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Acoustic Underwater Propulsion System via a 36° Y-cut LN Thickness-vibration-mode Transducer

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1. Introduction

Underwater propulsion systems using the acoustic propulsion force have no moving parts such as fins or screws propulsion force is generated at the interface when wave radiate from a solid to a liquid. The acoustic propulsion system for self-propelled robots in liquid has a higher power density and smaller size than conventional liquid propulsion systems[1-4].

In this study, single-crystal lithium niobate ($LiNbO_3$, LN) substrates based on excellent high-power characteristics are used to investigate underwater acoustic propulsion. To generate the thickness-vibration-mode, a 36° Y-cut $LiNbO_3$ square plate transducer (10 × 10 × 0.35 mm) is fabricated as an acoustic propulsion system.

2. LN thickness-vibration-mode transducer

As shown in **Fig. 1**, when an ultrasonic transducer is placed in water, acoustic radiation pressure is generated at the boundary between the solid and liquid because of the difference in acoustic impedance difference with the solid and liquid. An acoustic driving force is radiated into the liquid.

Since the other is in air, a one-way self-propelled propulsion system is possible.

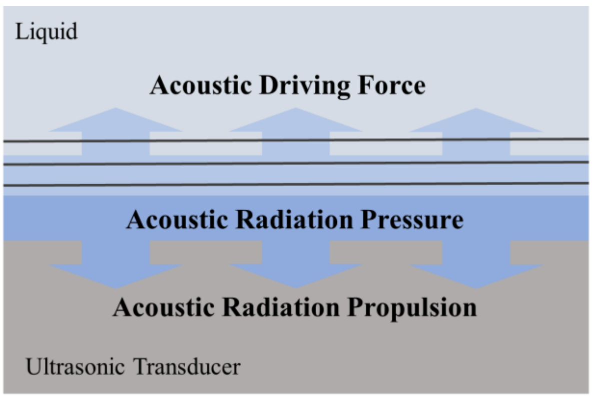

Fig.1 Acoustic radiation propulsion at interface of solid and liquid.

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$LiNbO_3$ is a ferroelectric single crystal with ilmenite structure. It has excellent vibration characteristics with low vibration loss and low heat generation. It also has low dielectric loss and excellent high-power characteristics. Thus, it is expected to be used as a vibration source for underwater ultrasonic propulsion systems. In this study, a single-crystal 36°Y-cut LN substrate (from Yamaju Ceramics) as shown in **Fig. 2**. A square plate transducer of 10×10×0.35 mm was fabricated to investigate the underwater acoustic propulsion system.

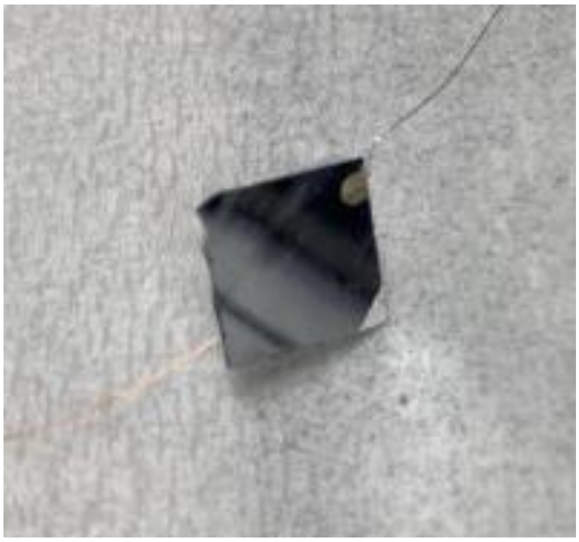

Fig.2 LN Transducer.

3. Measurements

3.1 Admittance characteristics

The admittance characteristics of the LN transducer were measured in air and one side of the transducer in water. The results are shown in **Fig. 3**. The driving frequency was around 8.5 MHz both in air and with a one-side in water. In air (blue line), the peak conductance of the LN transducer was 156 mS. When one side was in water (red line), the peak conductance of the LN-thick transducer dropped to 42.7 mS. Susceptance was 3.5 mS and 4.8 mS in air and one side in water in the driving frequency.

3.2 Propulsion

In order to investigate the acoustic propulsion force using the LN transducer, the zero-speed propulsion force was measured, when the transducer was restrained to the force sensor [Honeywell, FSG005WNPB].

As shown in **Fig. 4**, 0.2 mN zero-speed propulsion was measured in water, when the drive voltage was 4.5 V_{pp}. It increased with higher input voltage. 33.5 mN zero-speed propulsion was confirmed in water when the drive voltage was 28 V_{pp}.

Fig. 5 shows the results of the comparison with the PZT disk transducer (9×1 mm) in the previous study. At the 4 W input power, the zero-speed propulsion of the LN square plate transducer and the PZT thickness disk transducer in the unit area was 33.5 mN and 3 mN, respectively. At the same input power, the acoustic propulsion in a unit area by the LN transducer was 11 times greater than PZT transducer.

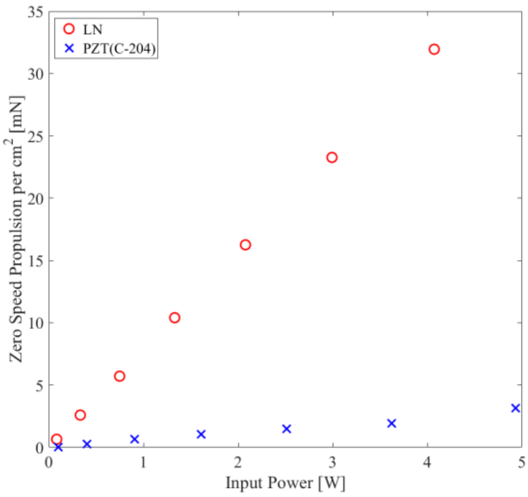

Fig. 5 Zero-speed propulsion of LN and PZT transducer.

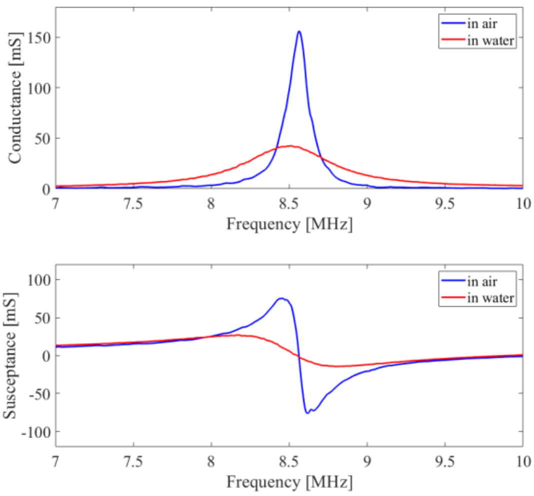

Fig. 3 Admittance characteristics.

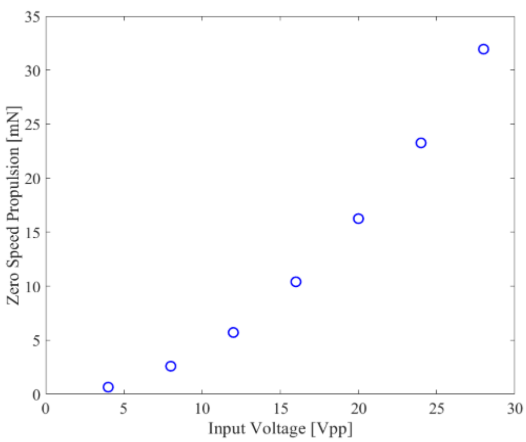

Fig. 4 Zero-speed propulsion measurement.

4. Conclusion

Underwater acoustic propulsion using the LN square plate transducer was investigated. At the same input power, the acoustic propulsion in the unit area by the LN transducer was 11 times greater than the PZT disk transducer. Thus, the 36° Y-cut LN transducer is expected as a underwater acoustic propulsion system.

Acknowledgment

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

References

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