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High-Temperature and High-Power Piezoelectric Characteristics of Bismuth Layer-Structured Ferroelectric Ceramics

ビスマス層状構造強誘電体セラミックスの高温ハイパワー圧電特性

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1. INTRODUCTION

Recently, many high-power piezoelectric ceramic devices, such as ultrasonic motors and piezoelectric actuators, have been developed. Hard $Pb(Zr,Ti)O_3$ [PZT] ceramics or $Pb(Mn_{1/3}Nb_{2/3})O_3$-$Pb(Zr,Ti)O_3$ [PMN-PZT] ceramics are usually used in high-power applications. However, PZT ceramics contain a large amount of PbO, therefore, lead-free piezoelectric materials to replace PZT are recently required from the viewpoint of environmental protection. One of the characteristics required for the ultrasonic transducer is vibration velocity. This is known to be proportional to the product of piezoelectric strain constant d_{33} and mechanical quality factor Q_m. Bismuth layer-structured ferroelectrics (BLSFs) have a high mechanical quality factor, Q_m. Therefore they are seemed to improve vibration velocity of lead-free piezoelectric materials[1]. Some of BLSF ceramics are one of possible candidate materials for high-power applications because they have high mechanical quality factor (Q_m > 3000) and vibration velocity ($v_{0\text{-}p}$ > 2.5 m/s) [2]. However it is known that the temperature usually increases owing to heat generation under continuous driving. Additionally, the high-power piezoelectric characteristics of BLSF ceramics at a high temperature have not been sufficiently clarified and cleared yet [3]. In this study, therefore, the high-power piezoelectric characteristics at a high temperature (~150°C) were studied to clarify the temperature stability of high-power piezoelectric properties of BLSF ceramics. In this proceeding especially, we described about $Bi_4Ti_{2.98}V_{0.02}O_{12}$[BITV] ceramics as an one of the examples of BLSF ceramics. Moreover, we compared the temperature dependences of high-power piezoelectric properties with those of hard PZT ceramic [NEC Tokin: PZT-N82].

2. EXPERIMENTAL PROCEDURE

BITV ceramic samples were prepared by a conventional ceramic fabrication technique. The starting raw materials were Bi_2O_3 of 99.99% of purity, TiO_2 and V_2O_5 of 99.9% of purity. Calcination temperature was 850°C for 2 h and then sintering temperature was 980°C for 2 h in air. Electrodes were made with fired-on Ag paste for electrical measurements. Applied field, E_p, temperature, T_p, and time, t_p, in the poling process were about 5 kV/mm, 200°C and 7 min, respectively. A longitudinal vibration of the (33) mode was measured using a rectangular specimen of 2×2×5 mm^3. Small amplitude piezoelectric properties were determined by a resonance and antiresonance method using a impedance analyzer (Agilent 4294A). The temperature dependences of piezoelectric strain constant d_{33} and mechanical quality factor Q_m were measured using the same impedance analyzer with the same set up from RT to about 150°C. The vibration velocity $v_{0\text{-}p}$ was measured using a laser Doppler vibrometer (Ono Sokki LV1710) equipped with an oscilloscope (Tektronix TDS3054B). The value of $v_{0\text{-}p}$ for short-time driving was determined by frequency sweep measurement at approximately the resonant frequency. The value of Q_m under high-amplitude vibration was determined by electric transient response measurement [4-5]. In addition, a PZT ceramic (NEC-Tokin N82) was also studied for comparison. The temperature dependences of $v_{0\text{-}p}$ and Q_m under high-amplitude vibration were measured using the analyzer set up for high-power measurement attached to a thermostatic oven for heat treatment. The sample temperature was directly monitored using thermocouples.

3. RESULTS AND DISCUSSION

Table I shows the electrical and piezoelectric properties of small amplitude vibration for BITV and PZT. Table I shows that the product of $d_{33}\times Q_m$ of PZT is approximately four times as large as that of BITV. The temperature dependences of d_{33} of BITV and PZT ceramics under the small amplitude vibration was measured. The d_{33} values of PZT ceramic gradually rise as the temperature increased. On the other hand, the d_{33}

values of BITV ceramic was nearly constant as the temperature increased. Figure 1 shows the temperature dependences of normalized Q_m change of BITV and PZT ceramics under the small amplitude vibration. The Q_m for the PZT ceramic continuously decreased with increasing temperature. On the other hand, the Q_m values of the BITV ceramic was nearly constant as the temperature increased from R.T. to 150ºC. Figure 2 shows the temperature dependences of the vibration velocity $v_{0\text{-p}}$ under frequency sweep measurement at a constant electric field for the BITV and PZT ceramics. The $v_{0\text{-p}}$ of the PZT ceramic markedly decreased as a function of temperature. On the other hand, the $v_{0\text{-p}}$ values of the BITV ceramic were nearly constant with increasing temperature. Figure 3 shows the temperature dependences of the Q_m at a constant electric field for the BITV and PZT ceramics. Similar to Fig. 1, Q_m for the PZT ceramic

Table I Electrical and piezoelectric properties of small amplitude vibration for BITV and PZT ceramics.

	$\varepsilon_{33}^T/\varepsilon_0$	k_{33}[%]	d_{33}[pC/N]	Q_m
BITV	143	24.0	25.3	3173
PZT	1400	72.0	337.1	1000

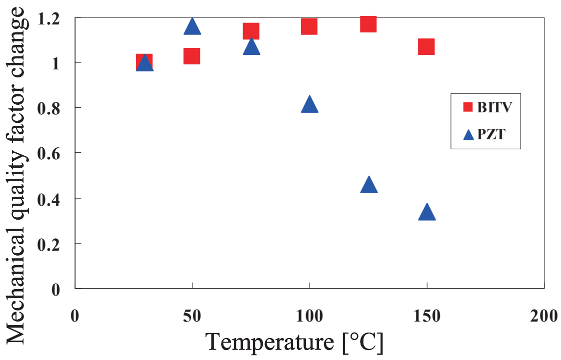

Fig. 1 Temperature dependences of Q_m change of BITV and PZT ceramics under the small amplitude vibration.

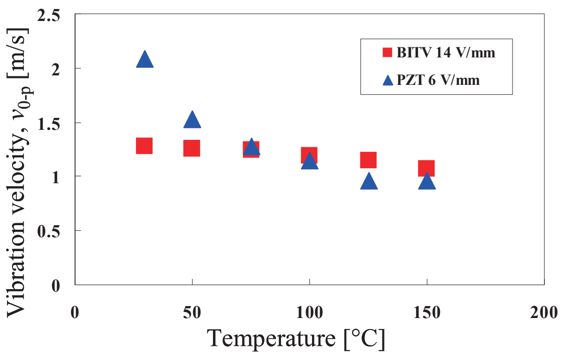

Fig. 2 Temperature dependences of the vibration velocity $v_{0\text{-p}}$ under frequency sweeping for the BITV and PZT ceramics.

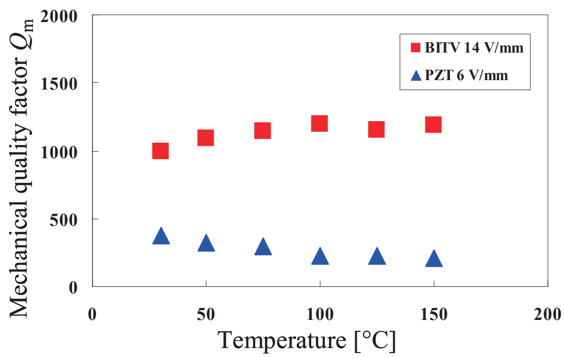

Fig. 3 Temperature dependences of the Q_m under large amplitude vibration at a constant electric field for the BITV and PZT ceramics.

continuously decreased with increasing temperature. On the other hand, the Q_m values of the BITV ceramic was nearly constant as the temperature increased. In summary, the vibration velocity of BITV ceramic shows satable temperature dependence, which is due the stability of Q_m as a function as temperature.

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4. CONCLUSIONS

High-power piezoelectric characteristics at a high temperature (~150ºC) were compared between BITV and PZT ceramics. The mechanical quality factor Q_m and vibration velocity $v_{0\text{-p}}$ of the PZT ceramic markedly decreased with increasing temperature. On the other hand, Q_m and $v_{0\text{-p}}$ for the BITV ceramic were nearly constant or slightly decreased with increasing temperature. From these results, the high-power piezoelectric characteristics of BITV ceramic at a high temperature were more stable than those of the PZT ceramic. Therefore, BITV ceramic is one of promising candidate materials for lead-free high-power piezoelectric devices.

REFERENCES

1) H. Ogawa, S. Kawada, M. Kimura, K. Shiratsuyu, and Y. Sakabe: IEEE trans. on UFFC. **54** (2007) 2500.
2) H. Nagata, M. Seki, Y. Noumura, and T. Takenaka: Jpn. J. Appl. Phys. **50** (2011) 09ND05.
3) Y. Doshida, H. Shimizu, Y. Mizuno, and H. Tamura: Jpn. J. Appl. Phys. **52** (2013) 07HE01, 6pp.
4) M. Umeda, K. Nakamura, and S. Ueha: Jpn. J. Appl. Phys. **37** (1998) 5322-5325.
5) Y. Sasaki, M. Umeda, S. Takahashi, M. Yamamoto, A. Ochi, and T. Inoue: Jpn. J. Appl. Phys. **40** (2001) 5743-5746.