



Fig. 13. Variation of  $(dp/dE)_F$  and  $(dp/dE)_T$  versus  $\varepsilon_1$ .

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  $\varepsilon_1$  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  $\varepsilon_1$  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  $\varepsilon_1$  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  $\varepsilon_1$ , 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  $d_h = 61 \times 10^{-12}$  C/N.

From measurements with a capacitance bridge we obtain  $\varepsilon = 2.75 \times 10^{-9}$  F/m which leads to  $g_h = d_h/\varepsilon = 45^{-1}$  m<sup>2</sup>/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  $g' = 43^{-1}$  m<sup>2</sup>/C and therefore  $g_h \approx g'$ . For a sample, with  $x = 0.07$  the  $g'$  and  $g_h$  values are

$$d_h = 48 \times 10^{-12} \text{ C/N}$$

$$\varepsilon = 2.4 \times 10^{-9} \text{ F/m } g_h = 50^{-1} \text{ m}^2/\text{C } g' = 40^{-1} \text{ m}^2/\text{C}.$$

### Conclusion

By introduction of two new piezoelectric coefficients  $d'$  and  $g'$  the behaviour of the materials through a F  $\rightarrow$  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 J/cm<sup>3</sup> 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. Fétiqueau, 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)