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High-power properties of lead-free piezoelectric ceramics under large-amplitude vibration

大振幅振動下での非鉛圧電体のハイパワー特性

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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.

Resently, 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) ceramics 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 dinsity than that PZT ceramics.[3]

BNBTM ceramics and SCNN ceramics also exhibited the jump phenomena with soft-spring effect similar to PZT ceramics and hard-spring effect as unique elasticproperties among the piezoelectric ceramics, respectively. 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 BNBTM ceramics, SCNN ceramics, and 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]

2. Experimental Procedure

BNBTM powder and SCNN powder were synthesized by a conventional solid-phase reaction.[1] These disks were sintered and had the dimensions of ϕ8 x 0.5 mm. 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^3 for the 31-mode.[2]

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

3. Results and Discussion

The equivalent stiffness of BNBTM disk decreased with an increase of vibration velocity and temperature rise as shown in **Fig. 1**. The quality factor decreased with increasing vibration velocity and slightly decreased with temperature rise as shown in **Fig. 2**. The mechanical nonlinearities of BNBTM ceramics were observed under large-amplitude vibration than that of previous study.[3]

The equivalent stiffness of SCNN disk slightly decreased with an increase of vibration velocity and increased with temperature rise as shown in **Fig. 3**. The quality factor showed nearly no dependence on the vibration velocity irrespective of sample temperature and also increased with temperature rise as shown in **Fig. 4**. The mechanical nonlinearities of SCNN ceramics were not observed. It will be attributed to free of non-180º domain walls in SCNN ceramics. The temperature coefficients of equivalent stiffness were almost the same in the previous study.[3] The temperature dependences of stiffness and quality factor are attributed to ferroelastic phase transition for SCNN ceramics.

We are evaluating the high-power properties of c-axis crystal-oriented SCNN plate and will report in detail on these results.

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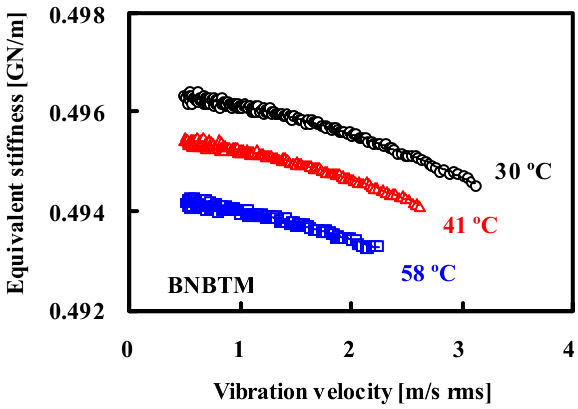

Fig. 1 Vibration velocity dependence of equivalent stiffness for BNBTM disk.

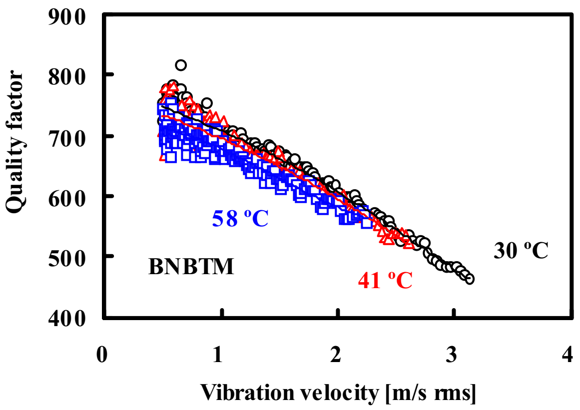

Fig. 2 Vibration velocity dependence of quality factor for BNBTM disk.

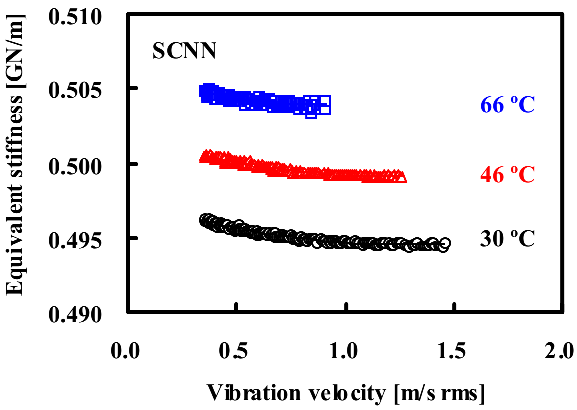

Fig. 3 Vibration velocity dependence of equivalent stiffness for SCNN disk.

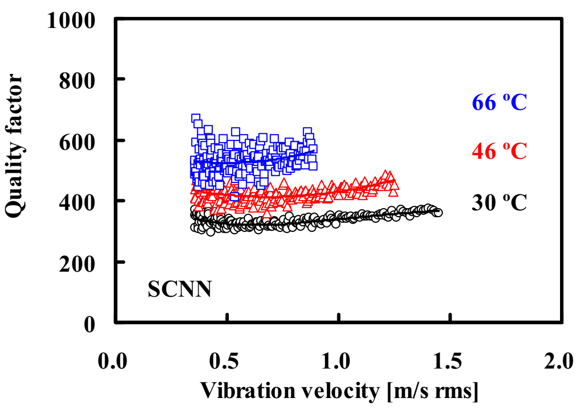

Fig. 4 Vibration velocity dependence of quality factor of SCNN disk.