Space-charge polarization in microstructured solid dielectrics

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1 Abstract

The electromechanical response of deformable solid dielectrics strongly depends on their polarizability, which is often the result of several concomitant micromechanisms of diverse origin. When a specimen possesses a fine microstructure and contains a certain amount of mobile ions, the intrinsic polarization of atomic and molecular origin can be significantly enhanced by an extrinsic polarization produced by space charges around microstructural interfaces blocking the flow of ions. This space-charge polarization has been recently proposed as a possible micromechanism responsible for the extreme dielectric enhancements observed in certain nanofilled polymers (Lopez-Pamies et al. 2014, Zhou et al. 2016, Lefèvre & Lopez-Pamies 2017). To assess these proposals experimentally it is common practice to study the variation of dielectric response with microstructural variables such as size and volume fraction of nanofillers. A continuum multiscale description that incorporates the influence of space-charge polarization and microstructure on the macroscopic dielectric response is thus required to adequately interpret experimental observations. The purpose of this work is to put forward such a description within the context of electrostatics. To ease the presentation, attention is restricted to mechanically rigid solids containing a single species of mobile ions. The formulation can, however, be adapted to more complex systems. The relevant field equations of electrostatics are recast in the form of a minimum energy principle for the electrostatic and chemical potentials, and a two-scale version of the principle in terms of an effective energy density is then proposed. Elementary bounds and approximate estimates for the effective energy density are also provided. By way of example, the formulation is used to explore the dependence of the macroscopic response upon microstructural morphology in multiphase layered media, with focus on constitutive nonlinearity and microstructural size effects.

References

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