報　文

Humidity Sensitive Actuator

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A "MONOMORPH" is a new type of actuator, composed of a single ceramic plate which is driven in a bending mode similar to the "BIMORPH". It has been observed that humidity influences the bending displacement, electric resistance and electrostatic capacitance of a porous Nb-doped PZT "MONOMORPH". A proton conductivity model is proposed to describe the humidity sensitive characteristics of this material. The model assumes a double layer capacitance is formed at the electrode-bulk interface under an applied electric field which plays an important role in the nonuniform distribution of the electric field. This "active layer" on and inside the surface brings about the bending displacement. This "MONOMORPH" has potential as a new piezoelectric humidity sensor.

1. Introduction

Piezoelectric ceramic actuators are preferable to the conventional electromagnetic drive actuators for cotrolling the position of precision machning tools, optical instruments and relays.

The "MONOMORPH" is one of these actuators which is composed of a single ceramic plate and driven in a bending mode similar to the "BIMORPH". It has been previously reported that "MONOMORPH" characteristics were observed in PZT based ceramics doped with metal oxides such as Nb[1]. The addition of such impurities inhibits grain growth and lowers the relative density in comparison with the non-doped PZT. It has also been observed that the bending phenomenon depends strongly on the microstructure of the sintered material.

In this investigation, the influence of humidity on the bending displacement, electrostatic capacitance, and electric resistance is reported. It is assumed that this humidity sensitivity originates from the change of polarization on and inside the surface of the ceramic plate due to water vapor adsorption. In order to clarify the mechanism by which the humidity affects the bending displacement, we have measured the complex impedance as a function of frequency.

2. Experimental Procedure

〔1〕 Specimen Preparation

The specimens were prepared by standard ceramic procedures using constituent oxides; PbO, ZrO_2, TiO_2 and Nb_2O_5, were proportioned to the formula $Pb(Zr_{0.53}Ti_{0.47})O_3+1$ mol% Nb_2O_5. The mixtures were sintered at 1150-1170°C for 1 hour after calcining at 800°C for 2 hours; the sintered materials were below 80% of the theoretical density.

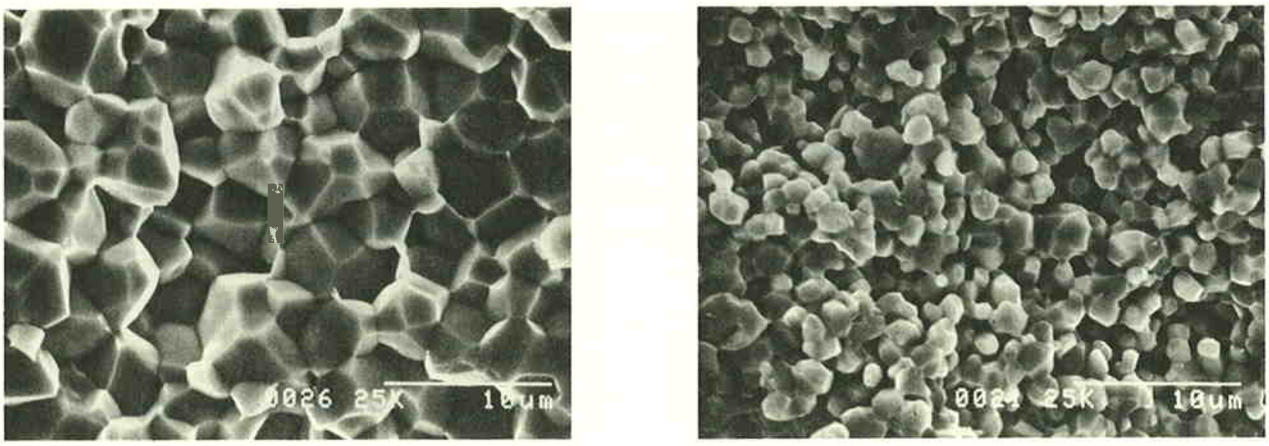
〔2〕 Mesurements

The microstructure was examined by SEM. Electrical measurements were conducted on 16 mm (width)×46 mm (length)×0.5 mm (thickness) plates which were sliced from the sintered bodies, and electroded with silver paste (Shoei Chemical INC., H-4563) by firing at approximately 800°C for 10 minutes. The bending displacement induced by the electric field was measured at the tip of the cantilever beam by using an eddy-current type noncontact sensor. (Kaman, SDP 2310). The resistance and the capacitance changes with adsorbed water were determined using an electrometer or an impedance analyzer. The complex impedance changes with frequency were measured using a frequency response analyzer. The relative humidity at 25°C was controlled from 20 to 100% in a thermostatic humidity generator.

3. Experimental Results

〔1〕 Porous Structure

A conventional piezoelectric actuator usually requires a fully dense sintered ceramic structure to obtain the optimum piezoelectric effect, as shown in Fig. 1(a). However, the microstructure of the Nb-doped PZT ("MONOMORPH") is typically characterized as a porous structure, such as the one shown in Fig. 1(b) with porosity was nearly 21%. Bulk density measured by the Archimedes method was nearly equal to the theoretical value, indicating that the structure has open pores. "MONOMORPHS" having an open pore structure can easily absorb water vapor.



(A) (B)

Fig. 1 Scanning electron micrographs of the fractured surface of sintered specimens, (A) conventional piezoelectric actuator material and (B) porous "MONOMORPH" ceramic.

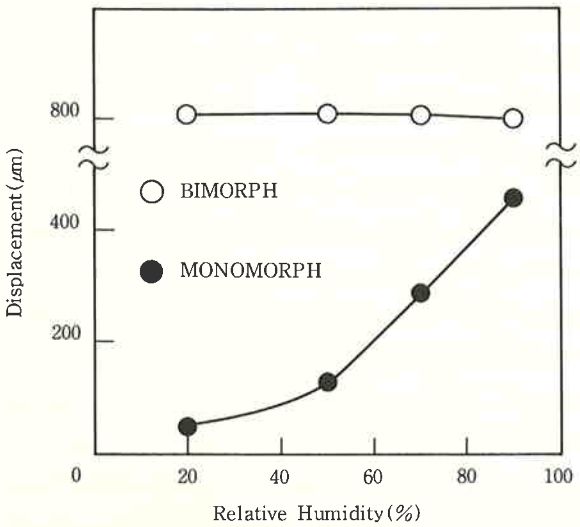


Fig. 2 Displacement as a function of relative humidity in a conventional "BIMORPH" and a "MONOMORPH" at 6 kV/cm, 25°C.

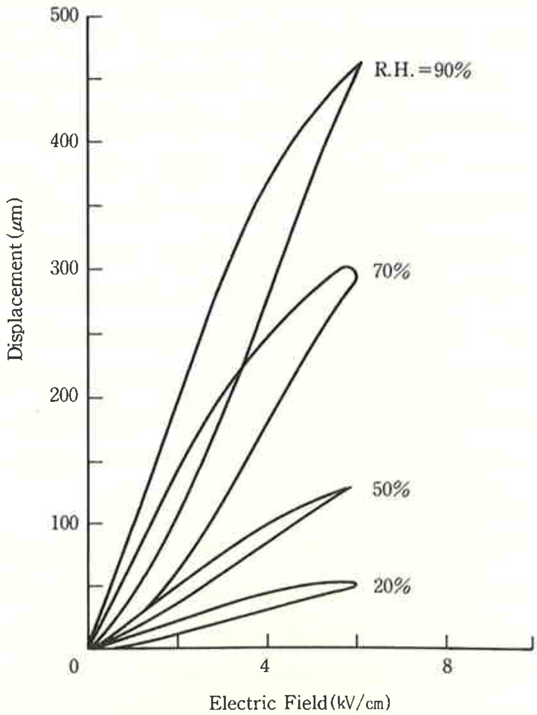


Fig. 3 Displacement versus applied electric field for the Nb-doped PZT at 25°C and 20-90% R. H..

〔2〕 **Bending displacement**

Generally, the displacement induced by an electric field in piezoelectric ceramics having high relative density are little affected by humidity, as shown in Fig. 2, Fig. 3 shows the value of the displacement versus applied electric field for the Nb-doped PZT when the humidity is controlled in the range 20–90%. The curve demonstrates clearly that humidity enhances the bending effect.

〔3〕 **Resistance and Capacitance**

Fig. 4 shows the dependence of the resistance and capacitance on the relative humidity of the "MONOMORPH" under an applied dc field, after the displacement becomes stable. As the relative humidity (R. H.) increases from 20 to 90%, the resistance decreases drastically. When the electric field is not applied to the specimen in advance, the value of the dc resistance at 90% R. H. is much lower. The capacitance increases with an increase in relative humidity and doubles when the R. H. is changed from 20 to 90%. This indicates that high humidity conditions enhance the polarization of the sintered material.

〔4〕 **Complex Impedance and Equivalent Circuit**

Complex impedance plots are useful for determining an appropriate equivalent circuit for a system and for estimating the values of the circuit parameters[2]. Fig. 5 shows such plots for 50, 70 and 90% of the relative humidity at 25°C. Each semi-circular arc corresponds to a roughly "lumped" R–C combination. The resistance can be derived from the circular arc in-

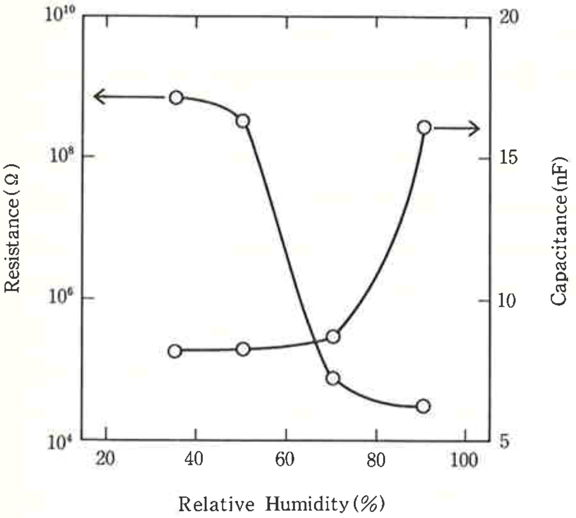


Fig. 4 Dependence of the resistance and the capacitance on humidity of Nb-doped PZT at 25°C.

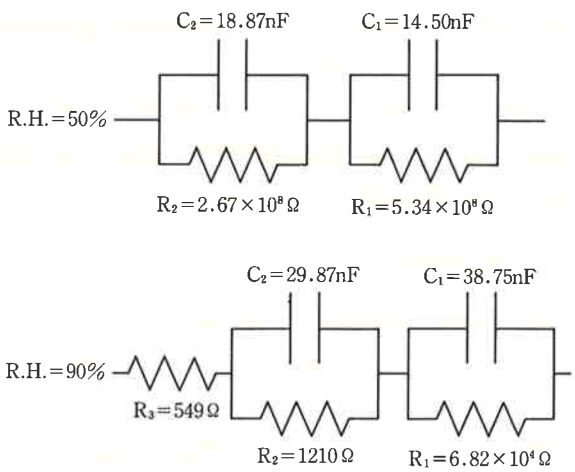


Fig. 6 Equivalent circuit of the electrode-bulk interface (R_1) and the bulk ($R_2(+R_3)$) at 50% and 90% R. H..

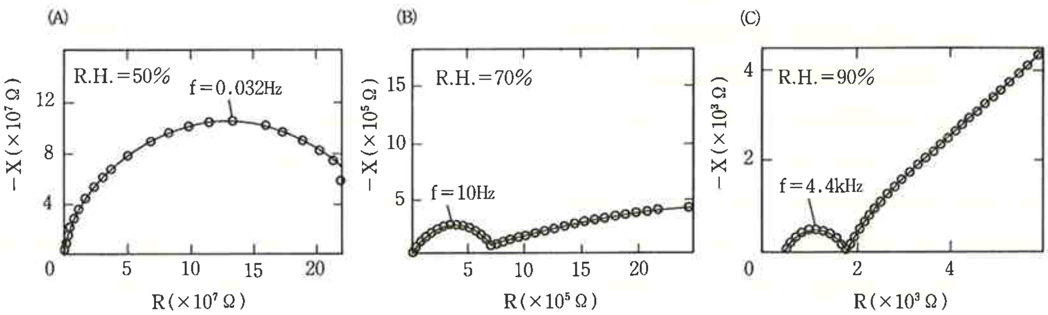


Fig. 5 Complex impedance plots of Nb-doped PZT. (A) 50% R. H., (B) 70% R. H., (C) 90% R. H. at 25°C.

tercepts on the R-axis, and the capacitance is derived from the equation involving the frequency at the peak of the circular-arc. As shown in Fig. 5, the diameter of the circular-arc is significantly decreased with increasing humidity. This may be attributed to polarization process in the bulk of the specimen. It has been reported that a linear relation similar to the curve observed at lower frequencies shown in Fig. 5(C) is due to the effect of Faraday Impedance which originates from the current generated by an electro-chemical reaction at the electrode-bulk interface[3]. The data for the complex impedance and the values of resistance and capacitance under a dc field indicate the presence of two different polarizations:

1) an electrode-bulk interface polarization characterized by a double layer capacitance, and

2) capacitive polarization at grain boundaries and within the grains. The equivalent circuits for 50 and 90% R. H. are shown in Fig. 6. R_1 and C_1 represent the electrode-bulk interface polarization processes, and R_2, C_2, and R_3 represent the grain bounderies and the grain polarization processes. At 50% R. H., R_1 is nearly equal to R_2, while at 90% R. H., R_1 is much higher than R_2+R_3.

4. Discussion

The results obtained for the porous structure and the Equivalent Circuit approaches can be explained by the ionic conductor model previously reported for ceramic humidity sensors[4]. The present porous ceramic easily absorbs water vapor into its pore structure. The absorbed water vapor condenses within the capillaries among the grain surfaces. Dissociation of the absorbed water on the "MONOMORPH" surface provides mobile protons. They can migrate by hopping from site to site across the surface[5]. When an electric field is applied to this porous ceramic, the protons move in the direction of the electric field and form a double layer at the electrode-bulk interface. This double layer capacitance increases with increasing humidity (Fig. 4). As shown in Fig. 6, the ratio of the electrode-bulk interface resistance over the bulk resistance ($R_1/R_2+(R_3)$), also increases with increasing humidity. This suggests a possible relationship between the double layer generated by the electro-chemical reaction and the observed electrical properties. When the electric field is applied along the thickness of the "MONOMORPH", the field is concentrated on and near the surface. Therefore, the "MONOMORPH" is bent in a fashion similar to a "BIMORPH".

5. Conclusion

A single sintered ceramic plate of Nb-doped PZT exhibits "MONOMORPH" characteristics. The "MONOMORPH" is driven in a bending mode similar to a "BIMORPH", when an electric field is applied. The bending displacement increases remarkably with increasing humidity. The "MONNOMORPH" has several characteristics that are common to ceramic humidity sensors concerning its microstructure, electric resistance and capacitance. The proton conductor model is adequate for explaining the humidity-characteristics of the present system, whereby absorbed water on the ceramic surface supplies protons, which move in the direction of the applied electric field generating a double layer capacitance at the electrode-bulk interface. The applied electric field may be distributed nonuniformly due to the presence of this double layer capacitance. This "active layer" on or near the surface region brings about a bending displacement of the ceramic plate.

The "MONOMORPH" has potential as a new piezoelectric device that can be utilized as a bending mode actuator and as a humidity sensor.

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