Dielectric Properties of the Lead Zirconate/Titanate Composition PZT 95/5 During Shock Compression at High Fields

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Motivation—Shock-induced depoling of the ferroelectric ceramic lead zirconate/titanate composition PZT 95/5 (PZT 95/5) is utilized in pulsed power devices. High fields can be generated within a PZT 95/5 element during shock transit if the depoling current passes through an external circuit with a large resistive load. Under these conditions, a portion of the depoling current is retained on the element electrodes to account for capacitance. This effect is governed by the dielectric properties of both unshocked, normally poled material (ahead of the shock) and shocked, depoled material (behind the shock). The retained current is "lost" in terms of delivery to the external circuit, and can represent a significant fraction of the original bound charge produced when the element was poled. Previous studies have used simple models for a relaxing dielectric to predict load currents from a single, normally poled PZT 95/5 element experiencing shock transit with high field generation. However, these load currents not only reflect the combined dielectric behavior of both unshocked and shocked material simultaneously, but could be influenced by field effects on depoling kinetics.

Accomplishment—New experimental methods have been developed to better isolate dielectric properties in both unshocked and shocked PZT 95/5. We are using shock-driven circuits containing multiple, small PZT elements that are displaced both parallel and perpendicular to the shock motion. As shown in Fig. 1, this allows different elements to be subjected to uniaxial-strain shock compression and release at different times during a single experiment. Shock depoling of the first element produces a current in a circuit consisting of the second element and a load resistor in parallel, as shown in Fig. 2. Current through the load resistor produces a common voltage across both PZT elements, and a portion of the depoling current provides displacement currents to both elements as their corresponding electric fields develop. Current-viewing resistors (CVRs) measure currents in each circuit segment. In one type of experiment, the second element is an axially poled disc with a large diameter-to-thickness ratio resulting in a capacitance much larger than that of the first element. This allows the dielectric response of the second element (poled, unshocked PZT) to be accurately measured prior to shock arrival as a function of different field conditions. Figure 3 shows a comparison of measured load currents from these experiments with currents predicted using a simple model for a relaxing dielectric (Debye approximation). Some variation in the model parameters is necessary to get good agreement in each case. In a second type of experiment, the second element is a normally poled sample identical to the first. Figure 4 shows recorded currents from such an experiment. As the shock transits each element, the displacement current charging the other element is recorded as the field develops and then terminates. These experiments are providing the first direct measurements of dielectric properties in shocked, depoled PZT 95/5.

Significance—Improved understanding of dynamic dielectric properties is required for further development of predictive models for the electrical response of PZT 95/5. Our experiments are providing measurements that will enable dielectric response models that account for more than field-independent, simple relaxation to be developed and assessed. Future experiments using the new configurations will include initial temperature effects.

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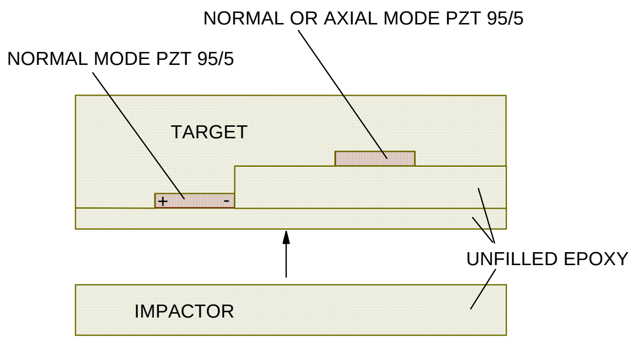

Figure 1. Configuration used for gas-gun experiments to investigate the dynamic dielectric properties of unshocked and shocked PZT 95/5.

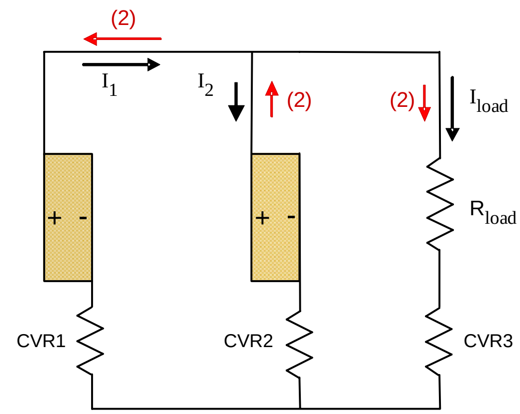

Figure 2. Electrical circuit for PZT 95/5 dielectric measurements. Red arrows indicate current flow when the shock transits the second element.

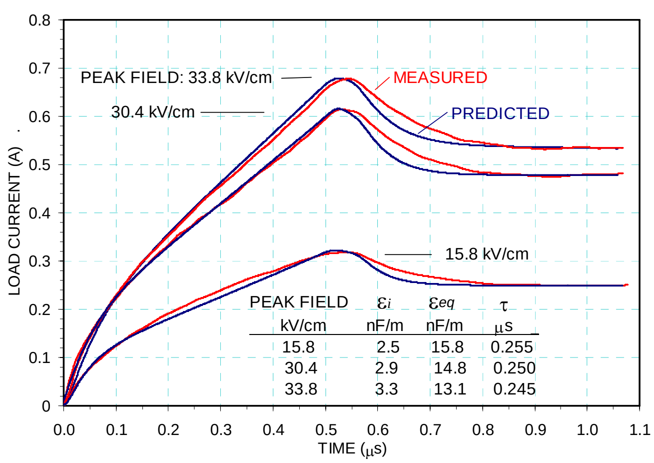

Figure 3. Comparisons between measured load currents in experiments using axial mode second elements and corresponding currents predicted using a simple model for a relaxing dielectric.

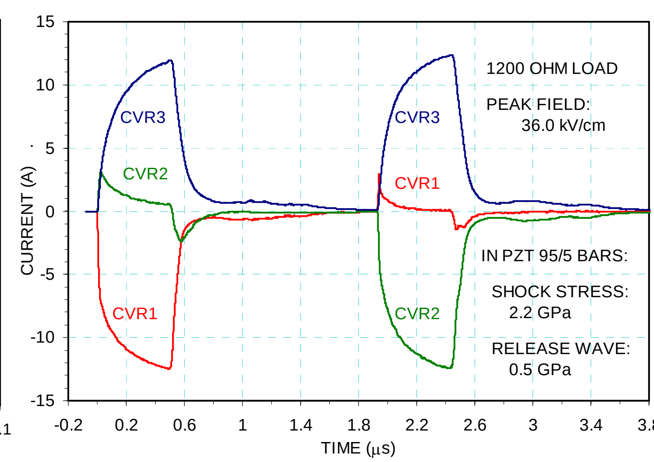

Figure 4. Measured currents in an experiment using identical, normally poled first and second elements. Currents generated during shock transit in the second element provide direct measurements of dielectric properties in PZT 95/5 that has been shocked then unloaded.