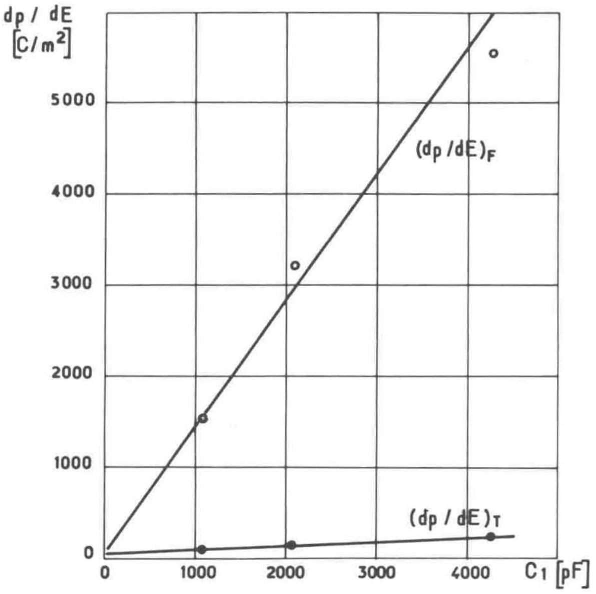

Fig. 13. Variation of $(dP/dE)_F$ and $(dP/dE)_T$ versus ε_1

In the depolarization cycles with capacitive loads the load capacity C_1 can be considered as a ceramic which has the same area A and the same thickness s, as the sample but a permittivity ε_1 such as $C_1=\varepsilon_1 A/s$. The variation of the dielectric displacement is now a linear function of the electric field: $dD=-\varepsilon_1 dE$ and for pressures lower than p_1 pressure we have $dD=-\varepsilon_1 dE = \varepsilon dE - d_h dp$ and consequently $dp/dE=(\varepsilon+\varepsilon_1)/d_h = 1/g_h + \varepsilon_1/d_h$.

The linear variation of dp/dE versus ε_1 gives the values of d_h and g_h.

Between the pressures p_1 and p_2 we can write $dD=-\varepsilon_1 dE = \varepsilon' dE - d' dp + \varepsilon dE - d_h dp$; *or* $dp/dE = (\varepsilon+\varepsilon'+\varepsilon_1)/(d'+d_h) = (\varepsilon+\varepsilon')/(d_h+d') + \varepsilon_1/(d_h+d') \approx 1/g' + \varepsilon_1/d'$ ($\varepsilon \ll \varepsilon'$, and $d_h \ll d'$).

The dp/dE versus ε_1 relationship is linear and enables us to determine the values of g' and d'. The preceding theoretical considerations are now applied to a sample with $x=0.08$ and compared with some experimental results.

The nearly linear variations of $(dp/dE)_F$ in the ferroelectric state and $(dp/dE)_T$ during the transition process, as functions of ε_1, are shown in Fig. 13. The g_h value is extrapolated for $\varepsilon_1=0$ with a very low precision, because of the important slope $(1/d_h)$ of the curve. Nevertheless, we have $g_h \approx g'$ and $d_h = 61\times10^{-12}\ C/N$.

From measurements with a capacitance bridge we obtain $\varepsilon = 2.75\times10^{-9}$ F/m which leads to $g_h = d_h/\varepsilon = 45^{-1}\ \mathrm{m^2/C}$. The very low slope $(1/d')$ of the $(dp/dE)_T$ curve does not allow a good determination of d'; on the other hand, the g' value is easily obtained to $g' = 43^{-1}\ \mathrm{m^2/C}$ and therefore $g_h \approx g'$. For a sample, with $x=0.07$ the g' and g_h values are

$$d_h = 48\times10^{-12}\ \mathrm{C/N}$$

$$\varepsilon = 2.4\times10^{-9}\ \mathrm{F/m}\quad g_h = 50^{-1}\ \mathrm{m^2/C}\quad g' = 40^{-1}\ \mathrm{m^2/C}\,.$$

Conclusion

By introduction of two new piezoelectric coefficients d' and g' the behaviour of the materials through a F→AF pressure – enforced phase transition can be explained. We find that d' is much larger than d_h but that g' is quite the same as g_h. These two coefficients have important values for solid solutions having highly coupled dipoles and therefore high remanent polarizations and low permittivities.

Among the various materials which hold such properties, those mentioned in this paper are particularly interesting for irreversible conversion of mechanical to electrical energy (energy storage). By irreversible depolarization of materials previously poled, induced by hydrostatic compression, it is possible to obtain $3\ \mathrm{J/cm^3}$ on an resistive load.

References

1. J. Paletto, M. Troccaz, P. Gonnard, G. Grange, L. Eyraud: C.R. Acad. Sc. Paris, t. 275 (30 Oct. 1972), Série B–657
2. D. Berlincourt: IEEE Trans. Sonics Ultrasonics. SU–**15**, 89 (1968)
3. D. Berlincourt, H. H. A. Krueger, B. Jaffe: J. Phys. Chem. Solids **25**, 659 (1964)
4. F. Bauer: Thèse, Lyon (1971)
5. M. Troccaz, J. Perrigot, P. Gonnard, Y. Fetiveau, L. Eyraud: C.R. Acad. Sc. Paris, t 275 (16 Oct. 1972), Série B 597
6. D. Berlincourt: IEEE Trans. Sonics Ultrasonics SU–**13**, 116 (1966)