A FEM Study of displacement sensor based on L-L Magnetostrictive/Piezoelectric block magnetoelectric composite material

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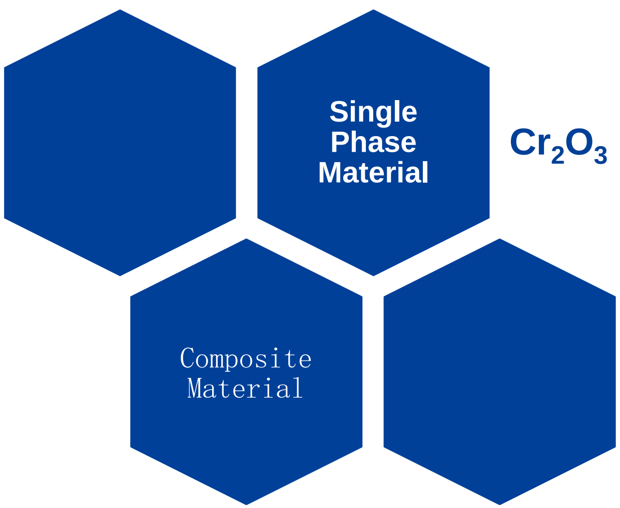
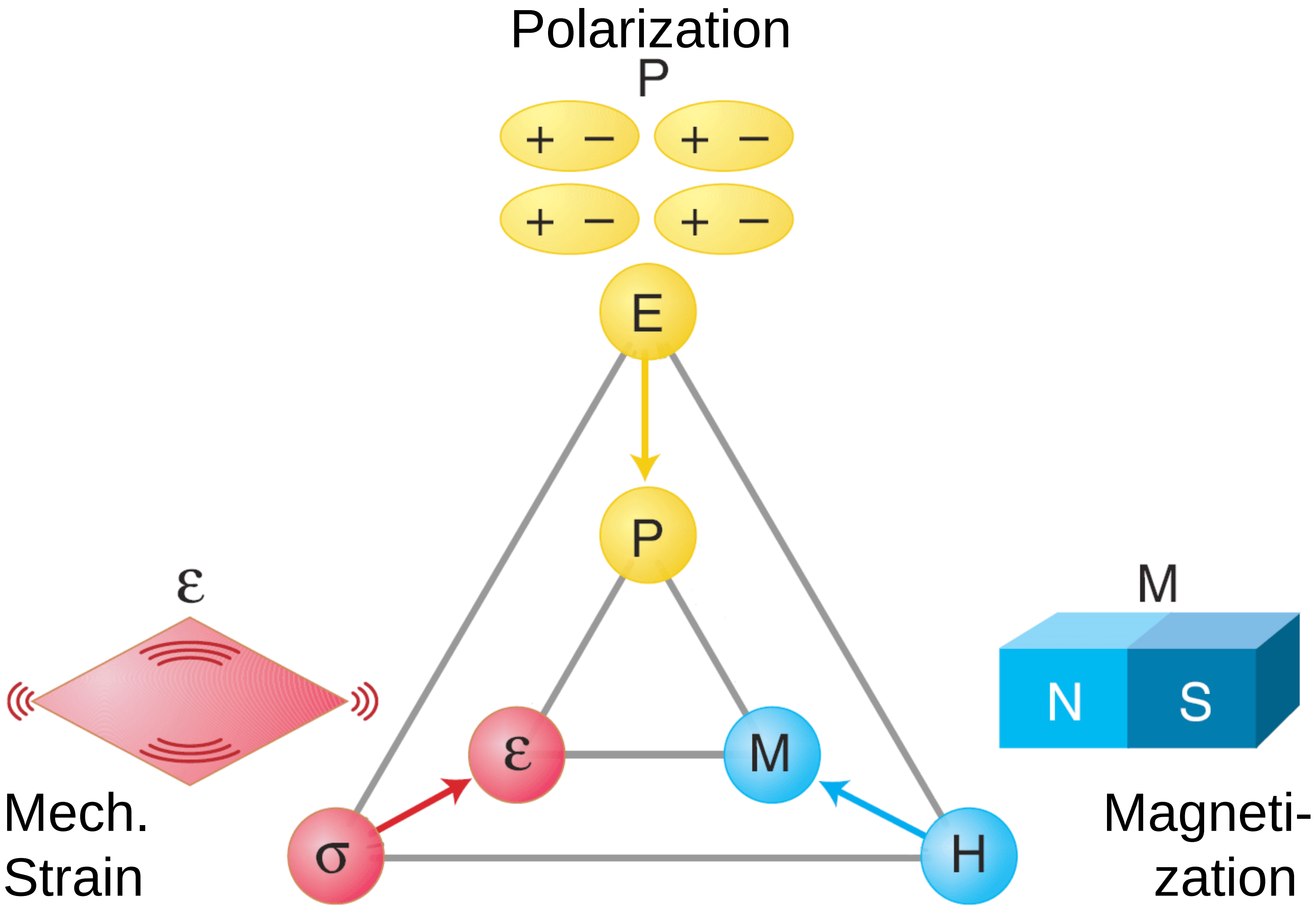
Contents

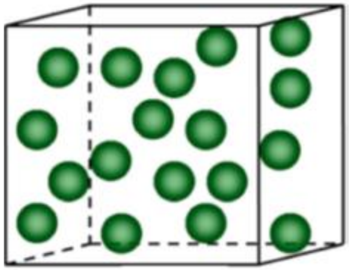
Introduction

- **Magnetoelectric effect (ME)** is the phenomenon of inducing magnetic (electric) polarization by applying an external electric (magnetic) field.

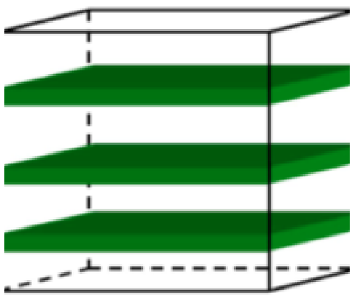



Polarization
P
+ −
+ −
+ −
+ −
E
P
ε
σ
ε
M
H
M
N
S
Mech.
Strain
Magneti-
zation

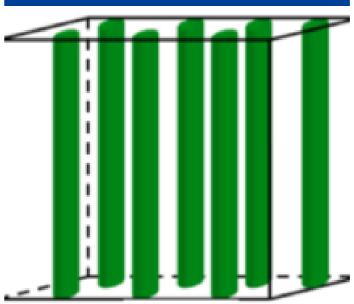
0−3 Type



2−2 Type



1−3 Type



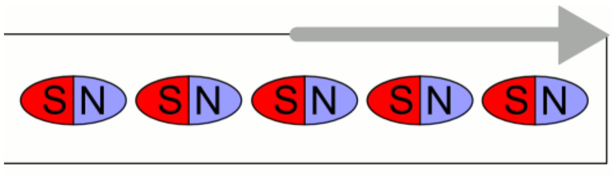
0 for particle
1 for fiber
2 for layer
3 for matrix

Product Property:

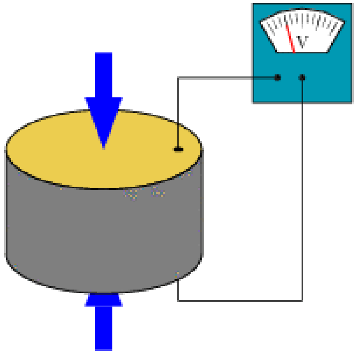
$$ME_H effect = \frac{magnetic}{mechanical} \times \frac{mechanical}{electric}$$

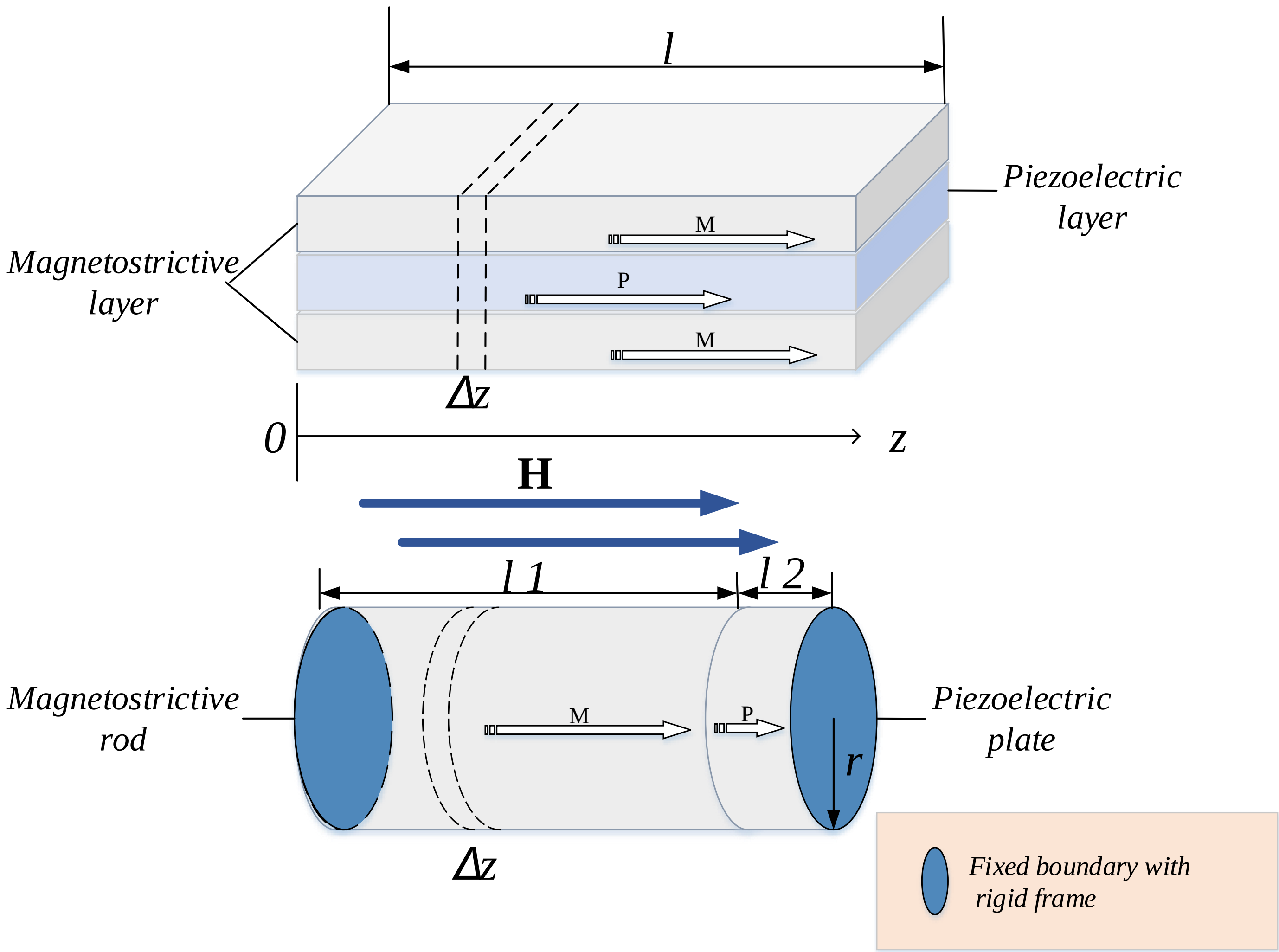
$$ME_E effect = \frac{electric}{mechanical} \times \frac{mechanical}{magnetic}$$

- **Magnetostrictive effect** is a property of ferromagnetic materials that causes them to change their shape or dimensions during the process of magnetization.



- **Piezoelectric effect** is the ability of certain materials to generate an electric charge in response to applied mechanical stress.




l
Piezoelectric layer
M
P
M
Magnetostrictive layer
Δz
0
z
H
l 1
l 2
Magnetostrictive rod
M
P
r
Piezoelectric plate
Δz
Fixed boundary with rigid frame

Modelling

- **Magnetostrictive nonlinear constitutive equation**

$$\varepsilon_i = \frac{3}{2}\lambda_s\left(\left(\frac{\mathrm{m}_i}{M_i}\right)^2 - \frac{1}{3}\right)$$

$$\varepsilon_{\parallel} = \lambda_s\left(\frac{M}{M_s}\right)^2, \varepsilon_{\perp} = -\frac{\lambda_s}{2}\left(\frac{M}{M_s}\right)^2$$

$$H_e = H + \alpha M + H_\sigma$$

$$\sigma = E\left[\varepsilon - \lambda(\sigma, \mathrm{H})\right]$$

$$B = \mu_0 H + \mu_0 M(\sigma, \mathrm{H})$$

$$\varepsilon_x = -\frac{\lambda_s}{2}\left(\frac{M_x}{M_s}\right)^2, \varepsilon_y = -\frac{\lambda_s}{2}\left(\frac{M_y}{M_s}\right)^2, \varepsilon_z = \lambda_s\left(\frac{M_z}{M_s}\right)^2$$

Modelling

- **Piezoelectric linear constitutive equation**

$$\sigma_e = c_e \varepsilon_e - eE$$

$$D = e^T \varepsilon_e + \kappa E$$

Implementation with COMSOL

SJTU

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- Corrosion Module
- Electrochemistry Module

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- ECAD Import Module
- LiveLink™ for Inventor®
- LiveLink™ for Revit®
- LiveLink™ for PTC® Pro/ENGINEER®
- File Import for CATIA® V5
- LiveLink™ for Excel®
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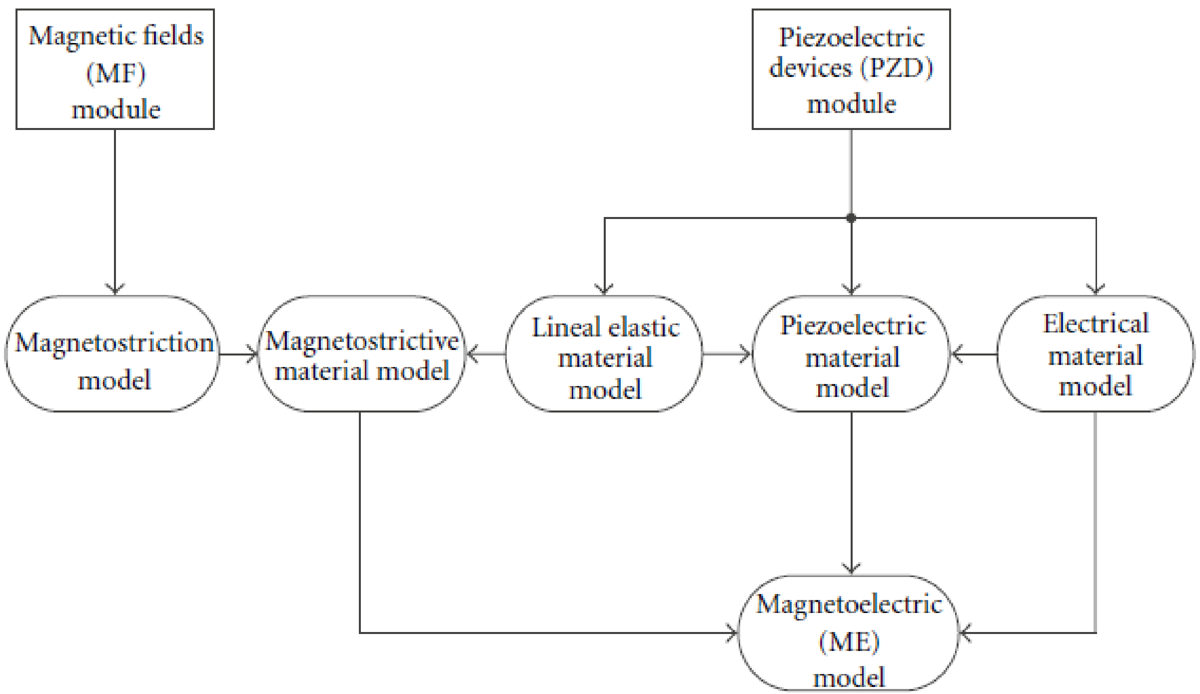
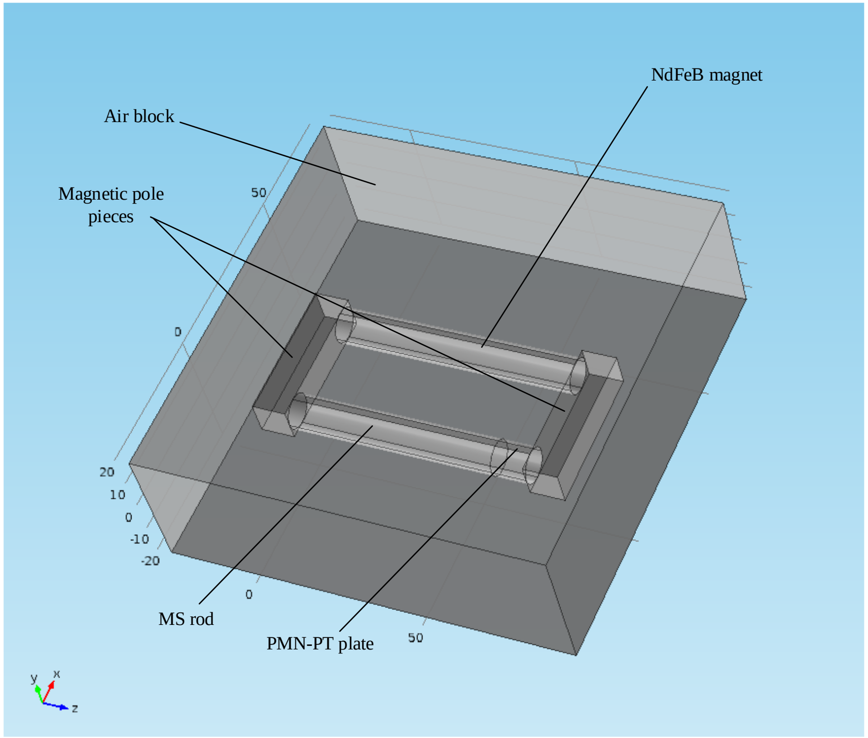
- LiveLink™ for SOLIDWORKS®
- LiveLink™ for AutoCAD®
- LiveLink™ for PTC® Creo® Parametric™
- LiveLink™ for Solid Edge®

Implementation with COMSOL



Implementation with COMSOL

- **Geometry**



Implementation with COMSOL

- **Realization of PZT material model**
  - The linear constitutive equations for piezoelectric material

$$s - S_0 = c_E \cdot (\varepsilon - \varepsilon_0) - \mathrm{e}^T \cdot E$$

$$D = D_r + e \cdot (\varepsilon - \varepsilon_0) + \kappa \cdot E$$

  - For solid mechanics, the elastic relations

$$\varepsilon = \frac{1}{2}[(\nabla \mathrm{u})^T + \nabla \mathrm{u}]$$

$$\sigma = s$$

$$-\nabla \cdot \sigma = F_V$$

  - For electrostatics, the electrical relations:

$$\nabla \cdot D = \rho_V$$

$$E = -\nabla V$$

Implementation with COMSOL

- **Realization of magnetostrictive material model**
  - The elastic relations

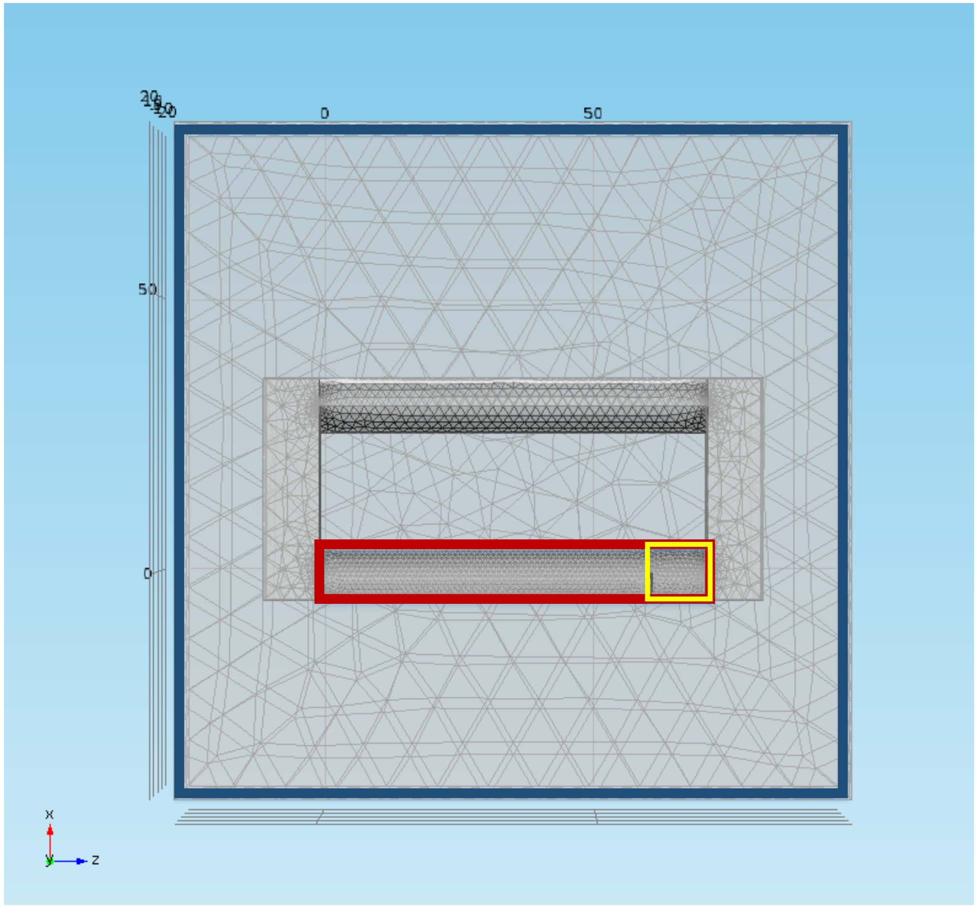
$$\sigma = c_E \cdot (\varepsilon - \varepsilon_0)$$

$$\varepsilon_0 = diag\left(\frac{-\lambda}{2}, \frac{-\lambda}{2}, \frac{-\lambda}{2}\right)$$

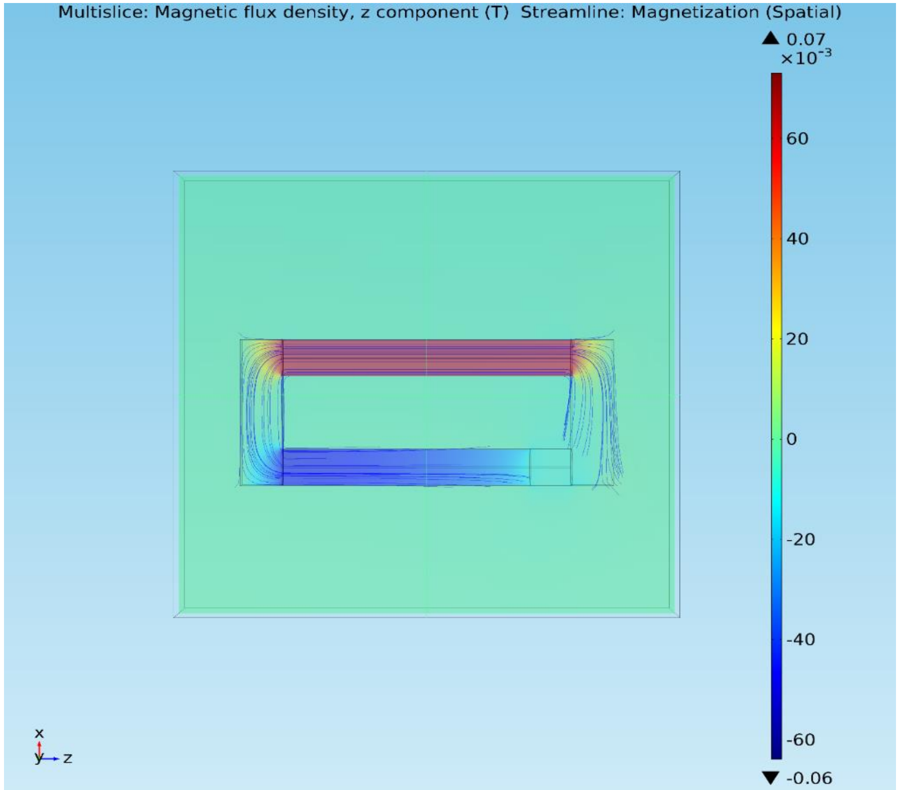
Properties	PMN–28PT
ρ, kg m^{-3}	8060
c^E_{11},GPa	115.4
c^E_{12},GPa	103.4
c^E_{13},GPa	102.6
c^E_{33},GPa	114.1
c^E_{44},GPa	68.9
c^E_{66},GPa	65.8
$\varepsilon^S_{11}/\varepsilon_0$	925
$\varepsilon^S_{33}/\varepsilon_0$	813
e_{13},C m^{-2}	-3.4
e_{15},C m^{-2}	10.1
e_{33},C m^{-2}	20.5

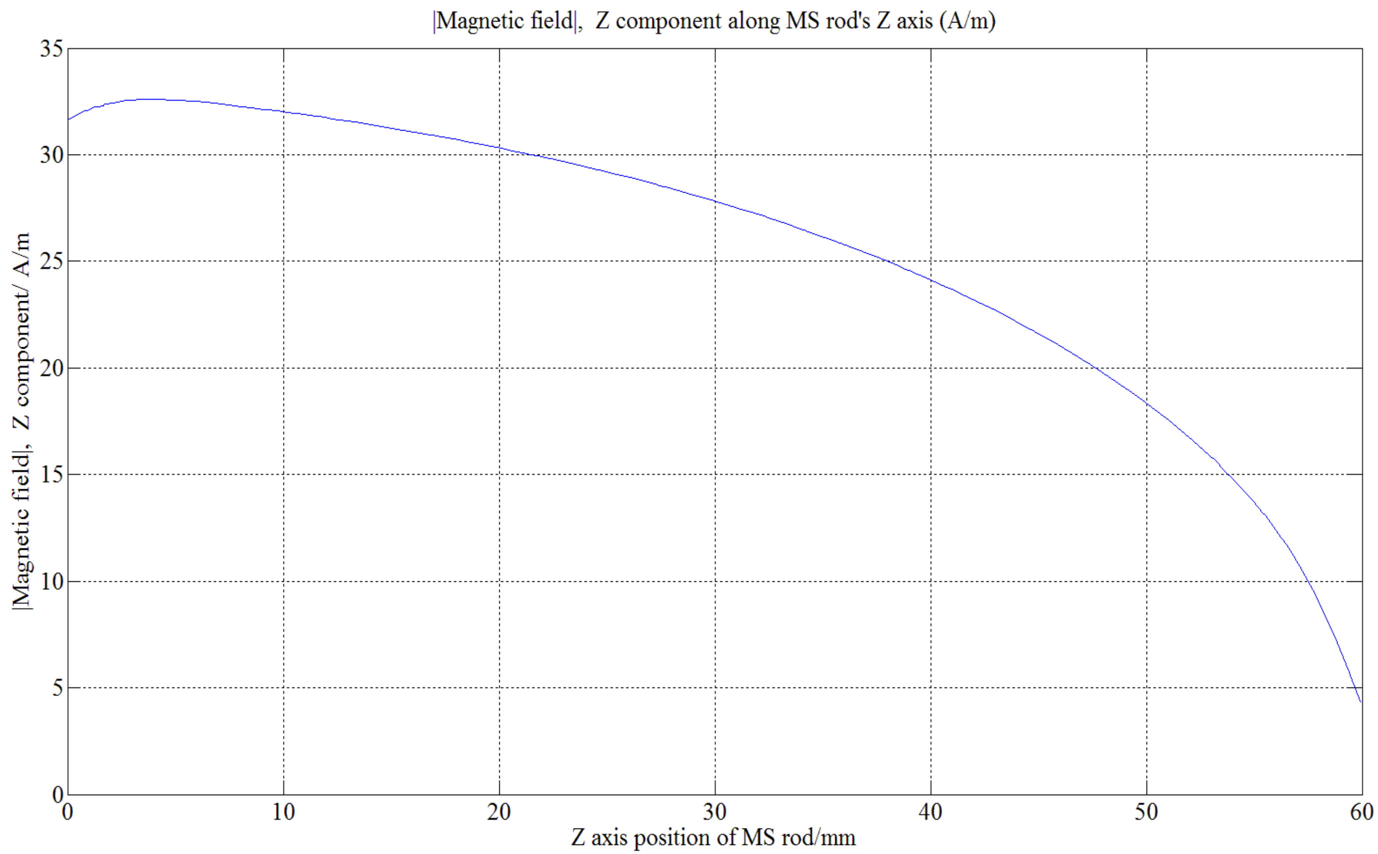
Implementation with COMSOL

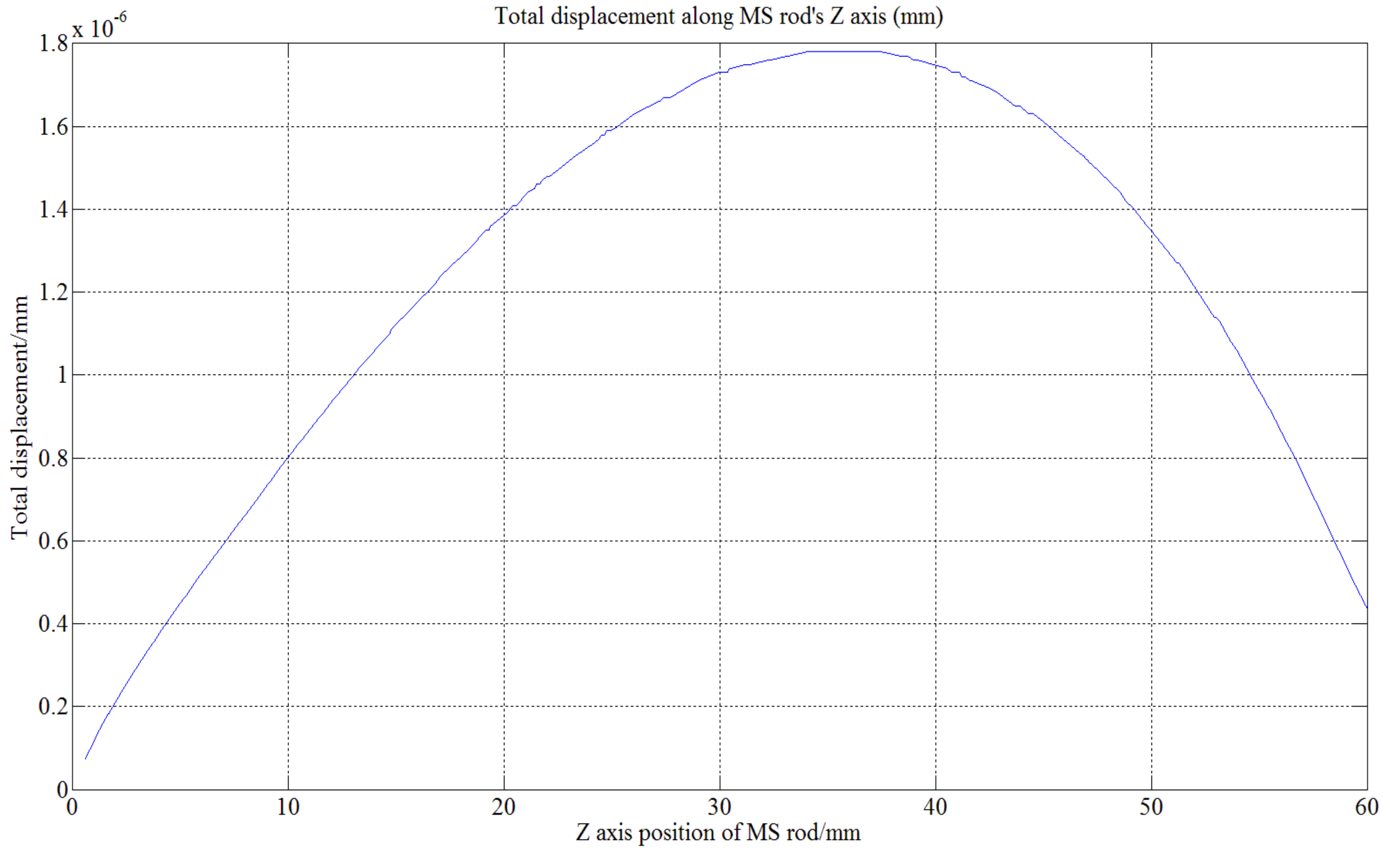
- **Boundary conditions & Mesh**

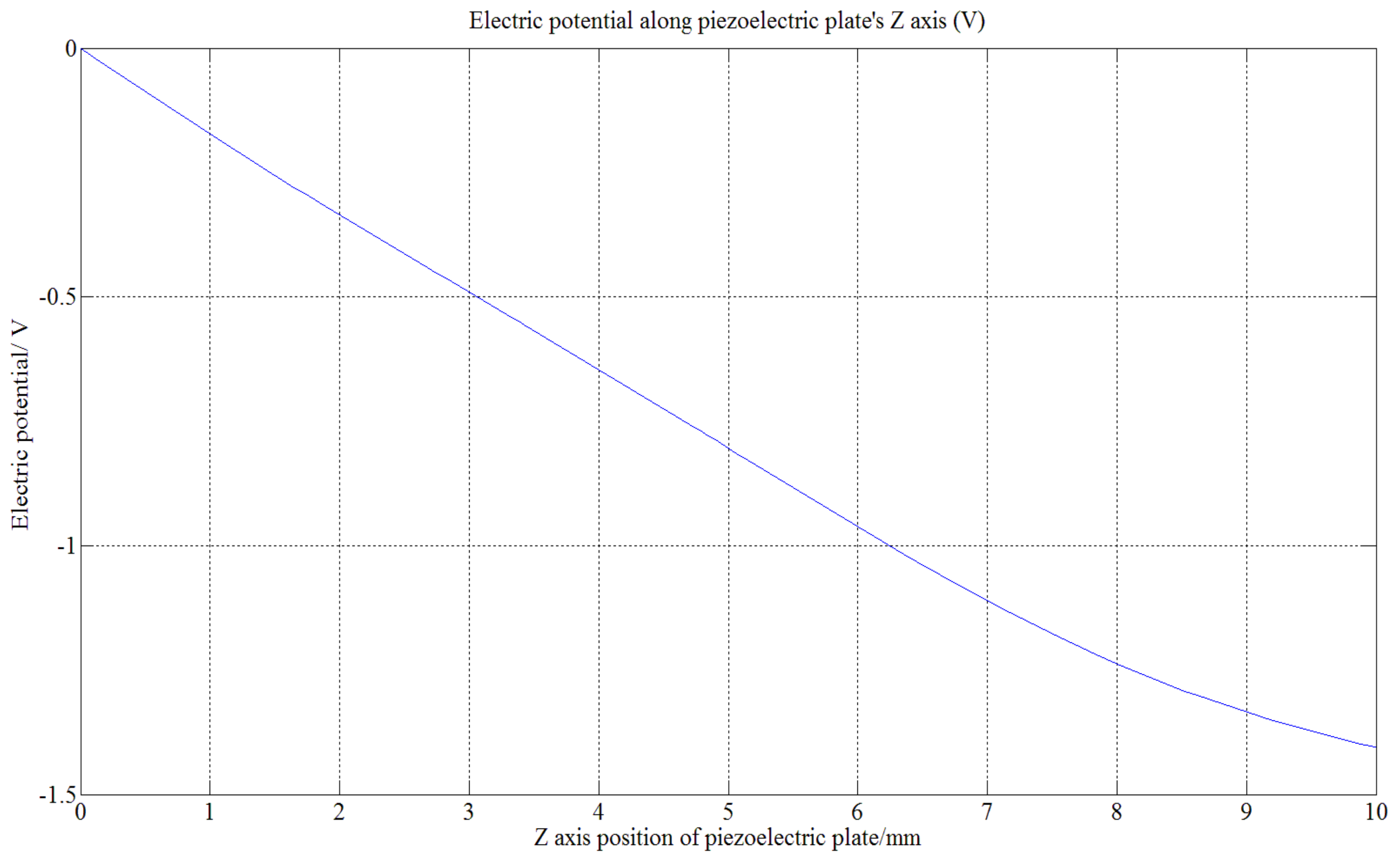


Results


Multislice: Magnetic flux density, z component (T) Streamline: Magnetization (Spatial)
▲ 0.07
×10^-3
60
40
20
0
-20
-40
-60
▼ -0.06
x
y
z


|Magnetic field|, Z component along MS rod's Z axis (A/m)
|Magnetic field|, Z component/ A/m
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
Z axis position of MS rod/mm


Total displacement along MS rod's Z axis (mm)
x 10^-6
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Total displacement/mm
0
10
20
30
40
50
60
Z axis position of MS rod/mm


Electric potential along piezoelectric plate's Z axis (V)
Electric potential/ V
0
-0.5
-1
-1.5
0
1
2
3
4
5
6
7
8
9
10
Z axis position of piezoelectric plate/mm

Thanks.