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# Coupling of thermomechanics with electromagnetism in FEniCS

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# Thermomechanics and electromagnetism

## Challenges in theory and implementation

- Coupling of electromagnetism and thermomechanics, Abraham–Minkowski debate
- Thermodynamically sound derivation of all constitutive equations using Minkowski momentum
- Balances of mass, momentum, energy, electric charge, and Faraday law, jump conditions

# Thermomechanics and electromagnetism

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- Balances of mass, momentum, energy, electric charge, and Faraday law, jump conditions
- Numerical method depends on the chosen gauge conditions
- Jump conditions to be implemented as terms in the variational formulation rather than element formulation
- Monolithic computation by using Lorenz gauge and jump conditions

# Implementation

Solving the weak form by using open-source packages:

- CAD in Salome
- Mesh via NetGen in Salome
- Code in Python
- Assembly, linearization, solving via FEM in space and FDM in time by FEniCS
- Visualization in ParaView

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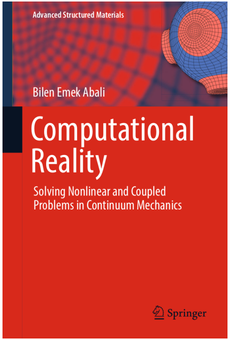
# Implementation

Simulation of multiphysics applications, FEM in space, FDM in time

- Elastostatics
- Nonlinear elasticity
- Plasticity
- Linear and nonlinear fluid dynamics
- Fluid-structure interaction
- Thermomechanics
- Electromagnetism
- Thermoelectric coupling
- Piezoelectricity
- Magnetohydrodynamics



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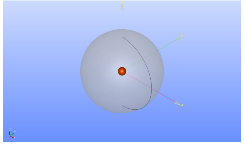
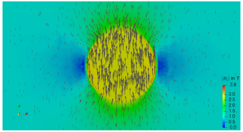
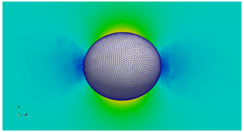
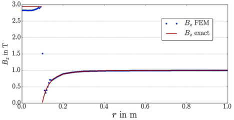
# Verification of the method

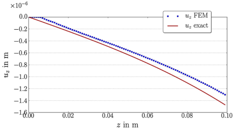
- Thermodynamically sound derivation of all constitutive equations in electromagnetism and thermomechanics
- Computation of displacement, $\boldsymbol{u}$, and magnetic potential, $\boldsymbol{A}$, such that magnetic flux, $\boldsymbol{B}$
- Analytical solution for verifying the novel numerical implementation using Lorenz gauge and jump conditions

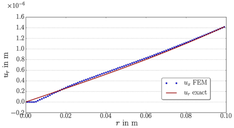






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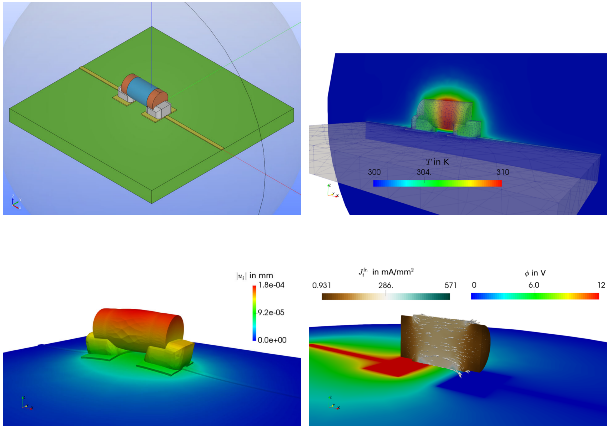
# Multiphysics in electronics, transistor on a board

- Coupled constitutive equations in electromagnetism and thermomechanics
- Monolithic computation of displacement, $\boldsymbol{u}$, temperature, $T$, electric potential, $\phi$, magnetic potential, $\boldsymbol{A}$
- Realistic Mini-MELF geometry and comparison to reduced order models

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# Thermal damage in lightning

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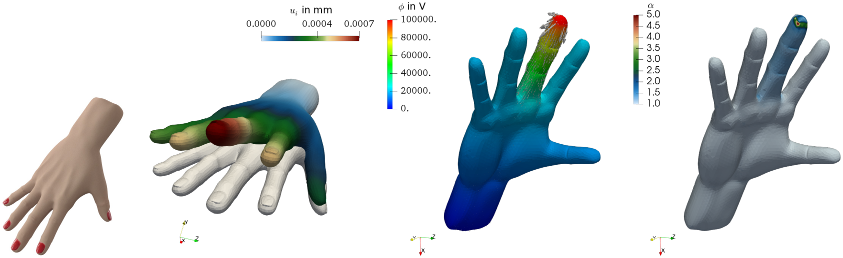


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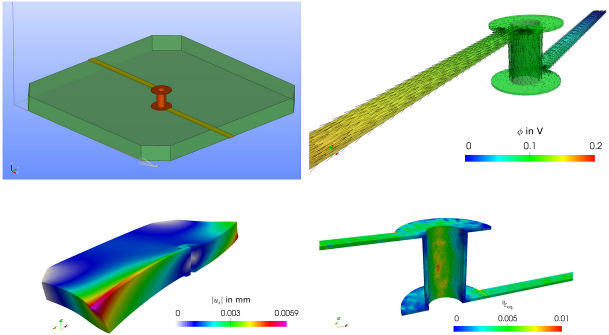
# Lifetime estimation in fatigue crack growth

- Plasticity, thermodynamics, and electromagnetism by using experimentally determined material parameters
- Experimental validation of results
- Coffin–Manson type fatigue related damage by using accumulated plastic strain





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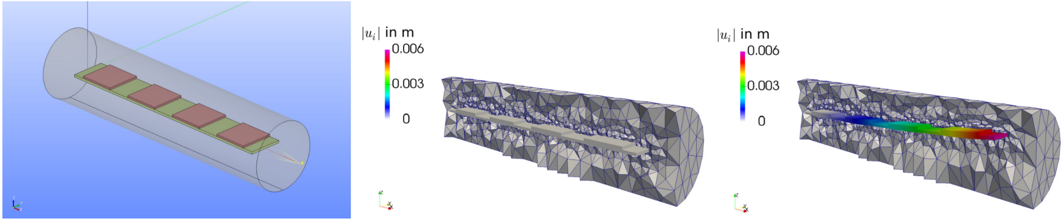
# Piezoceramic fan under large displacement

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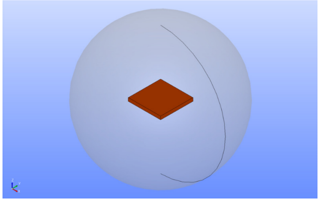
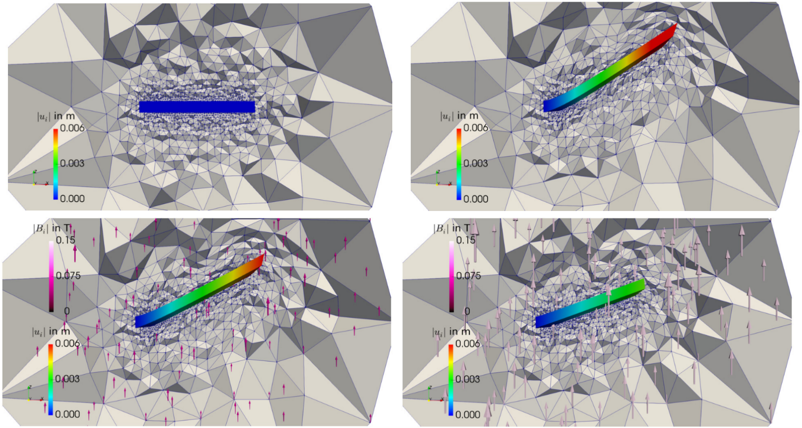
# Magnetorheological elastomer transducer



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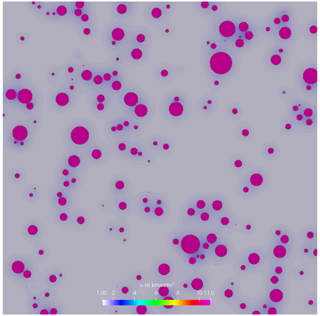
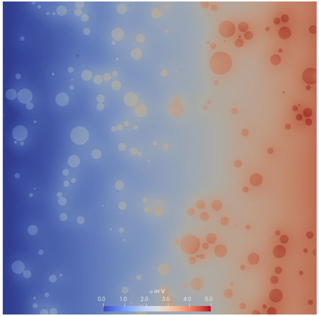
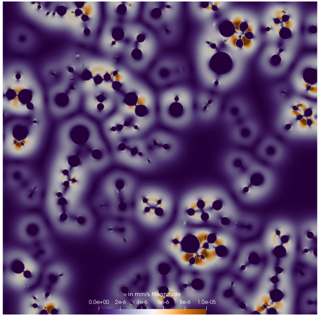
# Multiphysics in batteries, microscale computations

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# What computations we can do?

- Solving coupled and nonlinear partial differential equations
- Thermomechanics and electromagnetism in solids and mixtures
- Reversible phenomena
  - Piezoelectricity
  - Pyroelectricity
  - Magnetothermal coupling
  - Electromagnetic coupling
- Irreversible phenomena
  - Thermoelectric coupling (Peltier elements)
  - Plasticity and damage

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*Thanks a lot!*

http://bilenemek.abali.org