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Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 1-2
6-8 December, 2010

High-power Piezoelectric Characteristics at Continuous Driving of $Bi_4Ti_3O_{12}$-$SrBi_4Ti_4O_{15}$-based Ferroelectric Ceramics

$Bi_4Ti_3O_{12}$-$SrBi_4Ti_4O_{15}$ 系非鉛圧電セラミックスの連続駆動時における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. Important piezoelectric constants for obtaining high vibration velocity are both piezoelectric strain constant d and mechanical quality factor Q_m. In case of bismuth layer-structured ferroelectrics (BLSFs), they have been characterized as small d value but high Q_m. Especially, $Bi_4Ti_3O_{12}$ – $SrBi_4Ti_4O_{15}$ + x wt% $MnCO_3$ (BIT-SBTi + Mn x wt%, $0 \leq x \leq 1.0$) lead-free ceramics showed the extremely high Q_m more than 4000 in (33) vibration mode. At short time driving such as frequency sweep measurement [1], in the case of pure BIT-SBTi, its vibration velocity $v_{0\text{-}p}$ at 5 V/mm field is 1.5 m/s. The $v_{0\text{-}p}$ values of the BIT-SBTi + Mn 0.2 and 0.4 wt% ceramics were above 2.0 m/s at 5 V/mm. Also, we observed that the mechanical quality factor Q_m at a large amplitude vibration of BIT-SBTi + Mn 0.4 wt% was maintained higher than 4000 at $v_{0\text{-}p}$ of 2.0 m/s [2]. However, speculating for practical uses, high-power piezoelectric properties such as $v_{0\text{-}p}$ and temperature of samples at long time driving are of importance. In this study, high-power piezoelectric characteristics at continuous driving of the BIT-SBTi-based ceramics were investigated.

2. EXPERIMENTAL PROCEDURE

Ceramics samples of $Bi_4Ti_3O_{12}$-$SrBi_4Ti_4O_{15}$ + Mn x wt% (x=0~1.0) were prepared by a conventional solid-state reaction. The starting raw materials were Bi_2O_3 of 99.99% of purity, TiO_2, $SrCO_3$ and $MnCO_3$ of 99.9% purity. They were mixed by ball-milling for 10 hours and calcined at 600-850ºC for 1-3 hours. After calcining, the ground and ball-milled powders were pressed into disks 20 mm in diameter. These were processed to cold isostatic press (CIP) of 150 MPa to obtain dense ceramics. After the treatment, these disks were sintered at 1150-1200ºC for 2 h in air. The sintered ceramics were cut and polished into rectangular specimens of 2 × 2 × 5 mm^3 for (33) mode. Electrodes were made with fired-on Ag paste for electrical measurements such as dielectric, ferroelectric and piezoelectric properties. A piezoelectric transducer was driving by a function generator (NF WF1943A) and a power amplifier (NF HAS4052). Vibration velocity $v_{0\text{-}p}$ was measured using a laser Doppler vibrometer (Ono Sokki LV1710) with an oscilloscope (Tektronix TDS3054B). The vibration velocity $v_{0\text{-}p}$ of the short time driving was determined by a frequency sweep measurement around resonant frequency. On contrary, the long time driving was measured under the condition of constant voltage at resonant frequency. In the measurement of sample temperature under the continuous driving, optical thermometer (HIOKI Temperature Hightester 3445) was used.

3. RESULTS AND DISCUSSION

The crystal structure of obtained ceramics was confirmed by X-ray diffraction analysis, showing a single phase of mixed bismuth layer structure with m=3 and 4. The relative densities of sintered ceramics were all higher than 95% measured by Archimedes method.

Figure 1 shows the applied field E_a dependences of vibration velocity $v_{0\text{-}p}$ for BIT-SBTi + Mn 0.2 wt% ceramics. In the range below 2.5 m/s, the difference of the $v_{0\text{-}p}$ values between continuous driving and frequency sweep measurement is small. Figure 2 shows the $v_{0\text{-}p}$ dependences of resonant frequency change for BIT-SBTi + Mn 0.2 wt% ceramics. A clear difference is seen in frequency change between continuous driving and frequency sweep measurement. In case of frequency sweep measurement, the value of shifted frequency change is quite small about less than 0.01%. On the other hand, the result from the continuous driving indicated that the value of resonant frequency shift is larger than that of frequency sweep driving. However, in the vibration velocity at 1.5 m/s, the value of frequency change was under 0.1%, which was small as compared with perovskite-type ceramics [3].

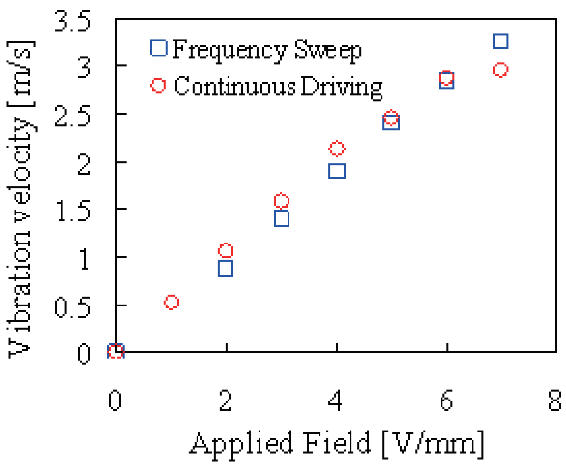

Figure 1 Applied field E_a dependences of vibration velocity $v_{0\text{-}p}$ for BIT-SBTi + Mn 0.2 wt% ceramics.

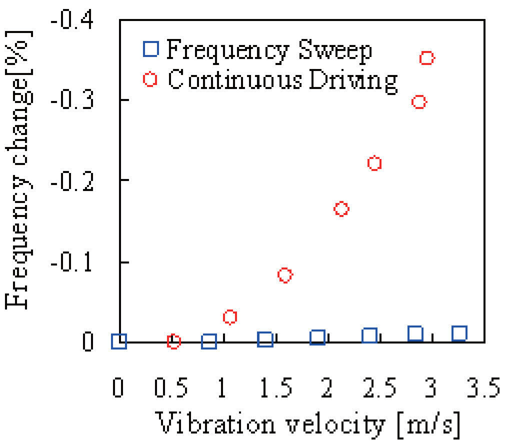

Figure 2 Vibration velocity dependence of resonant frequency change for BIT-SBTi + Mn 0.2 wt% ceramics.

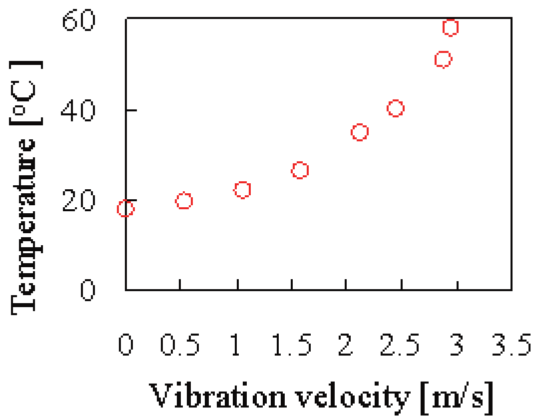

Figure 3 Vibration velocity dependence of temperature rising for BIT-SBTi + Mn 0.2 wt% ceramics.

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Figure 3 shows the vibration velocity dependence of temperature rising for BIT-SBTi + Mn 0.2 wt% ceramics. Temperature of ceramic samples rises with increasing the $v_{0\text{-}p}$. The curve of figure 3 is nonlinear. And as shown in figure 2, the tendency of temperature rising looks similar to the tendency of frequency change.

4. CONCLUSIONS

High-power piezoelectric characteristics at continuous driving of the mixed bismuth layer-structured ferroelectrics $Bi_4Ti_3O_{12}$-$SrBi_4Ti_4O_{15}$ with $MnCO_3$ x wt% (BIT-SBTi + Mn x wt%) were studied. Both measurements of frequency sweep and continuous driving, it is found that the $v_{0\text{-}p}$ of BIT-SBTi + Mn 0.2 wt% linearly increased up to approximately 3.0 m/s. There are remarkable differences such as resonant frequency change with temperature rising at continuous driving. However, the value of shifted resonant frequency as continuous driving of BIT-SBTi + Mn x wt% is quite small as compared with lead titanate-based ceramics. These materials are superior candidates for high-power applications such as ultrasonic transducer with frequency and temperature stabilities.

5. ACKNOWEAGEMENT

The authors would like to thank Professor Mikio Umeda of Nagaoka National College of Technology for his technical support and discussion on high-power measurements. This work was partially supported by a Grant-in-Aid from The Murata Science Foundation.

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