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High-power properties of crystal-oriented $(Sr,Ca)_2NaNb_5O_{15}$ piezoelectric ceramics and application to ultrasonic motor

$(Sr,Ca)_2NaNb_5O_{15}$ 配向体のハイパワー特性と超音波モータへの応用

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1. Introduction

The piezoelectric actuators are almost always fabricated using $Pb(Zr,Ti)O_3$-based (PZT) ceramics. However PZT ceramics easily experience a large strain and produce a notable degree of nonlinearity under practical use condition as the high-power properties, which increase heat generation with decreasing quality factor and deteriorate the performance of PZT ceramics.

Recently, lead-free piezoelectric ceramics have been actively studied not only from the viewpoint of environmental conservation but also for the possibility of outstanding high-power characteristics. It was previously reported that $(Bi,Na,Ba)(Ti,Mn)O_3$ (BNBTM) and $(Sr,Ca)_2NaNb_5O_{15}$ (SCNN) ceramics have good high-power properties, moreover c-axis crystal-oriented SCNN ceramics have the effective piezoelectric constant as large as that of hard PZT ceramics and superior high-power characteristics.[1,2] They represented higher output power density than that of PZT ceramics.[3]

The nonlinear behavior of PZT originated from the soft-spring effect through which the mechanical nonlinearity was induced and the temperature dependence of stiffness was enhanced.[3] On the other hand, the nonlinear behaviors of BNBTM and SCNN originated from the apparent soft- and hard-spring effects through which the temperature dependence of stiffness was induced.[3]

In this study, we investigated the high-power properties of c-axis crystal-oriented SCNN ceramics under much more high vibration velocity using an electrical transient response of burst voltage with changing the sample temperature, as the distinction between mechanical nonlineality and temperature dependence of properties.[4,5] And then, we fabricated ultrasonic motor using L1-vibration mode of c-axis crystal oriented SCNN ceramics and evaluated characteristics of the motor.

2. Experimental Procedure

SCNN powder were synthesized by a conventional solid-phase reaction.[1] The c-axis crystal-oriented SCNN ceramics were prepared by the high-magnetic-field method and had rectangular shape with dimensions of 12 x 3 x 1 mm for the 31-mode.[2] As comparison, we prepared randomly oriented SCNN and BNBTM disk samples with the dimensions of ϕ8 x 0.5 mm using conventional process.[2]

The high-power properties were measured as a resonator in the 31-mode using an electrical transient response of burst voltage after the sample temperature was changed by continuous driving it.[4,5]

The motor was fabricated as the stator vibrator using the 31-mode resonator of c-axis crystal-oriented SCNN ceramics. The contact area of the stator to the rotor is Al_2O_3 ceramic plate on short side surface of the SCNN ceramics because of rub resistance. The driving properties of the motor was evaluated.

3. Results and Discussion

The quality factor of crystal-oriented SCNN became about five times high of randomly oriented SCNN and BNBTM ceramics under large-amplitude vibration, which decreased slightly with increasing vibration velocity as shown in **Fig.1**. The temperature change of quality factor was not recognized by comparison with randomly oriented SCNN and BNBTM ceramics.

The equivalent stiffness of crystal-oriented SCNN ceramics were almost constant however the stiffness of randomly oriented SCNN and BNBTM ceramics changed linearly with increasing temperature in the measurement range as shown in **Fig.2**. There is no mechanical non lineality behavior of crystal-oriented SCNN ceramics under large-amplitude vibration. Remarkably, crystal-oriented SCNN ceramics decreased the equivalent stiffness and increased the quality factor significantly by c-axic crystal-orientation. The reason is thought that the internal stress induced from crystal anistropy of thermal expansion

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decreased with crystal-oriented morphology.[6]

Figure 3 shows the ultrasonic motor using crystal-oriented SCNN ceramics with experimental setup to measure load characterisctics of the motor.

The revolution speed and the efficiency of the motor as function of a torque are shown in **Fig. 4.** The motor was driven at 214.8 kHz, 50V_{rms} under 1.95N of preload. The revolution speed represent 190 rpm at 0 uN m of torque as maximum value. The revolution speed is about 100 rpm in the range of torque 150 uN m to 900 uN ms. The efficieny of the motor represented 3.5% at 657 uN m and 109 rpm as maximum value. The motor of crystal-oriented SCNN showed high output power than previous study using randomly oriented SCNN multilayer ceramics.

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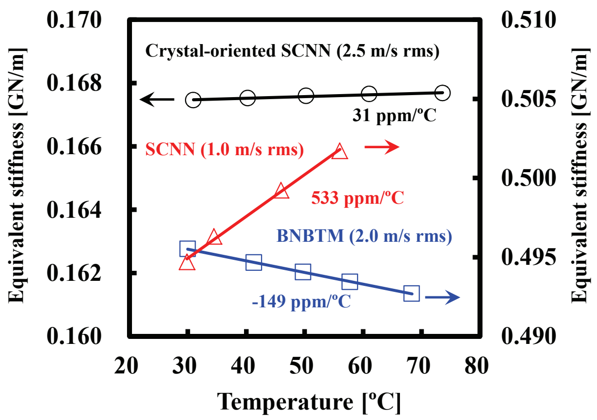

Fig. 2 Temperature dependence of equivalent stiffness of SCNN and BNBTM ceramics.

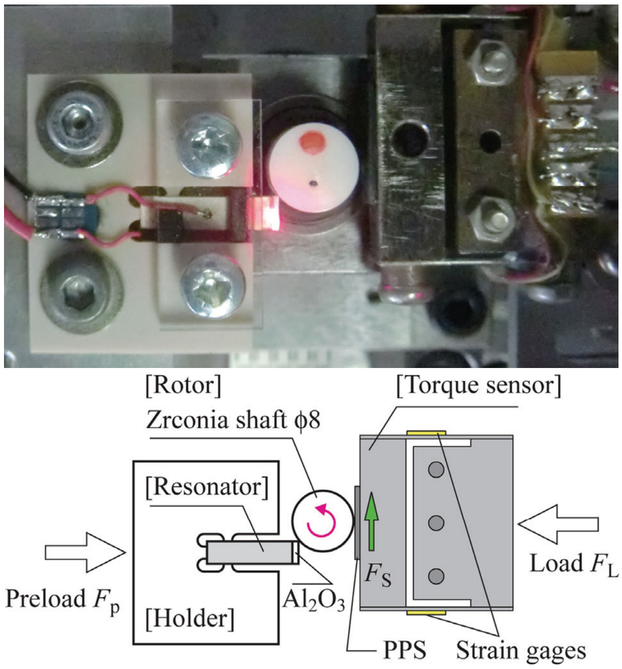

Fig. 3 Ultrasonic motor using crystal-oriented SCNN ceramics and experimental setup to characterize the motor.

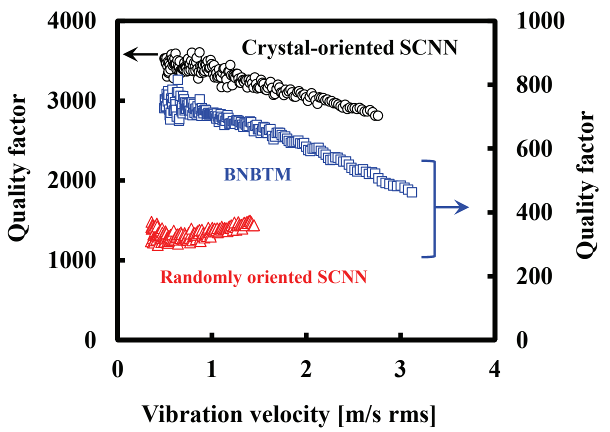

Fig. 1 Vibration velocity dependence of quality factor of SCNN and BNBTM ceramics.

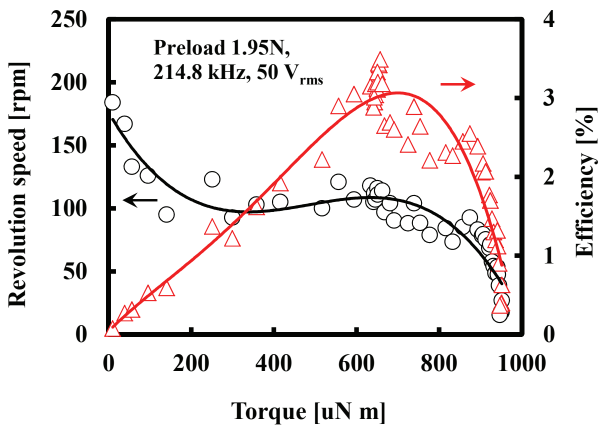

Fig. 4 The driving properties of the motor using crystal-oriented SCNN ceramics.