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# A multi-scale and multi-field coupling nonlinear constitutive theory for the layered magnetoelectric composites

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***Abstract*** **:** The magnetic, electric and mechanical behaviors are strongly coupled in magnetoelectric (ME) materials, making them great promising in the application of functional devices. In this paper, the magneto-electro-mechanical fully coupled constitutive behaviors of ME laminates are systematically studied both theoretically and experimentally. A new probabilistic domain switching function considering the surface ferromagnetic anisotropy and the interface charge-mediated effect is proposed. Then a multi-scale multi-field coupling nonlinear constitutive model for layered ME composites is developed with physical measureable parameters. The experiments were performed to compare the theoretical predictions with the experimental data. The theoretical predictions have a good agreement with experimental results. The proposed constitutive relation can be used to describe the nonlinear multi-field coupling properties of both ME laminates and thin films. Several novel coupling experimental phenomena such as the electric-field control of magnetization, and the magnetic-field tuning of polarization are observed and analyzed. Furthermore, the size-effect of the electric tuning behavior of magnetization is predicted, which demonstrates a competition mechanism between the interface strain-mediated effect and the charge-driven effect. Our study offers deep insight into the coupling microscopic mechanism and macroscopic properties of ME layered composites, which is benefit for the design of electromagnetic functional devices.

***Keywords:*** Magnetoelectric materials; multi-field coupling; nonlinear; constitutive theory; size-dependent.

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