Fractal Aspects and Critical Lengthscales in Ferroelectrics

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Particle size dependence of ferroelectricity was first demonstrated by Uchino on barium titanate and lead titanate based ceramics. Thin film ferroelectrics are known to degrade their performance with reducing the film thickness. Based on these experimental results, Uchino will discuss size effect on ferroelectricity in particle, thin film and amorphous statuses. Ferroelectric materials behave as fractal systems in their various dynamic characteristics. Polarization reversal takes place through the appearance of a certain number of seeds for domains of the opposite polarization which subsequently grow in the forward and lateral directions. The system manifests fractal properties, since lateral growth of the domain walls in the result of the formation of self-similar structures. The interest in relaxor ferroelectrics is stimulated by a diffuse phase transition in a wide temperature range, and dielectric relaxation, which seems to be originated from micro-domains created in unpoled crystals. In this paper, the author will refresh the previously-reported experimental results on (1) Dependence of the Crystal Structure on Particle Size [K. Uchino, E. Sadanaga and T. Hirose: J. Amer. Ceram. Soc. 72 (8), 1555-1558 (1989)], (2) critical exponents in the dielectric permittivity [K. Uchino and S. Nomura: Ferroelectrics Letters, 44, 55 (1982)] and (3) acoustic emission (AE) during the domain reversal [H. Aburatani, J. Witham and K. Uchino: J. J Appl. Phys., 37, 602 (1998)] from a consistent viewpoint, i.e., fractal analysis.

(1) Dependence of the Crystal Structure on Particle Size
Particle size dependence of the crystal structure in barium titanate reported the existence of the critical particle size (~ 0.1 micron) below which all ferroelectric ceramics will lose ferroelectricity.

(2) Critical exponents in the dielectric permittivity
Critical exponents of the permittivity γ (in terms of temperature sweep) and γ^* (hydrostatic pressure), and Curie-like constant C' for relaxor and normal ferroelectrics are summarized in **Table** below. Rather than normally accepted Curie-Weiss relations ships $1/\varepsilon \propto (T - T_C)$ or $(T - T_C)^2$ for a normal or a relaxor ferroelectric under the Smolenskii's model, $1/\varepsilon \propto (T - T_C)^\gamma$ or $1/\varepsilon \propto (p - p_C)^{\gamma'}$ seem to keep in a wide temperature or pressure range ($1 < \gamma, \gamma' < 2$). This critical index behavior suggests the strong interaction among micro/nano domains even in a temperature range much higher than the Curie (or phase transition) temperature.

(3) Fractal dimension on the domain dynamics
Figure below shows AE event count per cycle plotted as a function of AE signal threshold level for ferroelectric PZT. Fractal indexes m=1 and 2.8 were obtained in the domain reversal stage (low electric field range) and pure piezoelectric deformation after the reversal saturation stage (electric field higher than 20 kV/cm). The different fractal dimension seems to suggest that the elastic deformation is originated from 3D volumetric seeds in the pure piezoelectric range, while the AE in the dynamic domain motion range is originated from the lower (i.e., 1D) facet seeds. It is noted that the fractal dimension for an electrostrictive PMN ceramic was m=2 from the AE acoustic signal measurement.

Substances	γ	$C' (\times 10^5)$	γ^*
$BaTiO_3$	1.08	2.1	1.0[a]
$K(Ta_{0.55}Nb_{0.45})O_3$	1.17	2.9	1.00
$0.88Pb(Zn_{1/3}Nb_{2/3})O_3$-$0.12PbTiO_3$	1.58	63	—
$Pb(Mg_{1/3}Nb_{2/3})O_3$	1.64	140	1.66
$Pb(Zn_{1/3}Nb_{2/3})O_3$	1.76	200	—

Table Critical exponents of the permittivity γ and γ^*, and Curie-like constant C' for relaxor and normal ferroelectrics.

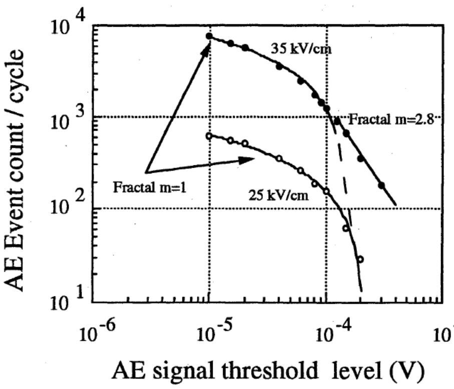

Figure AE event count per cycle vs AE signal threshold level for ferroelectric PZT.

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