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Shock-Wave Compression of Barium Titanate and 95/5 Lead Zirconate Titanate*

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The shock compression of the ceramics $BaTiO_3(5\% CaTiO_3)$ and $Pb(Zr_{0.95}Ti_{0.05})O_3(1\ wt\% Nb_2O_5)$ was measured in the ranges 5–200 kbar and 2–140 kbar, respectively. Barium titanate exhibits a two-wave structure above 30 kbar; the first wave has a velocity of 6.27 mm/μsec. The cusp in the Hugoniot at 30 kbar is interpreted as a dynamic elastic limit. Comparison of the first wave velocity with the measured longitudinal sound speeds of the tetragonal (ferroelectric) and cubic (paraelectric) phases (5.4 and ~6.2 mm/μsec, respectively) suggests, as does other evidence, that the material begins to transform to the cubic phase in the neighborhood of 7 kbar. Below 7 kbar, subsonic velocities are observed and it is speculated that this phenomenon is associated with domain reorientation.

The particular lead zirconate composition studied has a two-wave structure above about 40 kbar; the position of the cusp in the Hugoniot depends sensitively on initial density. This cusp is presumably the Hugoniot elastic limit. A weak cusp is also observed at about 2 kbar. The wave velocity is essentially sonic below 2 kbar and subsonic above 2 kbar, increasing to about sonic in the neighborhood of 40 kbar.

INTRODUCTION

Studies were made of the shock compression of two ferroelectric ceramics: barium titanate containing 5 wt% calcium titanate, and lead zirconate titanate having a Zr/Ti ratio of 95/5 and containing 1 wt% niobium oxide. These will hereafter be referred to as BT and 95/5 PZT, respectively. The specimens used in all experiments were unpoled.

The purpose of studying these materials was to aid in understanding electrical phenomena produced by shocking poled ceramic ferroelectrics. There was at the time of this work almost no published information on the mechanical properties of fine-grained ceramics under shock compression. In addition, it was believed possible that there might be some unusual behavior associated uniquely with the ferroelectric nature of the material. Because there is still a paucity of data, the results of these studies are being published despite their incompleteness. A general discussion of the shock behavior of solids (including ferroelectrics) has already been published.[1]

This work was performed concurrently with, but independent of, that of Reynolds and Seay,[2] who studied pure $BaTiO_3$ and a PZT having a Zr/Ti composition of 52/48. They observed two-wave structures for

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1 D. G. Doran and R. K. Linde, *Solid State Physics*, F. Seitz and D. Turnbull, Eds. (Academic Press Inc., New York, 1966), Vol. 19, pp. 229–290.
2 C. E. Reynolds and G. E. Seay, J. Appl. Phys. **33**, 2234 (1962).

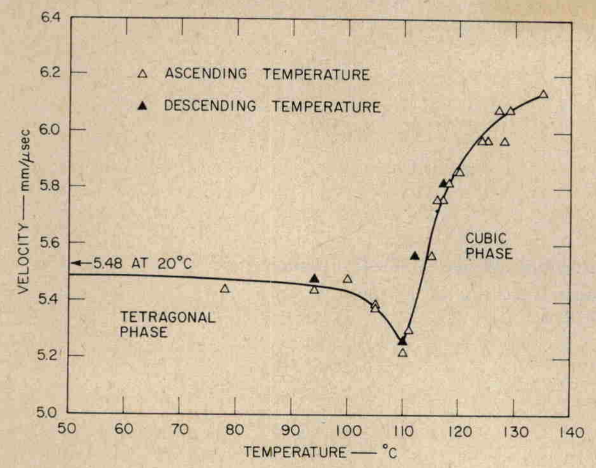

FIG. 1. Variation of longitudinal sound speed with temperature for $BaTiO_2$ (5% $CaTiO_3$)

both materials and concluded that the first-wave amplitudes, 25 kbar for pure BT and 19 kbar for 52/48 PZT, represent Hugoniot elastic limits. They suggest that the pure BT has transformed to the paraelectric phase at pressures less than 25 kbar. From measurements of charge release from 52/48 PZT, they concluded that the primary mechanism of charge release in this material by a shock moving parallel to the polarization direction is not domain switching, but rather a linear reduction of dipole moment by compression of the sample.

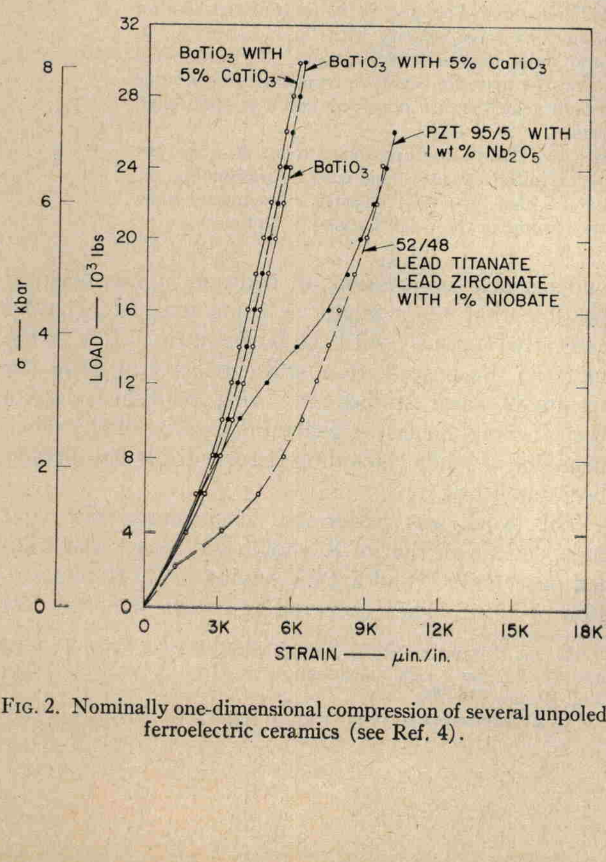

FIG. 2. Nominally one-dimensional compression of several unpoled ferroelectric ceramics (see Ref. 4).

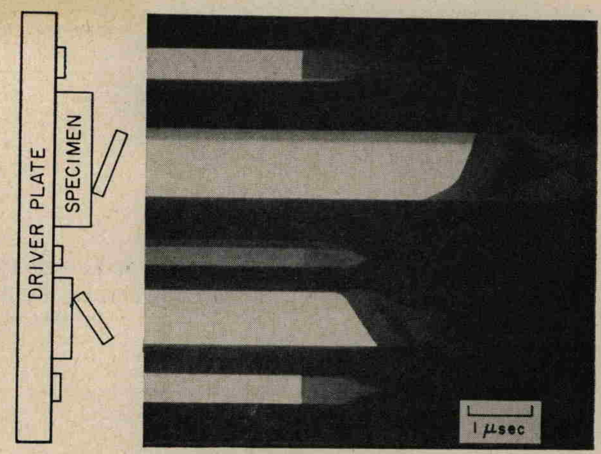

FIG. 3. Smear record for shot No. 7446 (including schematic side view showing mirror positions).

SPECIMEN CHARACTERIZATION

The BT was supplied in the form of 2×2×10-in. bars.[3] According to the supplier, the principal impurities in the barium titanate and their concentration,

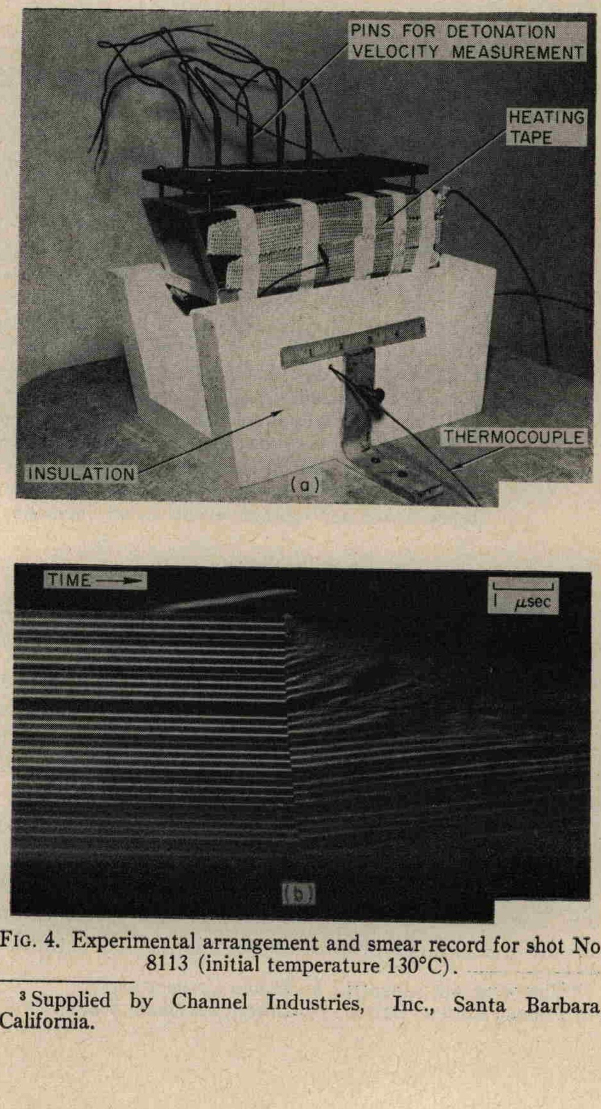

FIG. 4. Experimental arrangement and smear record for shot No. 8113 (initial temperature 130°C).

[3] Supplied by Channel Industries, Inc., Santa Barbara, California.