studies of mechanical response, described in sections 2 and 3, or in static-high-pressure studies of physical properties as described, for example, by Paul and Warschauer [63P2] or Drickamer [65D2]. In spite of significant complications in interpreting physical property measurements under shock loading, work to date has resulted in considerable progress toward understanding physical effects in solids under large deformation and in identifying electrical phenomena unique to shock deformation. These unique phenomena have provided insight into fundamental features of shock deformation. Measurements within the elastic range are subject to detailed interpretation and can be carried out with the highest precision. On the other hand, interpretation of measurements in solids with complex mechanical properties is among the most complex problems encountered in the field of shock compression of solids. Basic complications and characteristics of the shock-loading experiment as applied to physical property measurements are considered below before description of the various specific material responses.

The amplitude of the disturbance impinging upon a sample is subject to reasonable control, but the actual loading is carried out as an inertial reaction to the disturbance. Accordingly, the stress and deformation histories at various points throughout the sample depend explicitly on both its Hugoniot curve and strength properties. Such properties are not usually under the control of the experimenter and situations may be encountered for which the essential independent variables of strength, stress and volume are poorly characterized.

When the shear strength of a solid is exceeded, the material flows in inelastic deformation which is a macroscopic manifestation of microscopic processes involving dislocation motion, their complex interactions, possible twinning, formation of vacancies, higher-order vacancy complexes and possible relaxation in the defect states. As a result, a physical property measurement under shock loading is made on a sample whose defect state is essentially unknown but radically different from that of the virgin sample. It is well known that many physical properties are sensitive to, if not dominated by, defects. Thus, formation of shock-induced defects seriously complicates interpretation of physical property measurements. Any interpretation of defect-sensitive properties that ignores such shock-induced defects is of limited value and fails to take advantage of the unique opportunity afforded to probe defect states through physical property measurements.

The presence of shock-induced defects can easily lead to a situation in which deformation and temperature are highly localized (see section 3.4) and resulting physical effects may also be localized and not characteristic of bulk behavior. Accordingly, the validity of interpretation of observations in terms of bulk physical processes must be explicitly verified.

Restrictions on sample configurations play a major limiting role in our ability to carry out physical-property measurements. Two characteristically different configurations involving either a *thin sample* or a *thick sample* are used to achieve conditions subject to ready interpretation. Whereas measurements by the thick-sample method are made synchronously during the passage of the stress waves, measurements by the thin-sample method are made after a uniform stress is achieved due to impedance matching with buffers or after wave reverberations within the sample. The thin-sample method is, from a conceptual framework, the simpler of the two since, unlike the thick-sample method, it is possible to describe final stress-volume states achieved in the sample without detailed consideration of wave propagation. The thin-sample method is employed, for example, in resistance measurements on thin metallic samples placed directly in electrically insulating buffer disks or in conducting buffers insulated with polymeric films.

The conceptual simplicity of the thin-sample method results from limited consideration of the details of the transient loading within the sample. Furthermore, the measured electrical waveforms contain virtually no information on that loading process. Verification of representative conditions within the thin sample requires measurements using samples of varying design.

The thick-sample method is more difficult in both concept and practice, as potentially complex wave propagation within the sample must be explicitly analyzed. The measured electrical waveforms help to alleviate this difficulty since they contain a wealth of real-time information on both mechanical and electrical processes occurring in the space being probed. The direct effect of wave propagation forces explicit consideration of the transient loading. The configuration allows separation of elastic and plastic contributions and allows electrical boundary conditions to be varied. As more representative models of mechanical response are developed and incorporated in computer codes, the utility of the thick-sample method will be greatly increased. This method is typically employed in physical property measurements on dielectrics and the most critical mechanical detail is control of the simultaneity of the loading over the sample face, i.e., the "tilt".

4.2. Piezoelectrics

Favorable electrical properties and large Hugoniot elastic limits, combined with ready availability, has led to the widespread use of quartz and lithium niobate crystals for time-resolved stress gauges in shock-compression experiments. The importance of this application has motivated sufficiently quantitative studies that their piezoelectric, dielectric, and elastic properties have been determined in detail throughout the elastic range. The principal unique results from these investigations are determinations of second-order piezoelectric, higer-order piezoelectric, dielectric, and elastic constants, and investigation of unusual shock-induced dielectric breakdown phenomena.

Studies of piezoelectrics under shock compression stem from an extraordinarily perceptive investigation carried by Neilson and Benedick and first reported in 1961 [62N2]. They explained the electrical waveforms produced from explosively-loaded X-cut quartz in terms of a "three-zone model" incorporating the following principal assumptions: (1) above the Hugoniot elastic limit an elastic and inelastic wave structure separates the sample into three distinct zones, (2) the elastic precursor wave has an amplitude of about 4 GPa, (3) the shear stress vanishes in the region behind the inelastic wave, and (4) shock-induced conduction occurs in either the elastic or inelastic zone depending upon the piezoelectric polarity. This model is not only complex, but incorporates features at variance with then-current ideas of material strength and inelastic behavior. The assumptions concerning mechanical behavior were soon confirmed by Wackerle [62W1] and Fowles [61F2, 67F1], and investigations of large Hugoniot-elastic-limit values and loss of shear strength continue to the present time (see section 3.4). The dielectric breakdown phenomena observed electrically by Neilson and Benedick [62N1] and optically by Brooks [65B3] are still not understood and work continues on this problem as well (see section 4.6). A summary of investigations of piezoelectric crystals under shock loading is shown in table 4.1.

Studies of the response of piezoelectric solids to elastic shock compression are part of a larger question of nonlinear piezoelectric response. Although this problem is of considerable interest in connection with microwave acoustic phenomena (see, e.g., [67C1, 68M1, 71T1, 72K4, 72L1]), there are few quantitative data on nonlinear piezoelectric constants. Order-of-magnitude estimates based on ultrasonic investigations have been given for lithium niobate [75K2], while quantitative values are reported for quartz by Hruska [78H3], who was the first to detect a nonlinear piezoelectric effect [61H2]. Pressure derivatives of hydrostatic piezoelectric constants have been