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Evaluation of high power property of (Bi,Na)TiO_3-$BaTiO_3$ and its application for elastic fin type ultrasonic motor

(Bi,Na)TiO_3-$BaTiO_3$ の 33 効果のハイパワー特性評価と弾性フィン型超音波モータへの応用

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1. Introduction

Ultrasonic motors utilize the piezoelectric effect to convert electric input into mechanical output, which result in actuating slider or rotor. Because of this driving principle, characteristics of the piezoelectric material affect the performance of ultrasonic motor directly. In general, Pb(Zr,Ti)O_3 [PZT] is used for ultrasonic motors because it has high piezoelectric constant and can generate large output force and displacement. However, PZT includes lead, which is harmful and is restricted in RoHS. Currently, lead contained in piezoelectric materials is exempted from RoHS as a special case, but it would be prohibited in the near future. Therefore, various lead-free piezoelectric materials are developed[1]. However, it is difficult to develop lead-free piezoelectric materials which have high piezoelectric properties, outstanding temperature stability and low manufacturing cost as PZT.

However, some lead-free piezoelectric materials show higher vibration velocity under high electric field, internal stress and strain[2-3]. Such excellent power property is promising advantage of lead-free piezoelectric materials. (Bi,Na)O_3-$BaTiO_3$ [BNBT] is one of the lead-free piezoelectric materials, which possess such high power properties. In this research, we focus on its great high power characteristics. We evaluated the high power properties using nonlinear piezoelectric vibration model and developed a miniaturized ultrasonic motor using BNBT. To magnify the practical piezoelectric constant of BNBT; therefore, multilayer structure was introduced to enhance the piezoelectric displacement. Additionally, elastic fins structure was adopted to convert the piezoelectric linear motion into rotational moment of the rotor[4].

2. Evaluation of high power property

Piezoelectric high power property can be evaluated by higher order elastic constant. We have already developed the nonlinear *LCR* equivalent circuit method to obtain higher order elastic constants[5]. Measuring the admittance curve under high input voltage and fitting it with the nonlinear LCR equivalent circuit model, higher order elastic constants of piezoelectric transducer can be obtained. Measured real and imaginary parts of higher order elastic constant of BNBT, soft-type PZT(Fuji- Ceramics C6) and hard-type PZT(Fuji-Ceramics C203) are listed in **Table Ⅰ**. The absolute value of higher order elastic constants of BNBT are smaller than PZT; which means that BNBT has excellent high power property.

Table Ⅰ Higher order elastic constants

	Re ($c_{11(3)}^E$) [N/m^2]	Im($c_{11(3)}^E$) [N/m^2]
BNBT	-1.4×10^{15}	3.2×10^{14}
Soft PZT	-2.5×10^{18}	8.0×10^{17}
Hard PZT	-1.3×10^{17}	8.5×10^{15}

3. Design of the ultrasonic motor

Proposed ultrasonic motor and its rotor part are shown in **Fig.1** and **Fig. 2**. The size of the BNBT multilayer transducer was 5mm×5mm×8mm and consist of 140 layers. On the top surface of the multilayer transducer, four L-shaped elastic fins and the shaft were bonded. These elastic fins were made of beryllium copper and the angle of the fins were 15°. These elastic fins convert the longitudinal displacement of the multilayer transducer into the rotational movement of the rotor. Preload was given by the spring, whose spring constant was 0.118 N/mm or 0.765 N/mm.

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The driving principle of the elastic fin motor is shown in **Fig. 3**. From the initial state (a) to the state (b), the stator moves to upward and the rotor and elastic fin move together without slippage because of sufficient the normal force (= preload force + force from the stator). In the state (c), when the stator moves downward, the normal force (= preload - force from the stator) decreases and the slippage happen. In the end of the state (c), the rotor rotates in right direction from the state (a). In this way, by repeating the cycle of state (a)~(c) the rotor is driven in one direction.

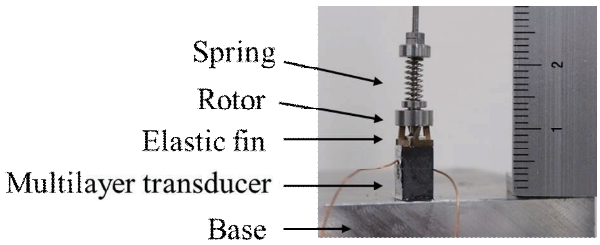

Fig. 1 The proposed ultrasonic motor

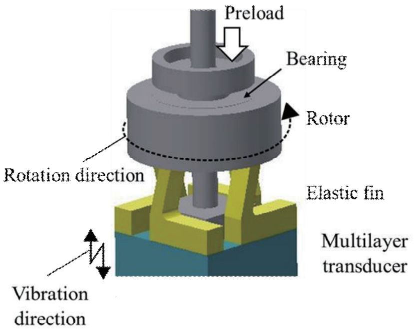

Fig. 2 Rotor part of the ultrasonic motor

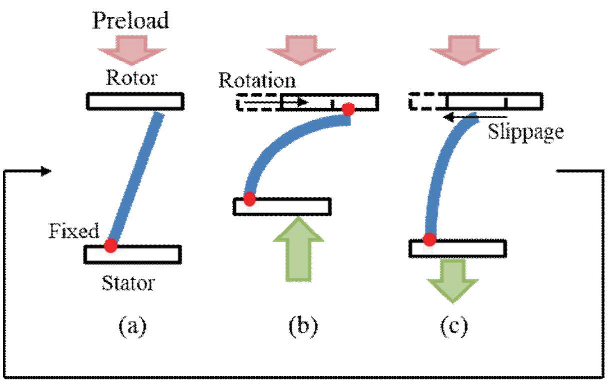

Fig. 3 Driving principle of the elastic fin motor

4. Measurement of the rotational speed

To evaluate the performance of the motor, the rotational speed of the rotor was measured by the laser doppler velocimeter. The relationship between the rotational speed and the input voltage under the preload of 2 N and 3 N is shown in **Fig. 4**. The resonance frequency was shifted from 60.2 kHz to 60.0 kHz by changing the preload from 2 N to 3 N. The rotational speed increased by increasing the input voltage and finally it was saturated. The rotation under 3 N preload was unstable compared to 2 N preload and the rotation was not confirmed under 4 N preload. It is because the too large preload result in erasing the slippage in the state of Fig. 3 (c). The maximum rotational speed was 898 rpm at 2 N preload and 922 rpm at 3 N preload.

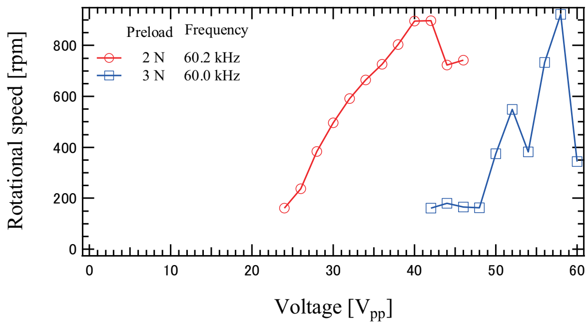

Fig. 4 The relationship between the voltage and the rotational speed

5. Conclusion

In this research, the miniaturized elastic fin type ultrasonic motor using the BNBT multilayer transducer was developed and evaluated. The maximum rotational speed 922rpm at 3 N was measured and the driving principle could be confirmed. To improve the performance of this motor, the material and angle of elastic fins must be investigated. For the future work, the performance difference between the lead-free piezoelectric material and lead-based piezoelectric material will be examined in terms of the usage for the stator of the ultrasonic motor.

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