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Characterizing the viscoelastic stiffness and damping of ferroelectrics during electric field cycling: experiments and modeling

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ABSTRACT

Motivated by a desire to engineer stiff materials (e.g., ceramics) to also have high energy dissipation, the viscoelastic stiffness and damping in ferroelectric ceramics subjected to electric fields higher than the coercive field is investigated. Indeed, dynamic excitations of ferroelectrics occur in many of their applications, e.g., in sensors and actuators; thus, there is interest in studying their dynamic behavior. However, in most applications, the material is subjected to small electric fields (below the coercive field). As a result, there have been few efforts to study their behavior under large electric fields (above the coercive field) that can produce polarization reorientation, which dissipates energy. Moreover, limitations of current experimental techniques such as Dynamic Mechanical Analysis have only yielded data on the viscoelastic response of ferroelectrics at low mechanical loading frequencies. Recently, aided by a one-of-a-kind Broadband Electromechanical Spectroscopy (BES) apparatus constructed in our lab, sets of earlier unavailable data on the viscoelastic stiffness and damping of ferroelectric ceramics for various mechanical and electrical loading rates have been obtained. Importantly, the BES apparatus also provides the capability to perform experiments under vacuum, which removes the damping effects of the surrounding air. Removing the damping effects of the surrounding environment allows for a more accurate comparison between models and experiments. In this presentation, viscoelastic stiffness and damping results will be presented on the widely commercially used lead–zirconate–titanate ferroelectric material. The evolution of the stiffness and damping during cycling of the polarization is dependent on the electrical and mechanical loading rates. A simple one-dimensional model for the driving force on the polarization evolution is presented to be able to reproduce experimental results and give insight into the relaxation time associated with polarization switching, which will aid in the design of materials that yield, e.g., superior damping. Results reveal order of magnitude increases in the damping capacity of the material during polarization switching. This gives rise to the possibility of creating materials whose damping capacity can be temporarily increased significantly by the push-of-a-button (i.e., by turning on an electric field). This capability is useful in materials and structures that are suddenly exposed to extreme vibrations (e.g., impacts) where quickly dissipating energy is important.