Piezoelectric Coupling in Non-piezoelectric Materials due to Nonlocal Size Effects at the Nanoscale: Fundamental Solutions (Green's Functions), Embedded Inclusions, and Multifunctional Composites

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Abstract: In a piezoelectric material an applied *uniform* strain can induce an electric polarization (or vice-versa). Crystallographic considerations restrict this technologically important property to non-centrosymmetric systems. It has been shown both mathematically and physically, that a *non-uniform strain* can potentially break the inversion symmetry and induce polarization in non-piezoelectric materials. The coupling between strain gradients and polarization; and strain and polarization gradients, is investigated in this work. While the conventional piezoelectric property is non-zero only for certain select materials, the nonlocal coupling of strain and electric field gradients is (in principle) non-zero for all dielectrics albeit manifesting noticeably only at the nanoscale. Based on a field theoretic framework accounting for this phenomena, we (i) develop the fundamental solutions (Green's functions) for the governing equations (ii) solve the general Eshelby's embedded inclusion problem with explicit results for the spherical and cylindrical inclusion shape and (iii) Illustrate using the simple example of a bilaminate how an apparently piezoelectric composite may be created without using constituent piezoelectric materials.

Expectedly, our results for the afore-mentioned problems are size-dependent and indicate generation of high electric fields in regions of strain gradients in isotropic centrosymmetric non-piezoelectric materials. Simple numerical estimates indicate that electric fields may reach high enough numbers in nano-inclusions indicating possible applications in band structure tuning of embedded lattice mismatched quantum dots.

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