Modelling Porous Ferroelectrics to Assess Piezoelectric Energy Harvesting Capabilities

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Aim: To evaluate the effect of porosity and porous structure on the energy harvesting capabilities of ferroelectric ceramics using a Finite Element Modelling approach.

Context

Porous piezoelectric ceramics are of interest for energy harvesting applications due to porosity causing significant reductions in permittivity, $\varepsilon_{33}$, compared with relatively small reductions in longitudinal strain coefficient, $d_{33}$, leading to increases in energy harvesting figures of merit, where $FOM_{33} = d_{33}^2/\varepsilon_{33}$ [1]. The development of an FE Model will allow different porous structures to be evaluated for their energy harvesting capabilities.

**Pre- and Post-Poling Porous BaTiO$_3$ network**

Fig. 1: (a) $30^3$ cells randomly designated material properties of either unpoled BaTiO$_3$ (blue) or air (empty), depending on density defined for run and (b) post-poling procedure with poled (red) and unpoled BaTiO$_3$ (blue) and air (empty). BaTiO$_3$ elements are poled when local E-field exceeds coercive field.

**FE Modelling Process**

- Generate network model geometry
- Determine random two phase distribution (unpoled BaTiO$_3$ and air) for given volume fraction of porosity
- Apply poling voltage to ‘electroded’ surfaces
- Establish distribution of polarised material
- Characterise porous piezoceramic performance in terms of $d_{33}$, $\varepsilon_{33}$ and energy harvesting FOM
- Clear model
- Record results

Fig. 2: Flow diagram of modelling process used to generate randomly distributed porosity with piezoelectric ceramic (adapted from [2])

**Initial Results**

- $d_{33}$ [PC/N] vs. Relative density (%)
- Relative permittivity vs. Relative density (%)
- FOM$_{33}$ [x10$^{-6}$ N/m$^2$/C] vs. Relative density (%)

Fig. 3: FE model data (blue) compared to experimental data BaTiO$_3$ (red) for (a) $d_{33}$, (b) relative permittivity and (c) FOM$_{33}$, all plotted as a function of relative density. Experimental data measured from BaTiO$_3$ ceramics with range of porosities obtained using the burnout polymer spheres (BURPS) process.

**Discussion & Outlook**

- Want to bring model and experimental data closer together
  - More accurate input data required
- Use model to investigate EH capabilities of different structures/ connectivities
  - Currently, only randomly distributed porosity (3-0/3-3) generated
  - Structure has effect on key properties, i.e. $d_{33}$, $\varepsilon_{33}$ and $S_{33}$ (elastic compliance)

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**References**
