Multiferroics are simultaneously ferroelectric and ferromagnetic:

- Fermomagnets (FM) → Possess spontaneous magnetization, possible to be reoriented by an external magnetic field \( \mathbf{H} \)
- Ferroelectrics (FE) → Possess spontaneous polarization, which can be reoriented by an external electric field \( \mathbf{E} \)

Multiferroicity can stem from different roots:

- FE LuFeO\(_3\) & ferrimagnetic LuFe\(_2\)O\(_6\) superlattice
- Magnetoelectric (ME) composite branch

Multiferroic family tree (Nature Materials, 2019)

### Introduction

Estimation of the equilibrium macroscopic magneto-electro-elastic properties of the ME composite have been done using the mathematical homogenization method [1]. A ME multiferroic composite occupying a volume \(\Omega\) of coordinates \((x, y)\) in an area \(\Omega\) and the displacement \(u\) and \(\epsilon\); the macroscopic fields/magneto-electric potentials respectively of a multiferroic composite [1]. Here the functions \(\tilde{q}(u, \epsilon, \phi)\) are the local variations (or field perturbations) describing the heterogeneous part of the solutions and are associated with \(\phi = \phi(x)\). Applying calculus of variations, utilizing the asymptotic Eq (1) and its derivates, the homogenization method essentially culminates in the characterization of effective magneto-electro-elastic moduli when the characteristic length of the period \(\epsilon \rightarrow 0\). The model quantifies all the local fields and potentials besides stress \((\sigma)\) and strain \((\epsilon)\) fields: magnetization (via magnetic flux density \(D\)), polarization (via electric displacement \(D\)) as well as von-Mises stress upon the application of an external field in a complex manner.

### Model

The ME composite of 1–3 BaTiO\(_3\)-CoFe\(_{3}\)O\(_{8}\) is subjected external electric/magnetic fields. The averages of polarization and magnetization of the polycrystalline BaTiO\(_3\)-CoFe\(_{3}\)O\(_{8}\) exceed that of the single crystal version. The depiction of local fields corresponding to the polycrystal configuration suggests nontrivial role played by randomness in better cross-coupling mediated by anisotropic and asymmetric strains.

### Results

<table>
<thead>
<tr>
<th>BTO phase</th>
<th>Orientation 1</th>
<th>Averages of (M_h)</th>
<th>(\langle M_h \rangle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single crystal</td>
<td>(001)</td>
<td>(2.83 \times 10^{10})</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(010)</td>
<td>(-6.48 \times 10^{10})</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>(001)</td>
<td>(-1.35 \times 10^{10})</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

\[ \tilde{q}(\mathbf{u}, \mathbf{\epsilon}, \phi) \] describes the heterogeneous part of the solutions and are associated with \(\phi = \phi(x)\). Applying calculus of variations, utilizing the asymptotic Eq (1) and its derivates, the homogenization method essentially culminates in the characterization of effective magneto-electro-elastic moduli when the characteristic length of the period \(\epsilon \rightarrow 0\). The model quantifies all the local fields and potentials besides stress \((\sigma)\) and strain \((\epsilon)\) fields: magnetization (via magnetic flux density \(D\)), polarization (via electric displacement \(D\)) as well as von-Mises stress upon the application of an external field in a complex manner.

### References


