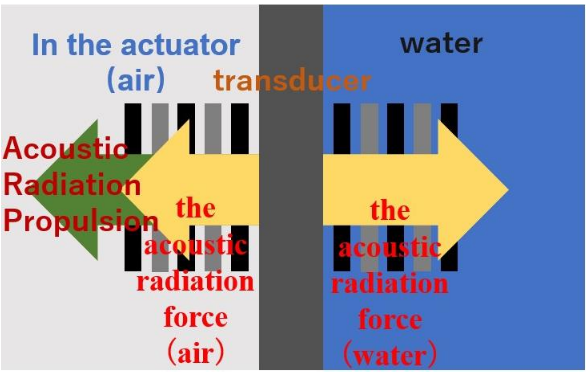

Fig. 3 The principle of the acoustic radiation propulsion.

4. Measurement Method

We measured the admittance characteristics of the BNBTM transducer, and the speed of the small underwater actuators of the BNBTM transducer driven by different voltages. In the experiment, we attached a small plastic board to make the balance in water. For the speed measurement, we use MATLAB to analyze the image of the small underwater actuator to obtain the proportional relationship between the actual length and the pixel points, then extract the color domain value of the actuator to identify the actuator in each frame of the video, then get the actual distance of the actuator movement between the two frames before and after, and finally calculate the speed of the actuator by the time interval between frames.

5. Results and Discussion

Firstly, we got the measurement data of conductance, as shown in Fig 4. From the figure, we can know that the resonance frequency of this BNBTM transducer is about 4.06MHz. Secondly, we got the maximum speed measurement data, as shown in Fig 5. From the figure, we can know that the maximum speed of this small underwater actuator by the BNBTM transducer is roughly linear with the voltage.

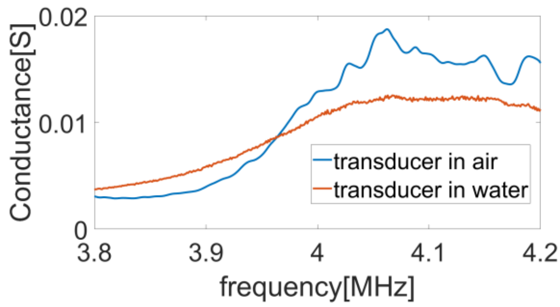

Fig. 4 The conductance of the small underwater actuator.

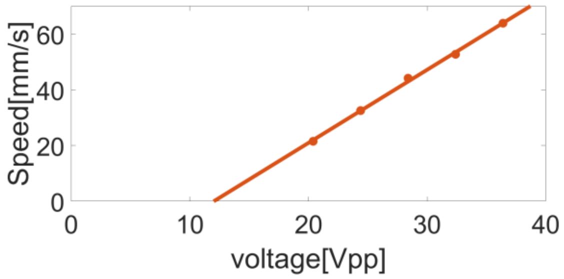

Fig. 5 Maximum speed of the underwater actuator by BNBTM transducer in water.

6. Conclusions

We made a small underwater actuator of the BNBTM transducer and conducted preliminary experiments to confirm that BNBTM piezoelectric ceramics have the feasibility of being applied to small underwater propulsion systems. In the future, we will further compare the thickness vibration modes of PZT piezoelectric ceramics and BNBTM piezoelectric ceramics to explore the potential of BNBTM piezoelectric ceramics in the application of small underwater Propulsion Systems.

Acknowledgment
The authors would like to thank K.Aihara for technical assistance with the experiments.

References

1. Deqing Kong, Kazuki Nishio, Minoru Kuribayashi Kurosawa: Sensors and Actuators A 309 (2020) 111943.
2. Deqing Kong, Kazuki Nishio, Minoru Kuribayashi Kurosawa: Smart Mater. Struct. 29 (2020) 02LT02 (6pp).
3. Yutaka Doshida, Hiroyuki Shimizu, Youich Mizuno, Ketia Itoh, Seiji Hirose, and Hideki Tamura: Jpn. J. Appl. Phys. 50 (2011) 09ND06.
4. Yutaka Doshida, Hideki Tamura, Satoshi Tanaka, Tomohiro Harada, and Hiroyuki Shimizu: Japanese Journal of Applied Physics 59, SKKA07 (2020).