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Thermal Characteristics of a PMN-PT Single Crystal and an Ultrasonic Motor in Ultralow Temperature Environment

極低温領域における PMN-PT 単結晶と超音波モータの温度特性の評価

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1. Introduction

An ultralow temperature, near liquid helium temperature, is an important environment in the advanced scientific research area.[1, 2] In the temperature environment, thermal noise in a measurement is low. Additionally, the quantum-mechanical effects control various phenomena. From these reasons, there are demands for actuatros that can be driven at the temperature.

Previously, we have fabricated a cryogenic ultrasonic motor using a PMN-PT single crystal. The motor can be rotated at 4.5 K, and has higher rotation speed than the motor using PZT ceramics.[3] Additionally, the motor using PMN-PT single crystal had a different thermal characteristics of driving performance from that using PZT.

In this study, we have evaluated the thermal characteristics of the PMN-PT single crystal and PZT ceramics. In addition, the characteristics of a motors using PMN-PT single crystal are compared with that of a motor using PZT ceramics.

2. Structure of the motor

The structure of the ultrasonic motor is shown in Fig. 1. The motor consists of a bolt-clamped Langevin-type transducer, a rotor, a spring, a casing, and a bearing. The rotor is driven by the friction between the rotor and the tip of the transducer. The contact pre-load is generated by the spring.

The structure of the transducer is shown in Fig. 2. The transducer has two piezoelectric rings. The rings are made of PMN-PT single crystal or PZT ceramics. We fabricated and evaluated two types of transducers using each piezoelectric material. When a driving temperature is fallen from room temperature to ultralow temperature, the transducer is affected by the thermal stress. This stress damages the piezoelectric rings. In this study, the themral stress is simulated by using finited element method analysis.[4] The diameter and length of the transducer are 6 and 16 mm. The diameter of the flance is 20 mm.

Those motors are driven at ultralow temperature. The applied voltage was 50 V_{p-p}. The rotation speed and starting torque of the motor using PMN-PT were 63.0 rpm and 15.6 μNm at 4.5 K. The rotation speed and starting torque of the motor using PZT were 131 rpm and 0.31 μNm at 4.5 K.

3. Evaluation of piezoelectricity at ultralow temperature

The piezoelectricity of PMN-PT single crystal and PZT ceramics were evaluated at ultralow temperature. The piezoelectric constant d_{31} was measured by using rectangular specimens made of each material. The length, width, and thickness of the specimens are 12, 3, and 0.2 mm, respectively. The specimens have electrodes on both sides. The crystal orientation of PMN-PT is (100). Both specimens were polarized in the thickness direction. The schematic of the experimental setup is shown in Fig. 3. A specimen

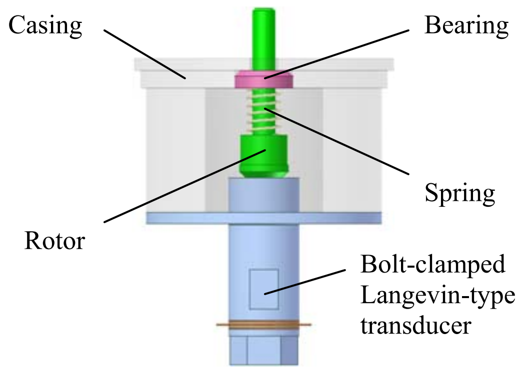

Fig. 1 Structure of the ultrasonic motor

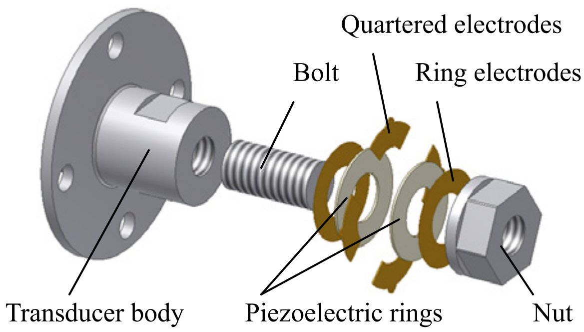

Fig. 2 Structure of the bolt-clamped Langevin-type transducer

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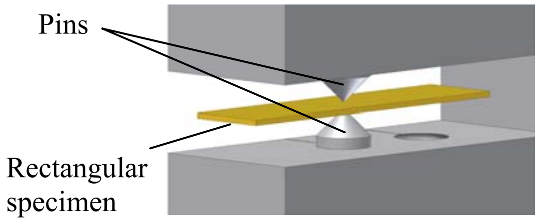

Fig. 3 Experimental setup for measuring d_{31} of piezoelectric material specimens

is supported by two pins at the center. The driving voltage is applied on the electrodes of the specimens by the pins.

The relationship between the temperature and the d_{31} is shown in Fig. 4. d_{31} is measured and calculated by the resonance-antiresonance method. The PMN-PT single crystal has higher piezoelectricity than PZT ceramics at each temperature. However, d_{31} of PMN-PT single crystal decreased rapidly when the temperature ranged from 296 to 240 K and from 180 to 60 K.

The relationship between the dielectric loss and the temperature is shown in Fig. 5. From this result, the dielectric loss has a peak at 150 K. In addition, the rapidly decreasing of the d_{31} is attributed to this increasing of the dielectric loss.

4. Comparison of thermal characteristics

The relationship between efficiency of the motors and the temperature is shown in Fig. 6. From this result, the motor using PMN-PT has higher efficiency than the motor using PZT at each temperature. Additionally, the efficiency of using PMN-PT decreased rapidly when the temperature ranged from 240 to 180 K.

From the comparison of Fig. 4 and Fig. 6, the decreasing of efficiency was attributed to the decreasing of piezoelectricity. However, the temperature of rapid efficiency decrease is different from that of rapid piezoelectricity decrease. The reason of this difference is attributed to the pre-load of the transducer.

5. Conclusion

In this study, the piezoelectricity and dielectric loss of the PMN-PT single crystal and PZT ceramics were evaluated at ultralow temperature. In addition, the efficiency of the motors using PMN-PT and PZT is evaluated at ultralow temperature. From the comparison of these results, the efficiency of the motor was attributed to the piezoelectricity and the dielectric loss.

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References

1. N. Suehira, Y. Tomiyoshi, K. Sugiyama, S. Watanabe, T. Fujii, Y. Sugawara, S. Morita: Appl. Surf. Sci. **157** (2000) 343.
2. G. Martinet, S. Blivet, F. Chatelet, M. Fouaidy, N. Hammoudi, A. Olivier, H. Saugnac: Proc. EPAC, 2006, p. 390.
3. D. Yamaguchi, T. Kanda, K. Suzumori: Sens. Actuators A **184** (2012) 134.
4. D. Yamaguchi, T. Kanda, K. Suzumori, M. Kuroda, D. Takeda: Jpn. J. Appl. Phys. **51** (2012) 07GE09.

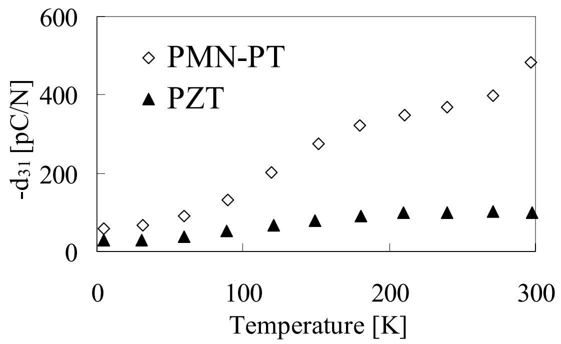

Fig. 4 Relationship between the temperature and d_{31}

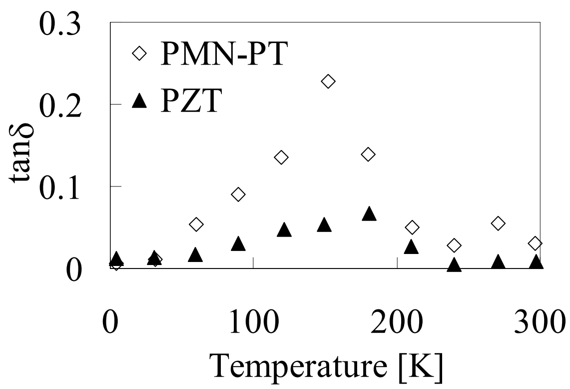

Fig. 5 Relationship between the temperature and the dielectric loss

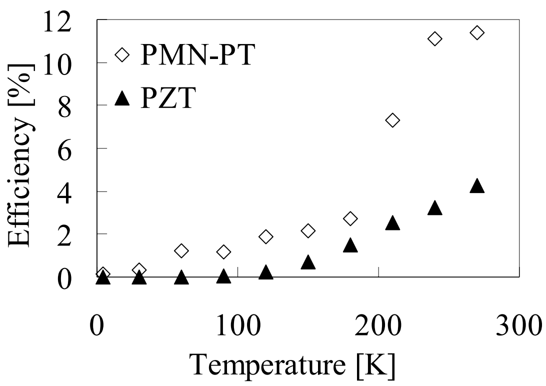

Fig. 6 Relationship between the temperature and the efficiency of the motors