Title
ELECTRICAL PROPERTIES OF POROUS PZT CERAMICS

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The purpose of the present work was to conduct a systematic study of the dielectric and piezoelectric properties of lead zirconate titanate (PZT) ceramic containing a controlled amount of spherical porosity, which reduces the dielectric strength[1] and affects many electrical properties.[2,3] The PZT samples (composition $Pb_{0.99}\square_{0.01}(Zr_{0.52}Ti_{0.46}Nb_{0.02})O_3$ where $\square$ is a lead vacancy (were fine-grained (2 to 5 μm)(Fig. 1) ceramics in which the grain size was controlled by doping with 1 mol% niobium oxide. It was found[4] that addition of 5.5 wt% excess lead oxide enhances the sintering process and densities of >99% theoretical value were easily obtained. Spherical pores (100 to 150 μm in diam.) were introduced[4] into the specimens (Fig. 1(A)) using organic materials mixed with PZT powders before sintering. Specimens were sintered at 1 atm oxygen pressure and 1200°C for 8 h. A packing powder[4] ($PbZrO_3$ + 5 wt% ZrO_2) technique was used to prevent PbO loss from the specimens and to maintain the stoichiometry.

Silver was evaporated onto the surface of ≈19-mm-diam. by 1.9-mm-thick samples. The capacitance (C) was measured before and 24 h after poling using an impedence bridge.* The samples were poled in a high dielectric silicone oil at 120°C and cooled to room temperature with the field applied (3kV/cm). The relative dielectric constant (ε_m') was

*Type 1650-A, General Radio Co., Concord, Mass.

calculated from the capacitance, the thickness, and the area of the samples.

The piezoelectric planar coupling coefficient, K_p, and the mechanical quality factor, Q_m, were measured after poling by the resonance method in accordance with IRE standards.[5] Values were calculated from the resonance and antiresonance frequencies and the resistance at resonance.

PZT porosity systems can be considered as a mixture of two phases of matrix (m) and porosity (p). The relative dielectric constant for the mixture ε' can be predicted from the Maxwell relation[6] which gives an expression for a matrix containing a dispersion of spherical particles as:

$$\varepsilon' = \frac{v_m \varepsilon_m' \left(\frac{2}{3} + \frac{\varepsilon_p'}{3\varepsilon_m'} \right) + v_p \varepsilon_p'}{v_m \left(\frac{2}{3} + \frac{\varepsilon_p'}{3\varepsilon_m'} \right) + v_p} \tag{1}$$

where ε_m' and ε_p' are the relative dielectric constants of a matrix and the dispersed particles (spherical porosity in this case) and V_m and V_p are the volume fractions of matrix and pores, respectively. Taking the dielectric constant of porosity ε_p' as 1, the experimentally determined dielectric constants of PZT (ε_m') as 1032, and $V_m=(1 - V_p)$, the relative dielectric constant of porous PZT ceramics (ε') was calculated from Eq. (1) and is plotted vs the volume fraction of porosity (Fig. 2). The experimentally measured dielectric constants fit very well with the Maxwell prediction of 2-phase mixtures in which a low dielectric constant phase (porosity) was dispersed in a high dielectric constant matric (PZT).

The electromechanical coupling factor (K_p) is the measurement of strength of the piezoelectric effect. When an electric field is applied, K_p measures the fraction of electric energy converted to mechanical energy or vice versa when the ceramic is stressed. The experimentally measured K_p value for nonporous PZT ceramic was 0.545; it decreased linearly as porosity increased (Fig. 3). Figure 3 also shows a slight decrease in the mechanical quality factor (which is a measure of the ratio of strain in phase with stress to strain out of phase with stress in a vibrating body) with volume fraction of porosity. As the energy is lost due to mechanical damping, a high Q_m is desirable for piezoelectric ceramic. The experimentally measured Q_m values agree with the reported value.[7] Therefore, the presence of 10 to 15% porosity reduces the dielectric constant and the piezoelectric coupling factor considerably; a slight decrease in the mechanical quality factor is observed in niobium-doped PZt polycrystalline ceramics.

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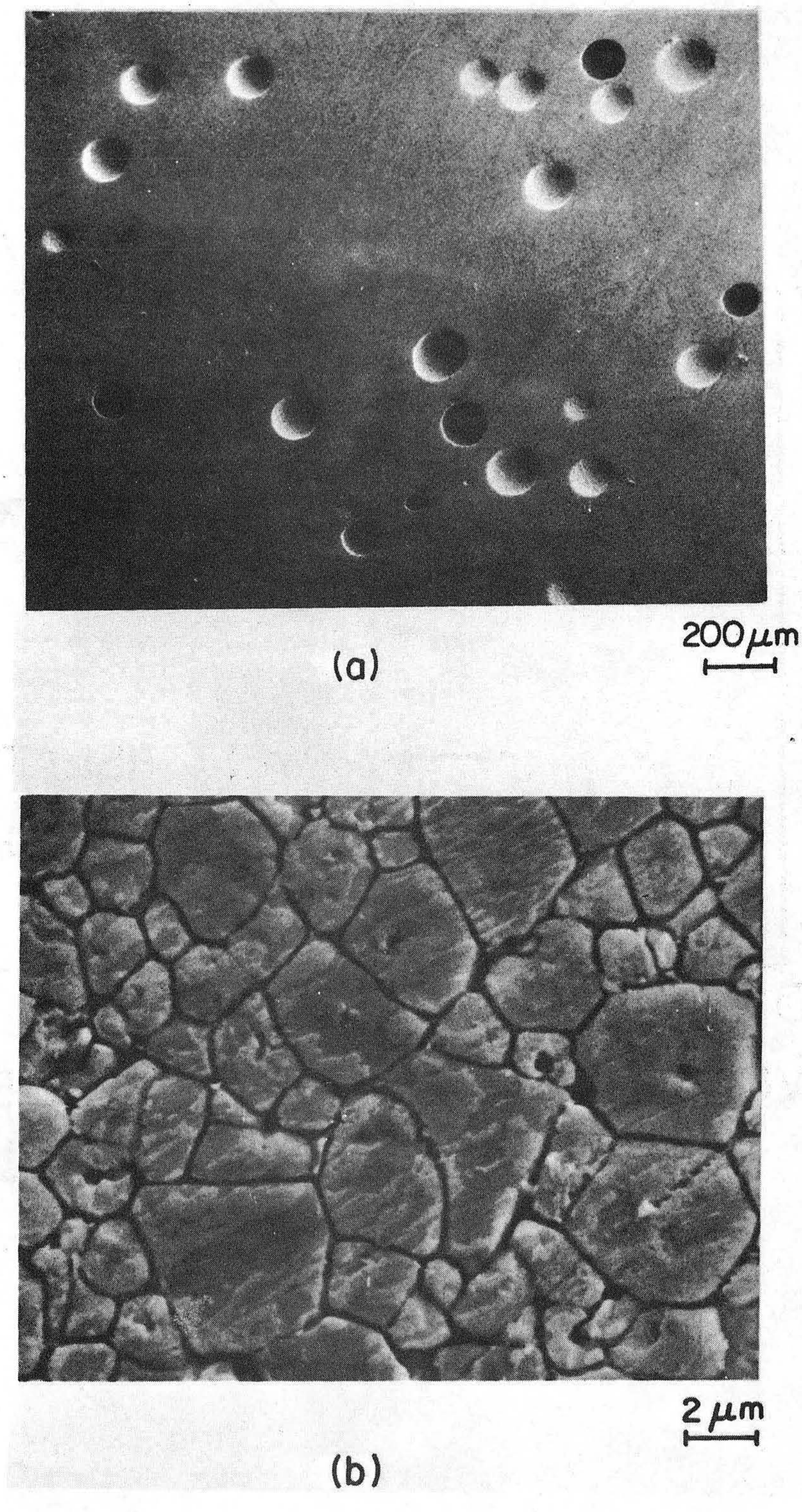
FIGURES

Fig. 1. Typical microstructure of PZT ceramic showing (A) distribution of pores in PZT matrix and (B) distribution of grain size.

Fig. 2. Relative dielectric constant vs. volume fraction porosity.

Fig. 3. Electromechanical coupling factor (K_p) and mechanical quality factor (Q_m) as functions of porosity.



XBB781-1

Fig. 1

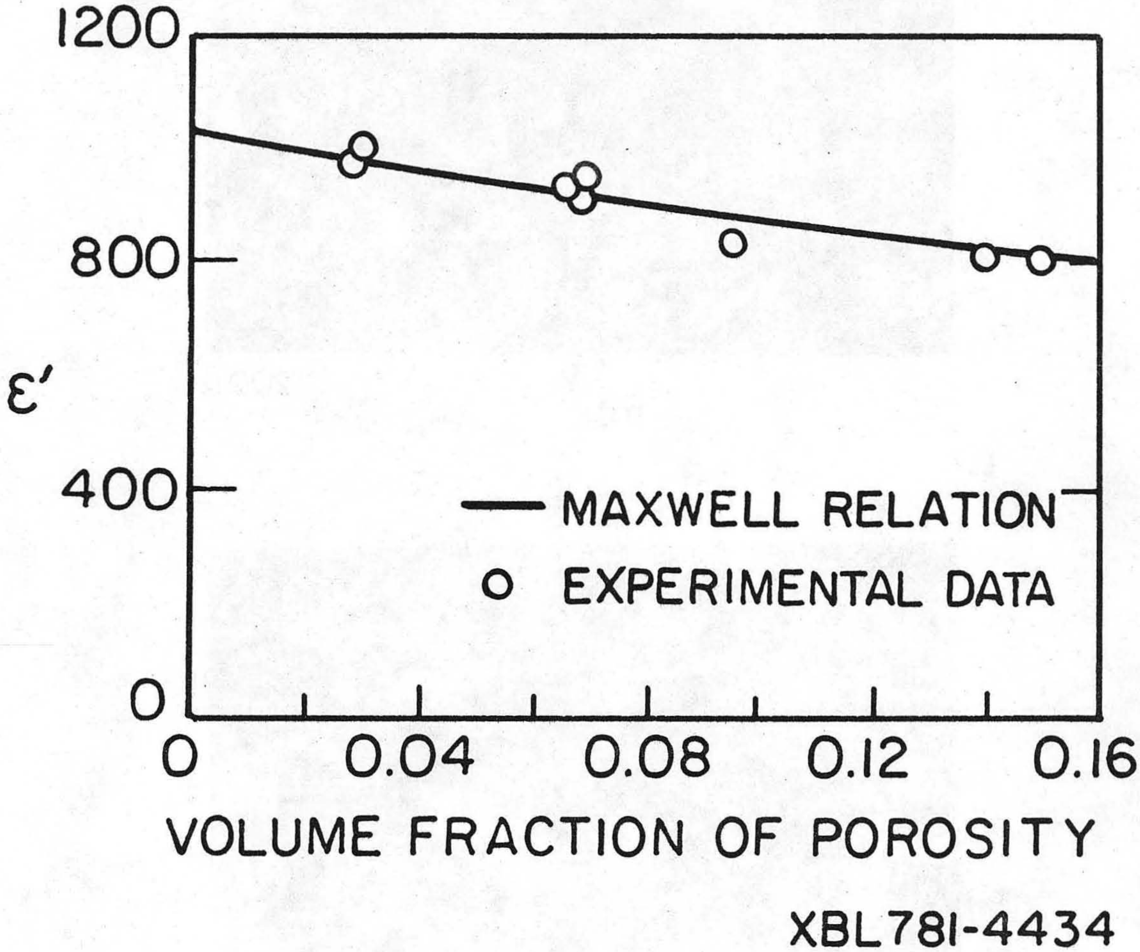

1200
800
400
0
ε'
MAXWELL RELATION
EXPERIMENTAL DATA
0
0.04
0.08
0.12
0.16
VOLUME FRACTION OF POROSITY
XBL781-4434

Fig. 2

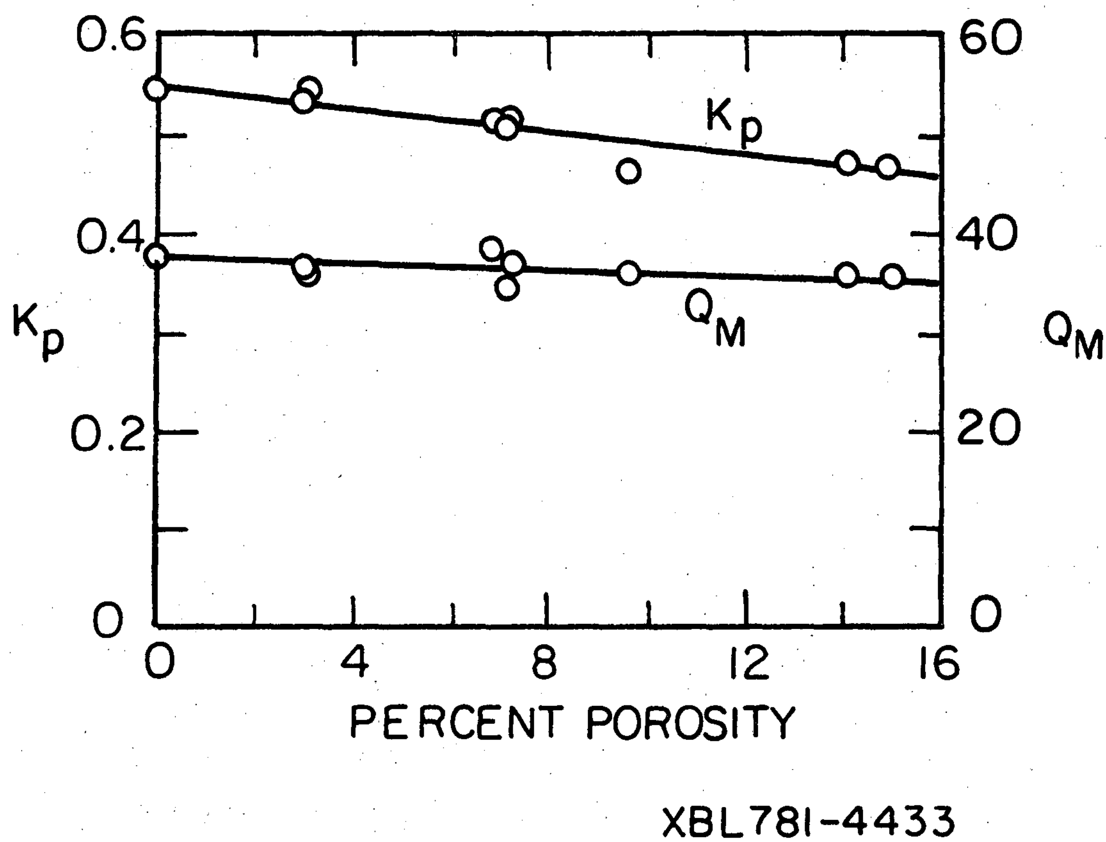

0.6
0.4
0.2
0
Kp
60
40
20
0
QM
Kp
QM
0
4
8
12
16
PERCENT POROSITY
XBL781-4433

Fig. 3

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