Ferroelectric Film Dynamics Simulated by a Second-order Time-dependent Landau Model

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Based on the work of B. Wang *et al.* [J. Appl. Phys., **94**, 3384 (2003)] that established a second-order time-dependent Ginzburg–Landau equation and a model for domain switching in ferroelectric films that employs this equation, we simulate the reaction of a ferroelectric film system's polarization $\tilde{P}$ to an applied electric field $\tilde{E} = \tilde{E}_0 \sin(\tilde{\omega}\tilde{t})$ where $\tilde{E}_0$, $\tilde{\omega}$, and $\tilde{t}$ represent field amplitude, field frequency, and time, respectively. Polarization hysteresis loop structure as a function of $\tilde{E}_0$ and $\tilde{\omega}$ are examined. The relationship between hysteresis loop area $\langle\tilde{A}\rangle$ and $\tilde{\omega}$, i.e., hysteresis dispersion, is calculated. $\langle\tilde{A}\rangle$ represents the energy dissipated during one cycle of the applied field. Departing from the work of Y.-L. Wang *et al.* [J. Mater. Sci., **46**, 2695 (2011)] that established the considered model produces experimentally expected hysteresis dispersion in the low-$\tilde{\omega}$ regime, we demonstrate that this model also produces experimentally expected hysteresis dispersion in the high-$\tilde{\omega}$ regime. Furthermore, we determine that this dispersion implies, in agreement with empirical observations, that a characteristic time τ_1 exists for system relaxation and that this time is inversely proportional to $\tilde{E}_0$ when the latter is sufficiently high. It is the value of τ_1 relative to $\tilde{\omega}^{-1}$ that determines whether or not complete domain reversal occurs. We also determine the dependence between field parameters and whether $\tilde{P}$ exhibits a symmetry-restoring oscillation (SRO) or a symmetry-breaking oscillation (SBO). Only SROs exhibit a symmetry identical to that of the applied field, i.e., $X(\tilde{t}) = -X(\tilde{t} + T/2)$ where T represents the period of the applied field and X represents $\tilde{E}$ or $\tilde{P}$.

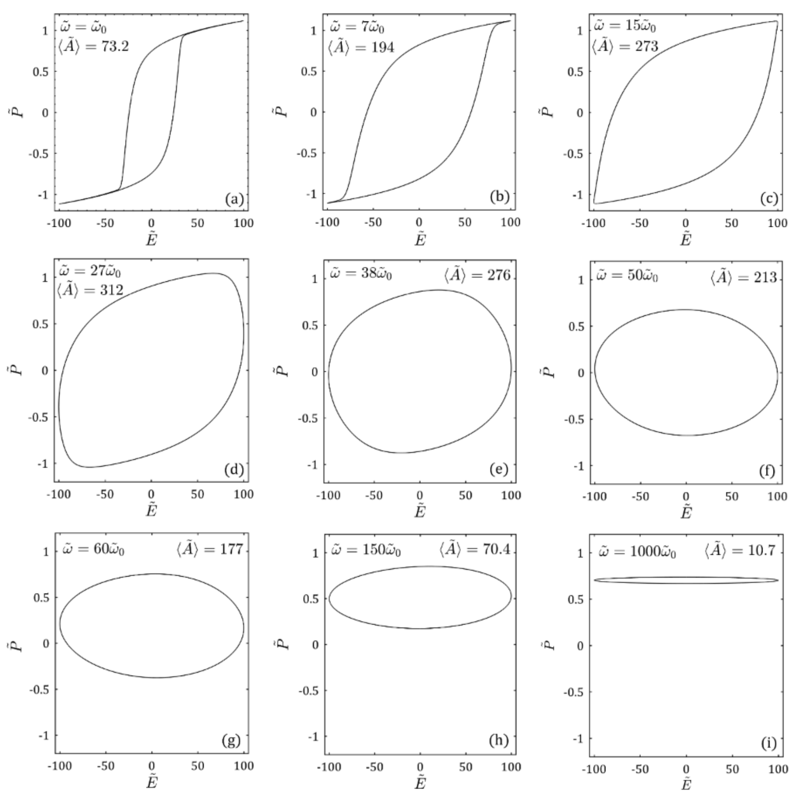

FIG. 1. Steady-state hysteresis loops for $\tilde{E}_0 = 100$ and the field frequencies indicated. The area $\langle\tilde{A}\rangle$ of each loop is displayed.

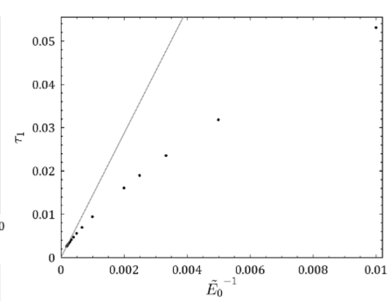

FIG. 2. The solid line, which serves as a guide to the eye, represents an inverse linear relationship between τ_1 and $\tilde{E}_0$.

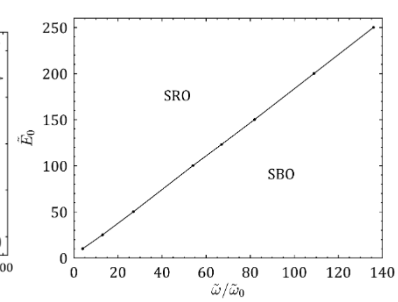

FIG. 3. Bifurcation curve indicating whether a SRO or a SBO exists for the parameters indicated.

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