for quartz and lithium niobate occurs well within the elastic range and under conditions in which the strains and electric fields can be accurately calculated.

The sample-polarity anomaly in current pulses from X-quartz quartz shocked above the Hugoniot elastic limit gave the first indication of unusual conduction phenomena in that material [62N2]. Subsequent work [62G1, 68G4, 72G4] showed that anomalies in current pulses in the minus-X orientation were encountered at all fields once a threshold stress of 1.2 GPa was exceeded. The observed rapid reduction in current in an external short circuit, combined with intense localized luminescence indicative of localized high-current densities [62N2, 65B3, 68G4], supply strong evidence to support a breakdown phenomenon.

Certainly the most prominent feature of the breakdown process is its dependence on the polarity of the electric field relative to the shock-velocity vector. This effect is manifest in current pulse anomalies from minus-X orientation samples or positively-oriented samples subjected to short-pulse loading (see fig. 4.5). The individual effects of stress and electric field may be delineated with short-pulse loadings in which fields can be varied by utilizing stress pulses of various durations

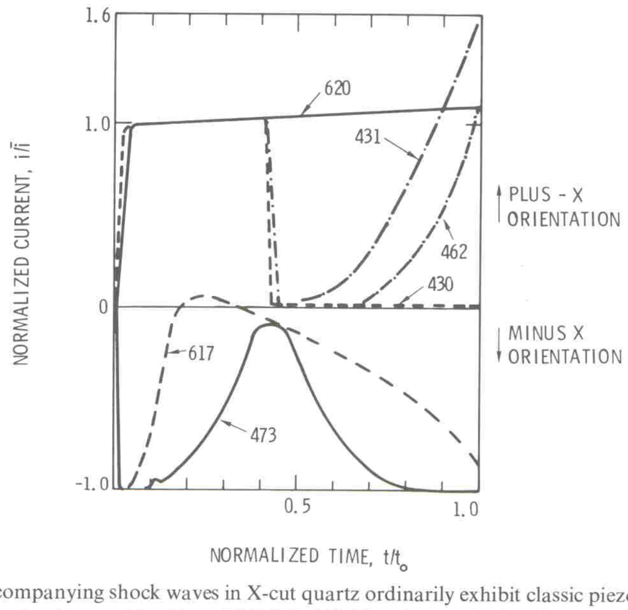

Fig. 4.5. Piezoelectric current accompanying shock waves in X-cut quartz ordinarily exhibit classic piezoelectric behavior as indicated in Shot 620 (2.49 GPa) for long-pulse loading and for Shot 430 (0.942 GPa) for short-pulse loading. In certain ranges of stress and electric field anomalous currents are observed for short-pulse loading such as are shown in Shots 431 (1.90 GPa) and 462 (1.54 GPa). In the minus-X orientation the currents are negative and above a threshold stress of 1.12 ± 0.7 GPa the waveforms are drastically distorted as shown in Shot 617 (2.1 GPa) and Shot 473 (1.12 GPa). The current pulse distortions are thought to be a consequence of a stress-induced dielectric breakdown initiated above the threshold stress and field. The effect of specimen polarity indicates that negatively charged species which originate at the shock front are the source from which the breakdown proceeds.

[72G4]. As shown in fig. 4.6, these studies provided evidence that the breakdown was characterized by a fixed threshold stress of 1.1 GPa and a fixed threshold field of 2.8×10^7 V/m. Once the threshold stress is exceeded, the conduction is controlled by the field and is independent of the stress. The threshold field is in reasonable agreement with the field of 7×10^7 V/m below which a recovery from breakdown is observed when the field decreases due to the internal conduction [68G4].

A time delay for breakdown has been observed which depends upon the electric field but is,

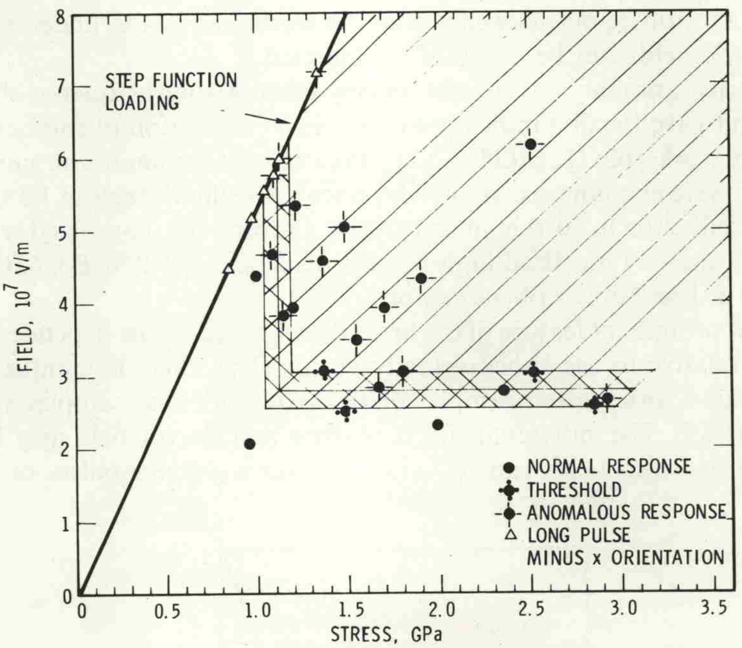

Fig. 4.6. Short-pulse loading can be used to control the electric field in a piezoelectric sample independent of the stress amplitude. Data from such experiments as shown in fig. 4.5 have been used to delineate the region in which anomalous current pulses (thought to be due to dielectric breakdown) are observed. The data shown indicate that a stress threshold of 1.12 GPa and an electric field threshold of 2.5×10^7 V/m must be exceeded to cause the effect. After Graham and Ingram [72G4].

again, independent of stress once the threshold stress is exceeded [75G6]. Such a delay time has also been observed in short-pulse loading experiments [76B5].

It appears that the observed breakdown must be explained in terms of the transient behavior of stress-induced defects even though the stresses are well within the nominal elastic range. Brown [78B5, 79B1] is developing a model whereby stress-induced, high-speed dislocation motion causes high local concentrations of charged vacancies whose diffusion under high electric fields and stress gradients leads to internal flaws and local breakdown. In lithium niobate and aluminum oxide the extent of the breakdown appears to be strongly influenced by strains that develop during growth of the crystal [77G6, 68G5]. In the vicinity of the threshold stress, dielectric relaxation associated with defects may have a significant effect on current observed in the short interval preceding breakdown (see section 4.7).

The effect of shock-induced conduction is less distinct in ferroelectrics than in piezoelectrics but is nevertheless apparent from a number of studies (see table 4.3 and Novitskii [79N3]). Differences in conduction with sample polarity, such as are seen in quartz but of opposite sign, are observed in ferroelectrics (see, e.g., Cutchen [66C1] and Mineev and Ivanov [76M4]).

Resistance measurements on solids undergoing shock-induced insulator-to-metal transitions are of considerable interest and such a transition has been identified from Hugoniot measurements and equation-of-state calculations in iodine [77M1]. Unfortunately, such resistance measurements as have been performed on solids have not yielded any explicit information on the transitions (see the summary of Duvall and Graham [77D6]).