HIGHLY ANISOTROPIC
ELECTROMECHANICAL PROPERTIES
IN MODIFIED LEAD-TITANATE
CERAMICS

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Highly anisotropic electromechanical properties in modified lead
titanate ceramics

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The Pennsylvania State University, 1987

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Highly Anisotropic
Electromechanical Properties
in Modified Lead Titanate Ceramics

A Thesis in

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by

Dragan M. Damjanovic

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ABSTRACT

The dielectric, elastic and piezoelectric properties of modified lead titanate ceramics were investigated with the goal of better understanding their highly anisotropic electromechanical behavior.

Two compositions, $(Pb_{0.85}Sm_{0.10})(Ti_{0.98}Mn_{0.02})O_3$ (or PST) and $(Pb_{0.76}Ca_{0.24})[(Co_{1/2}W_{1/2})_{0.04}Ti_{0.96}]O_3$ (or PCT), where investigated as representatives of modified lead titanate ceramics. Measurements of dielectric, elastic and piezoelectric properties of PST and PCT ceramics, using a standard resonance technique, showed that the large anisotropy in the electromechanical coupling factors is exclusively due to the anisotropy in the piezoelectric coefficients d_{33} and d_{31}. The ratio d_{33}/d_{31} depends on both poling field and temperature.

The thickness coupling factor, k_t, remains almost constant with temperature for PCT and PST ceramics. At room temperature d_{33} increases with poling field, saturating to near 60 pC/N at large poling fields. At the same time d_{31} initially increases and then decreases with poling field thus causing a large d_{33}/d_{31} ratio.

Measurements of complex material coefficients relevant for the planar coupling mode, using an iterative technique, showed that d_{31} as well as the elastic compliance, s_{11}^{E}, and the dielectric permittivity, ε_{33}^{X}, must be considered as complex in order to accurately describe the resonant properties of these ceramics. Measuring the complex d_{31} as a function of temperature (-180°C to +100°C), it was possible to show that the real component d_{31}', in both ceramics, changes sign with temperature, thus causing a zero planar coupling factor, k_p, at a certain temperature. The examination of the dependence of complex d_{31} on temperature with poling field as a parameter (10 to 90 kV/cm) showed that the temperature at which d_{31}' becomes zero depends on the poling field. This shift of zero crossover point of d_{31}' with poling field causes a decrease of d_{31}' (and k_p) with poling field at room temperature.

A significant imaginary component of the piezoelectric coefficient and a similar temperature behavior of imaginary elastic, dielectric and piezoelectric coefficients in these ceramics indicate a presence of piezoelectric relaxational mechanisms, whose origin is in a coupling between elastic and dielectric losses. Assuming that the complex d_{31} in PST and PCT ceramics may be represented as a sum of the intrinsic piezoelectric effect, d_{31}^{∞}, and extrinsic relaxational contributions, $\Delta d_{31}'-id_{31}''$, it is possible to consistently interpret the dependence of the experimentally determined real part, $d_{31}'= d_{31}^{\infty}+ \Delta d_{31}'$, on poling field and temperature through competing effects of d_{31}^{∞} and $\Delta d_{31}'$.

A large anisotropy in piezoelectric coefficients seems to be only enhanced by zero d_{31} since a large d_{33}/d_{31} ratio was observed even in those samples which, due to differing processing conditions, did not exhibit a change of sign in d_{31}' over the investigated temperature range. This large anisotropy in piezoelectric coefficients seems to be a consequence of averaging of single crystal properties of modified lead titanate ceramics.

The neutron powder diffraction study showed that Sm in PST ceramics was properly incorporated at the A site in the perovskite structure. A model with Ca cation substituting only for Pb as well as a model with Ca randomly occupying the A and B site lead to unrealistic stochiometries of PCT composition. In both compositions as well as in a pure $PbTiO_3$ powder, the shifts of O1 and O2 oxygens in respect to their ideal cubic positions are different, causing an asymmetric oxygen octahedron.

The equivalent circuit of a piezoelectric resonator with a large piezoelectric phase angle was derived allowing that it may include a frequency dependent resistive term. This was necessary in order to describe piezoelectric contributions to the total energy dissipation of the resonator.

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