Strain Induce by Electric Field on Piezoelectric Ceramics

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Recently, piezoelectric actuator have been attracting attention for their fine displacement-controllability and compactness, and have been extensively developed and commercialized. When piezoelectric ceramics are used for actuator applications, much larger electric fields are generally need in the antiresonance and, as a result, piezoelectric materials must have different electromechanical resonance characteristics from those used for other purposes.

In this study, the effect of crystal structure,grain size and doped impurities,which controlled the piezoelectric property, on the strain induced by an external electric field were investigated for ceramics with lead zirconate titanate system compositions.

1. INTRODUCTION

Recently, displacement-controlling element have been increasingly in demand, for submicron-order processing and precision position-locating, accompanying processing of electric and mechanoelectronic devices.[1] [-3] Piezoelectric actuators employed as displacement type devices and are utilized under the condition of applying high electric field over 1kV/mm in order to obtain large displacement. Under applied high electric field,Uchino and Furuta[4] as well as Masuda and Baba[5] reported that the measured strain (δ) exhibits a larger value than the strain (δ cal) calculated from the product of electric field (E) and piezoelectric constant (d constant) measured by the resonance antiresonance method, and the authors clarified the phenomenon that when high electric field is applied repeatedly, δ decreases gradually. In addition, we also reported that the cause is a decrease in δ p owing to the orientation of domains in the direction of electric field by repetitious electric field application. In other words, δ p change is strain generated by domain arrangement. Especially in the case of actuators to utilize strain in the application of electric field, the contribution of δ p is large, making it necessary to investigate its effect in detail.

Consequently, this study addressed the effect of crystal structure[6] , grain size[7] and doped impurities[8] of piezoelectric ceramics on the strain induced by an external electric field.

2.EXPERIMENTAL

2.1. Sample preparation

The raw materials utilized in the experiment were oxides and carbide powder of purity higher than 98%.After a ball-milled and calcined for 2h at 975°C ,the samples were reground into fine powder by means of a zirconia ball mill for 24h, then pressed into disks of 22mm in diameter.

2.1.1. Controlling Crystal Structure

The effect of the crystal structure on the strain was investigated by changing the Zr/ (Zr+Ti) ratio (x) from 0.50 to 0.55, in the compositional component of $(Pb_{0.845}Sr_{0.050}Ba_{0.105})$ $((Zr_xTi_{1-x})_{0.95}Sn_{0.045}Nb_{0.005})$ O_3, and finally sintered between 1210 and 1300°C for 2h.

The crystal symmetry were obtained by a powder X-ray diffractometer.

2.1.2. Controlling Grain Size

The effect of grain size on the strain was investigated for ceramics with the composition $(Pb_{0.845}Sr_{0.050}Ba_{0.105})$ $((Zr_xTi_{1-x})_{0.95}Sn_{0.045}Nb_{0.005})$ O_3 series (x=0.49,0.52,0.55) , in which the grain size was controlled by hot pressing (HP) , under the following condition : holding temperature : 1100-1300°C ; holding time : 3-10h ; and pressing pressure : 50-500kgf/cm², in order to prepare samples with various grain sizes and porosities. The average grain size and porosity values were obtained by the image processing of SEM photographs.

2.1.3.Doping Impurities

The effect of donor and acceptor impurities on the strain was investigated. The impurities of Ni, Fe, Nb and W were added to the composition $(Pb_{0.95}Sr_{0.05})$ $((Zr_{0.54}Ti_{0.46})$ O_3, then was sintered by hot pressing to controll the grain size.

2.2 . Measurements

Piezoelectric properties were measured using disks 1mm in thickness. The disks were Ag-electrode, then poled under 2.0kV/mm for ·30min in a silicone oil kept at 100°C. Piezoelectrical constant (d_{31}) was determined by impedance analyzer (resonance-antiresonanc method) . The measurement of strain was performed by attaching strain gauges onto the center of the electrode surfaces of the samples. Strain (δ) with applied electric fields was determined from strain in the diametral direction in the case of applying each electric field with triangular waves (0.01Hz) in the constant-temperature chamber at 30°C.

3.RESULT AND DISCUSSION

3.1 .Crystal Structure Dependence of Strain

Fig. 1 shows the lattice constants of samples with composition (x=0.50-0.55) examined in this study. As a result, the morphotropic phase boundary (MPB) , where the phase transition from tetragonal to rhombohedral occurs, is located at x=0.52. From x=0.52 to 0.55, the compound is in the rhombohedral phase. Fig. 2 illustrated the electric field dependence of strain (δ) on each composition . δ of each sample increased uniformly with an increasing of electric field. δ in this case exhibited larger values than strain (δ cal) determined from the product of d_{31} constant and applied electric field, and the difference between δ and δ cal was known the strain (δ p) by domain rotation (orientation) . We think that δ p is important for actuator for the application of high electric field[6] [-8] . δ p here was calculated from a difference of δ and δ cal. Fig. 3 illustrates the electric field dependence of δ p. In the case of the composition of x=0.50 and 0.51, δ p increased almost linearly with an increasing of electric field strength. However,for the composition of x $\geq$ 0.52, δ p was saturated when the electric field rose. In particular the

trend was distinct in the case of composition near the MPB of x=0.52.

Fig. 4 illustrated the contributive factor, which contributed δ p to δ , in this study. For each sample, the contributive factor decreases with increasing the electric field. The decrease of contributive factor was small on the tetragonal phase and was large on the phase boundary. In high electric field, it was found that the effect of strain by domain rotation is the smallest on the phase boundary.
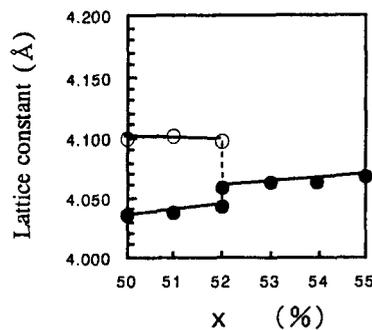
Fig.1 Lattice contant as a function of Zr ratio (x) .
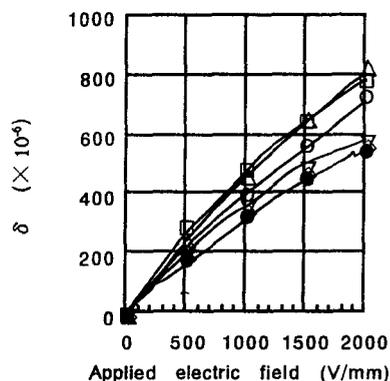
Fig.2 Measured strain (δ) as a function of applied electric field. ($\bigcirc$: x=0.50, $\triangle$: x=0.51, $\square$: x=0.52, ∇ : x=0.53, $\diamondsuit$: x=0.54, $\bullet$: x=0.55)

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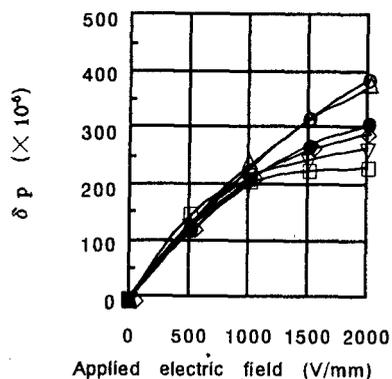
Fig.3 Strain (δ p) by domain orientation as a function of applied electric field. (○ : x=0.50, △ : x=0.51, □ : x=0.52, ▽ : x=0.53, ◇ : x=0.54, ● : x=0.55)
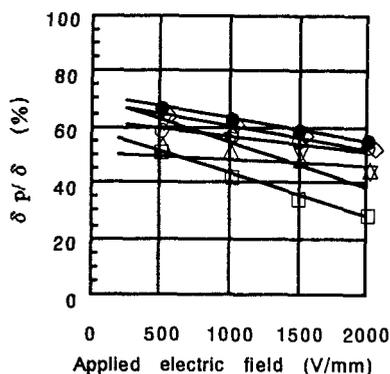
Fig.4 Contributive factor (δ p/ δ) as a function of applied electric field. (○ : x=0.50, △ : x=0.51, □ : x=0.52, ▽ : x=0.53, ◇ : x=0.54, ● : x=0.55)

3.2 .Grain Size Dependence of Strain

By controlling hot-press conditions for preparation, their grain size of samples varied in the range of 2-12 μ m could be obtained and their porosities were maintained at an almost constant value (2-4%) . Fig. 5 illustrates the relationship between the grain size and strain (δ) under applied field of 1.2kV/mm. In each composition sample, the δ value changed linearly with the logarithm of grain size. Fig. 6 illustrates the relationship between the grain size and δ p under applied electric field of 1.2kV/mm. It showed that there is the sample with larger grain size have great δ p, as well as composition dependence is large in the composition of x=0.52 (phase boundary) and small in the composition of x=0.49 (tetragonal system) . Fig. 7 illustrated the contributive factor, which contributed δ p to δ , in this study. For each sample, the contributive factor increases with increasing grain size. The increase of contributive

factor was small on the tetragonal phase and was large on the phase boundary and the rhombhedral phase. In large grain size of all samples, it was found that the effect of strain by domain rotation is large on the phase boundary.
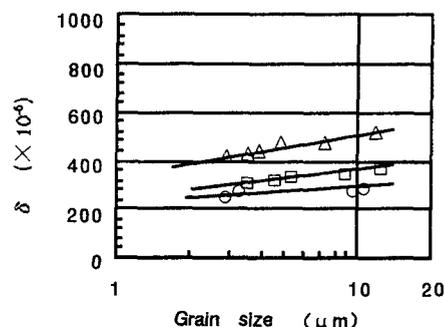
Fig.5 Measured strain (δ) under applied field of 1.2kV/mm as a function of grain size. (○ ; x=0.49, △ : x=0.52, □ : x=0.55)
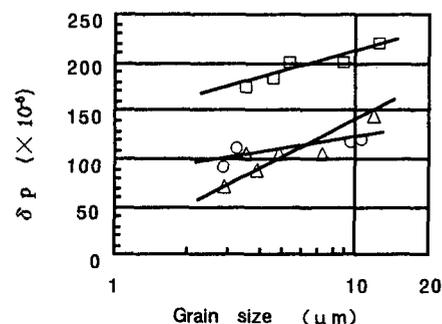
Fig.6 Strain (δ p) under applied field of 1.2kV/mm as a function of grain size. (○ ; x=0.49, △ : x=0.52, □ : x=0.55)
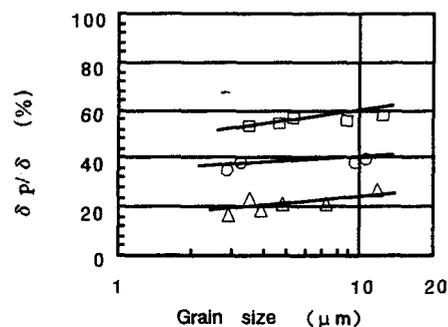
Fig.7 Contributive factor (δ p/ δ) under applied field of 1.2kV/mm as a function of grain size. (○ ; x=0.49, △ : x=0.52, □ : x=0.55)

3.3.Impurity Dependence of Strain

Fig. 8 illustrated the relationship between impurity and strain (δ) under applied field of 1.5kV/mm. As a result, it was found that δ was larger for Nb and W donors-doped samples and smaller for Ni and Fe acceptors-doped samples than that of non doped sample. In all samples, δ was larger than the calculated strain (δ cal) ., as a result, Fig.9 suggests that there is the strain (δ p) associated with domain orientation due to an electric field. δ p of donor-doped samples were larger than that of non doped sample, and those of acceptor-doped samples were smaller than that of non doped sample. Fig. 10 illustrated the contributive factor, which contributed δ p to δ , in this study. The contributive factor was large for donors doped samples, and was small for acceptors doped samples.For each sample, the contributive factor increases with increasing grain size.
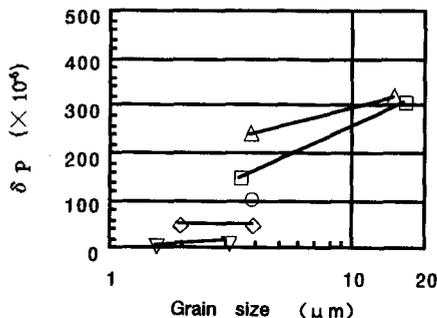
Fig.10 Contribution factor (δ p/ δ) under applied field of 1.5kV/mm as a function of grain size of sample doped impurity. (○ : Non-doped, ◇ : NiO-doped, ▽ : Fe2O3-doped, △ : Nb2O5-doped, □ : WO3-doped)

4.CONCLUSIONS

In this study, the effect of crystal structure, grain size and doped impurities on the strain induced by an external electric field were investigated for ceramics with lead zirconate titanate system compositions. Amount of δ p changes markedly owing to the difference in crystal structure, grain size and impurity doping.

For actuator of position locating, compounds in the tetragonal phase with small grain size are very suitable in comparison with compounds with other crystal structures.

Fig.8 Measured strain (δ) under applied field of 1.5kV/mm as a function of grain size of sample doped impurity. (○ : Non-doped, ◇ : NiO-doped, ▽ : Fe2O3-doped, △ : Nb2O5-doped, □ : WO3-doped)

Fig.9 Strain (δ p) under applied field of 1.5kV/mm as a function of grain size of sample doped impurity. (○ : Non-doped, ◇ : NiO-doped, ▽ : Fe2O3-doped, △ : Nb2O5-doped, □ : WO3-doped)

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