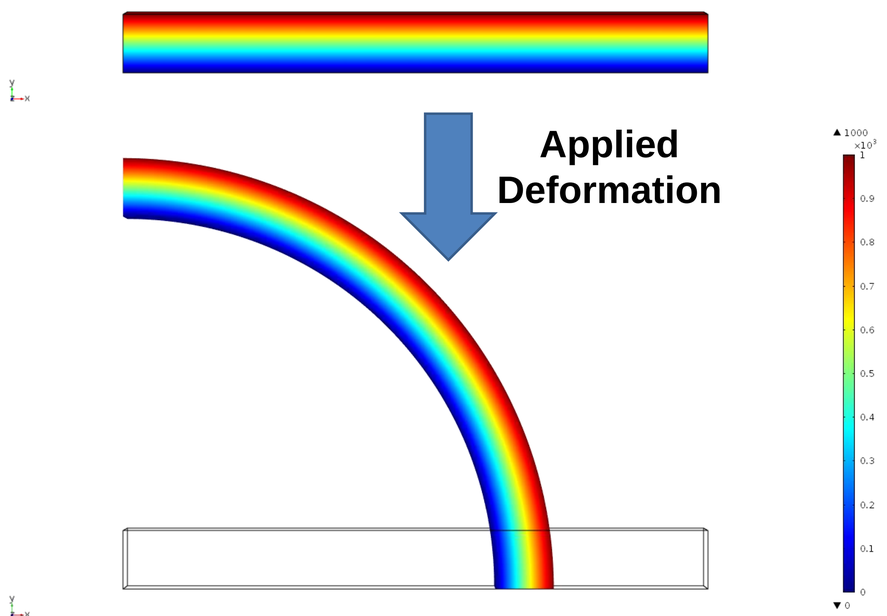
EM Energy Coupled to Finitely Deforming Matter

S&T Campaign: Materials Research
Manufacturing Science
Energy Coupled-to-Matter

Brian Powers
(410) 306-1961
brian.m.powers.civ@mail.mil

Research Objective

- **The goal is to enable the simulation of the complex electro-mechanical loading experienced in both materials processing and Army-specific applications.**
- **Focus areas include: mathematical and numerical framework for finite deformations in a EM field, constitutive models for electroactive media, and experimental techniques for verification/validation.**



Mapping of the Electric Potential with the deformation in convected coordinates

Challenges

- **Simulations of ceramic based piezoelectrics (e.g. SiC and AlN) neglect full coupling of Maxwell's equations with the mechanical equations of motion**
- **Radiated EM fields influence deformation and failure of piezoelectric ceramics**
- **Full coupling of the field equations is needed to understand how transient mechanical waves can generate radiated electromagnetic power, (power harvesting from vibrating mechanical devices)**

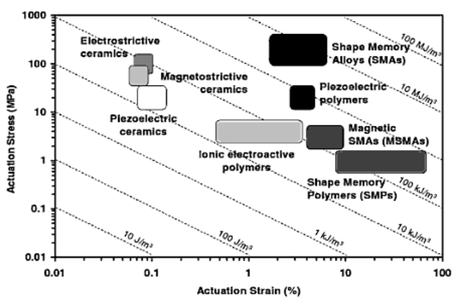


Fig. 1.1. Actuation energy density diagram indicating typical ranges of actuation stress, actuation strain, and the actuation energy densities of different active materials that exhibit direct coupling.

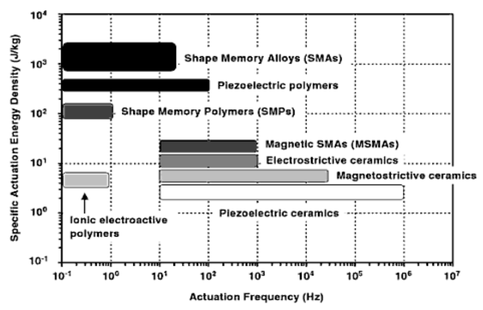
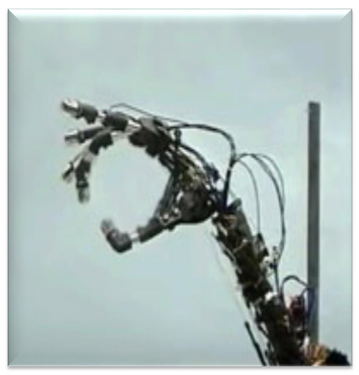


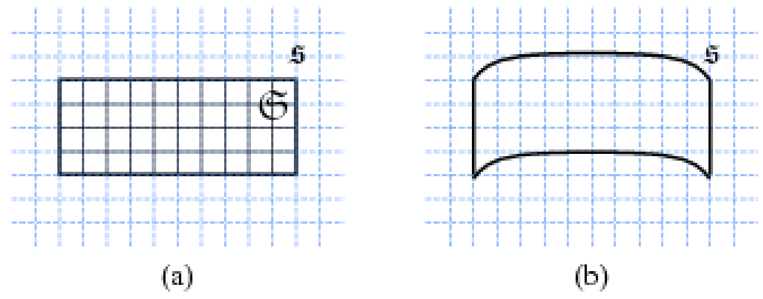
Fig. 1.2. Actuation frequency diagram comparing the actuation frequency ranges of different active materials that exhibit direct coupling.



Develop modeling capabilities for wide range of applications

ARL Facilities and Capabilities Available to Support Collaborative Research

- **Provides access to HPC resources**
- **Allows access to COTS/GOTS software provided on HPC and ARL systems**
- **Recent results presented for electromagnetomechanics comprise two reports:**
  - "A Convective Coordinate Approach to Continuum Mechanics with Application to Electrodynamics," ARL-TR-6298, January, 2013.
  - "On the Proper Formulation of Maxwellian Electrodynamics for Continuum Mechanics," Continuum Mechanics and Thermodynamics, Volume 26, Issue 3 (2014), Page 387-401
- **ARL researchers have extensive expertise in CEM/CSM modeling and software development**



$$d^i \doteq \epsilon_0 \left(\delta^{ij} e_j\right) + p^i$$
$$\tilde{d}^{\tilde{m}} = \epsilon_0 g^{\prime\prime\prime\prime} \left(e_{\tilde{i}} + \sqrt{g}\, \epsilon_{\tilde{i}\tilde{j}\tilde{k}} \psi^J b^{\prime}\right) + \tilde{p}^{\tilde{m}}$$

Analytical framework for coupling Maxwell's Equations with deformation

Complementary Expertise / Facilities / Capabilities Sought in Collaboration

- **Electroactive materials requires development of sophisticated multiscale material models that are consistent with temporally disparate multiphysical fields (electromagnetic and mechanical)**
- **Requires cross-disciplinary skills in solid mechanics/electromagnetics/physics and expertise in CSM/CEM**
- **Verification and validation of theory requires comparison with carefully conducted Kolsky bar, plate impact & other experiments which are specially calibrated to simultaneously measure transient electromagnetic and mechanical fields**