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The electrical and mechanical response of lithium niobate shock loaded above the Hugoniot elastic limit[a)]

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Z-cut lithium niobate has been subjected to shock loading over a wide stress range to determine the general character of its response. Unusual electrical and mechanical effects are observed.

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Lithium niobate has been studied under impact loading at stresses up to the Hugoniot elastic limit, about 2.5 GPa, and shown to have a nonlinear piezoelectric response which can be described in terms of an elastic-dielectric model with conduction.[1] The present studies of Z-cut single-crystal lithium niobate subjected to plane-wave impact loading at stresses above the Hugoniot elastic limit have revealed some unexpected electrical and mechanical results. These results may be summarized as follows:

(1) The plastic wave velocity is unusually slow relative to the elastic wave velocity. Accordingly:

(2) There exists a broad range of impact stresses over which an elastic wave is propagated.

(3) Despite internal conduction, there is a substantial piezoelectric response up to at least 90 GPa impact stress.

(4) The electrical behavior above the Hugoniot elastic limit shows some differences from that of X-cut quartz.

(5) There is evidence for a reduction of shear strength above the Hugoniot elastic limit.

Prior work on X-cut quartz shock loaded above the Hugoniot elastic limit[2] has shown that piezoelectric current pulses can be quantitatively described in terms of the Neilson-Benedick three-zone model.[3] The electrical and mechanical configurations for the model are shown in Fig. 1. Because the material has yielded mechanically, it can be anticipated that two waves, an elastic and a plastic wave, will propagate and divide the sample into three zones. An unstressed zone (1) is in advance of the elastic wave, while the zone between the elastic and plastic waves (2) is stressed to the level of the Hugoniot elastic limit and electrically polarized by the stress due to the piezoelectric effect. The zone behind the plastic wave (3) is assumed to be a good electrical conductor. The thicknesses of the zones are changing in time and, as a result, the current pulse can be shown to be described by[2]

$$il/A=(U_1-U_2)(1-U_2t/l)^{-2}P_H,\ \ 0<t<l/U_1, \qquad (1)$$

where i is current, l is the thickness of the sample, A is the area of the charge collecting electrode, U_1 and U_2 are the velocities of the elastic and plastic waves, respectively, and P_H is the piezoelectric polarization at the Hugoniot elastic limit. For the case of $+X$ oriented quartz, it has been observed that current pulses are in quantitative agreement with predictions from Eq. (1).[2]

The present investigation extends this earlier work on quartz to an interesting new material with possible uses in applications such as shock detectors. Lithium niobate is a "frozen-in" ferroelectric for which electric field and pressure have not been observed to cause domain reorientation except in the vicinity of the Curie temperature of 1485 K.[1,4]

The material used in the experimental study was transducer-grade lithium niobate produced by Crystal Technology, Inc., San Jose, Calif. It was selected for low residual stress as described in Ref. 1.

Impact experiments were performed over a wide range of impact stresses in an attempt to identify the principal features of the electrical and mechanical behaviors. The conditions of the experiments are summarized in Table I.

In the lower-stress experiments, the electrical responses were monitored by recording the current pulses from the samples through a small resistance connecting the back electrode to ground, using the guard ring configuration described in Ref. 5. In some cases, simultaneous measurement of the mechanical behavior was accomplished with a VISAR velocity interferometer[6]

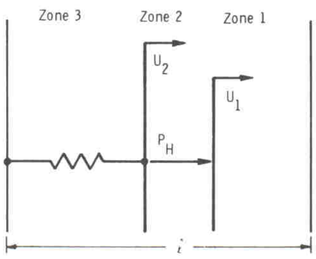

FIG. 1. Neilson-Benedick three-zone model. U_1 and U_2 are the elastic and plastic wave velocities, respectively. P_H indicates the region is piezoelectrically polarized at a level corresponding to the Hugoniot elastic limit stress.

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