Simulation of Nuclear Radiation Based Energy Harvesting Device using Piezoelectric Transducer

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Excerpt from the Proceedings of the 2011 COMSOL Conference in Bangalore

INTRODUCTION

Sources of power supply

Battery power

- Limited lifetime
- Rechargeable/replacement/disposal
- Cost

Renewable Energy Harvesters

- Unlimited lifetime
- Maintenance free operation
- Eco friendly
- Low output power

Energy Extraction Methods

Conversion techniques

- **Electrostatic (capacitive).**
- **Piezo electric**.
- Electromagnetic (inductive).
- Thermal.
- Piezo resistivity.

β Particles Energy Conversion

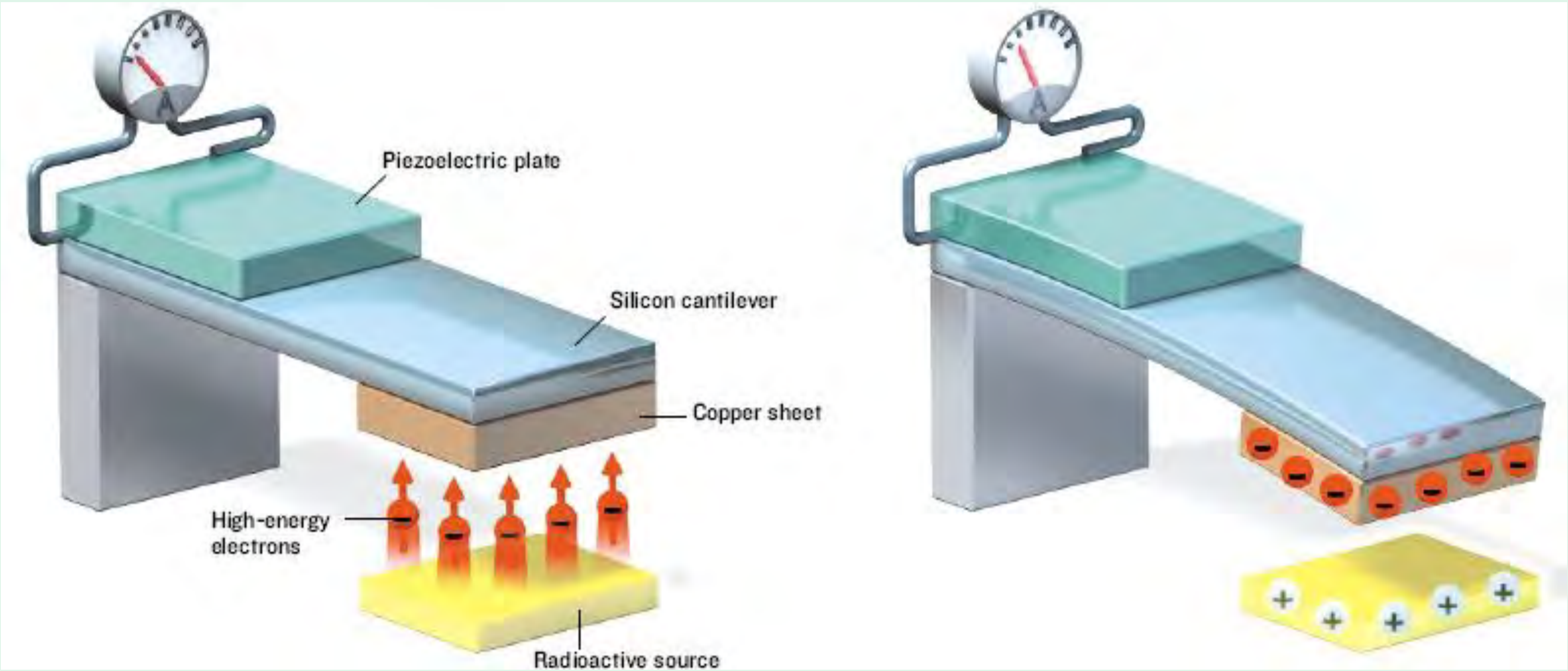


Fig 1. Beta particles (high-energy electrons) fly spontaneously from the radioactive source and hit the copper sheet, where they accumulate.

Fig 2. Electrostatic attraction between the copper sheet and the radioactive source bends the silicon cantilever and the piezoelectric plate on top of it.

Fig 3. When the cantilever bends to the point where the copper sheet touches the radioactive source, the electrons flow back to it, and the attractive force ceases

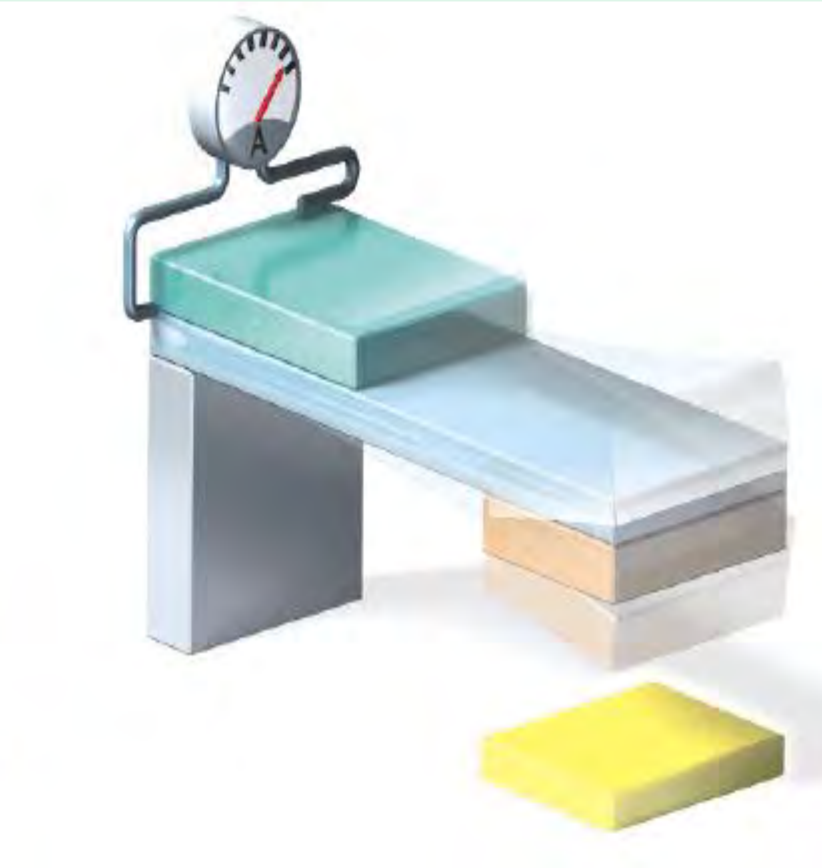


Fig 4. The cantilever then oscillates, and the mechanical stress in the piezoelectric plate creates an imbalance in its charge distribution, resulting in an electric current

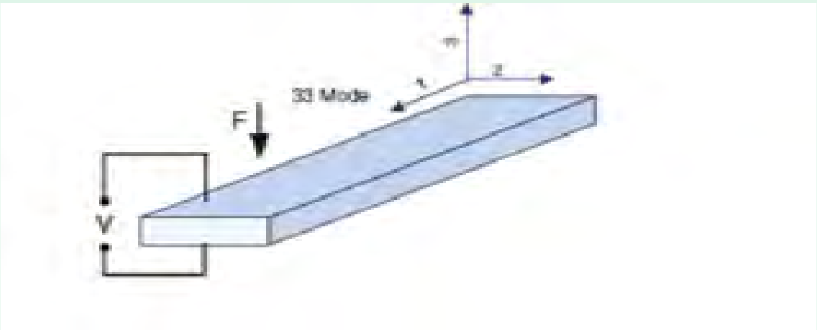
Use of COMSOL Multyphysics

Application modes:

Piezoelectric: mechanical / electrical behavior

- generated charge / electrical potential
- vertical vibrations application

Electrostatic: electrostatic force /electric field behavior



GEOMETRY

3D cantilever

– length L = 500µm*;*

– width w = 100 µm*;*

– copper thickness t_{copper}= 2 µm*;*

– piezoelectric layer thickness t_{ZnO} = 2 µm.

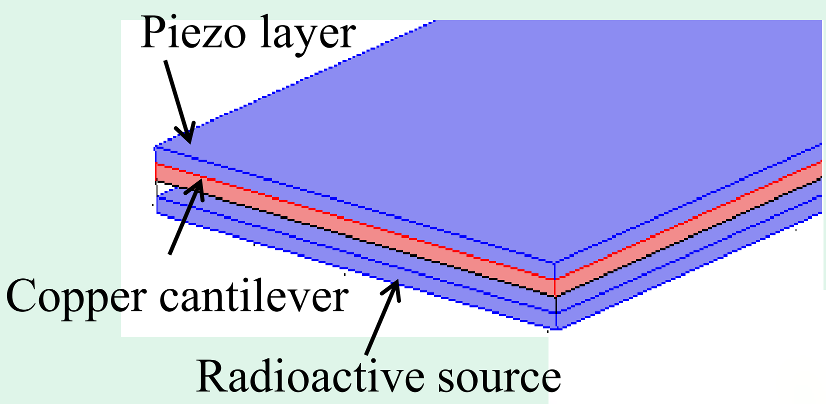
–air layer thickness t_{air}=2 µm.

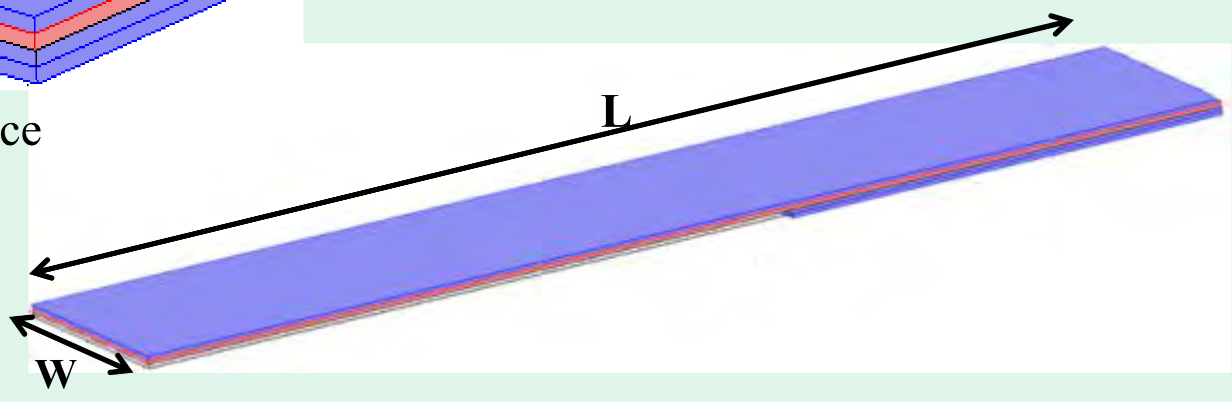
Radioactive source:

– length L = 200µm

– width w = 100 µm

– thickness t_{source}= 2 µm



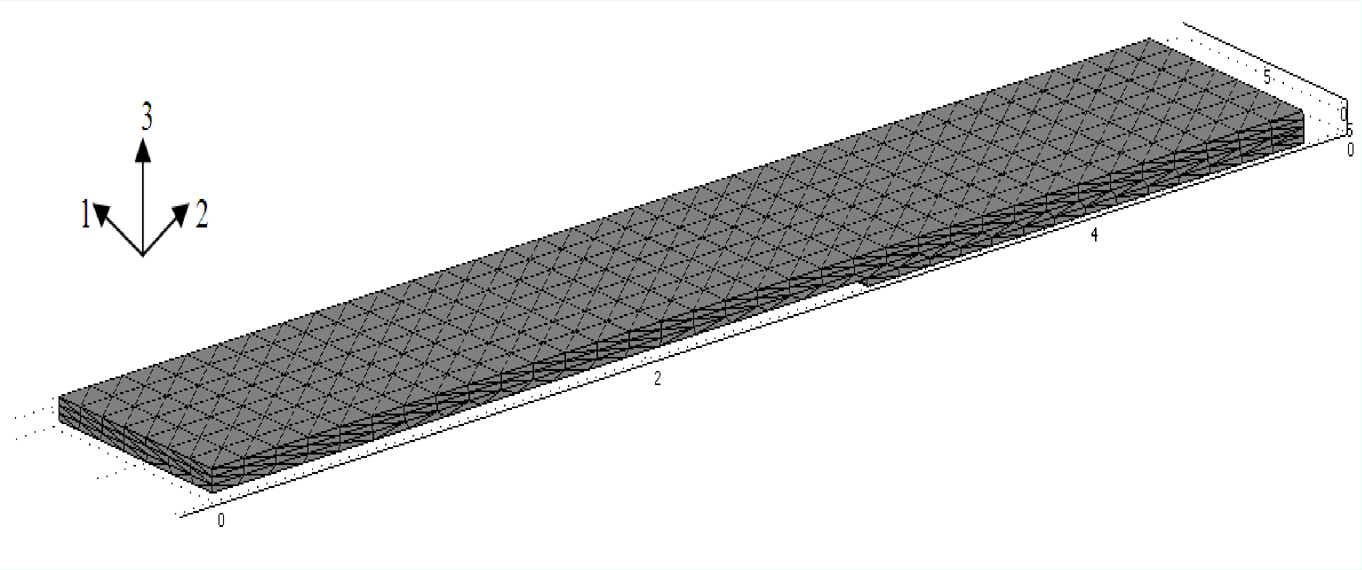


Meshing

Mapped mesh:

–finer mesh :piezo ,cantilever ,radioactive source layer

Mesh remaining free :air layer



Governing Equations

Piezoelectric layer

– strain-charge form

$$S = s^E T + dE$$

$$D = \varepsilon^T E + dT$$

S = *mechanical strain*
T = *mechanical stress [N/m²]*
s^E = *elastic compliance [Pa⁻¹]*
d = *piezoelectric coefficient [C/N]*
D = *electric displacement [C/m²]*
E = *electric field [V/m]*
ε^T = dielectric permittivity [F/ m]

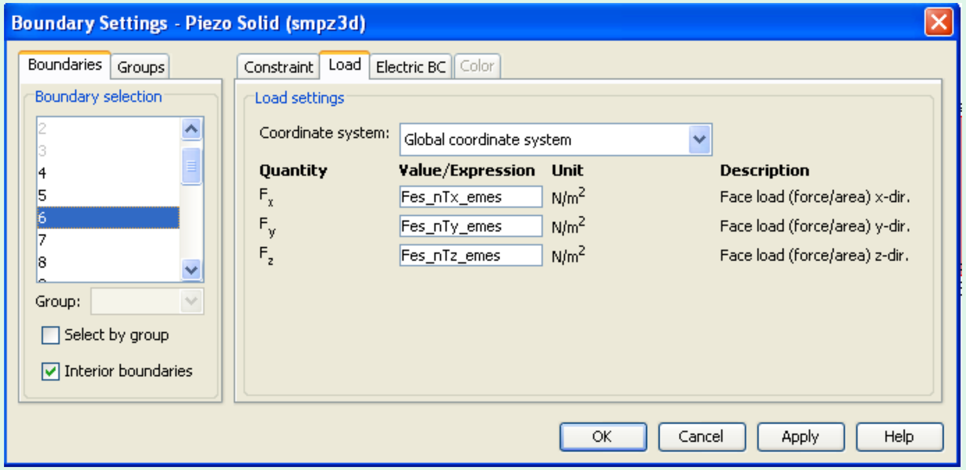
radio active source

– electrostatic potential

$$V = \frac{q}{4\pi r\varepsilon}$$

$$\rho = 5680 Kg / m^3$$

Subdomain and Boundary settings



Mechanical boundary conditions

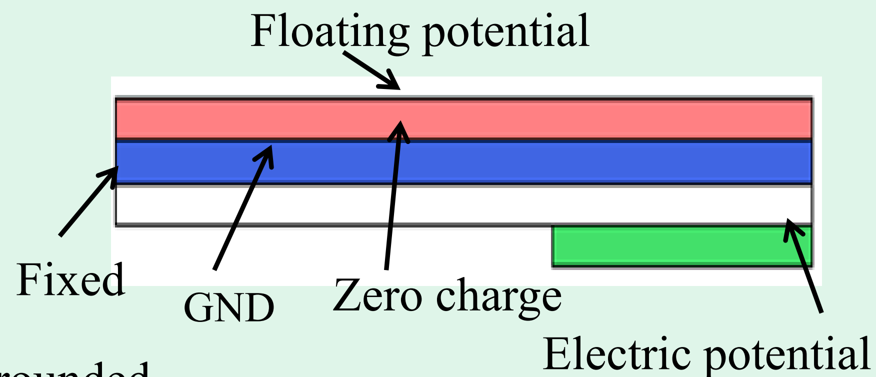
– fixed end

Electric boundary conditions(piezo solid)

– bottom surface: grounded

– upper surface: floating potential

– other surfaces: zero charge



Electrostatic boundary conditions

– bottom surface of copper cantilever : grounded

– upper surface of radio active source: electric potential

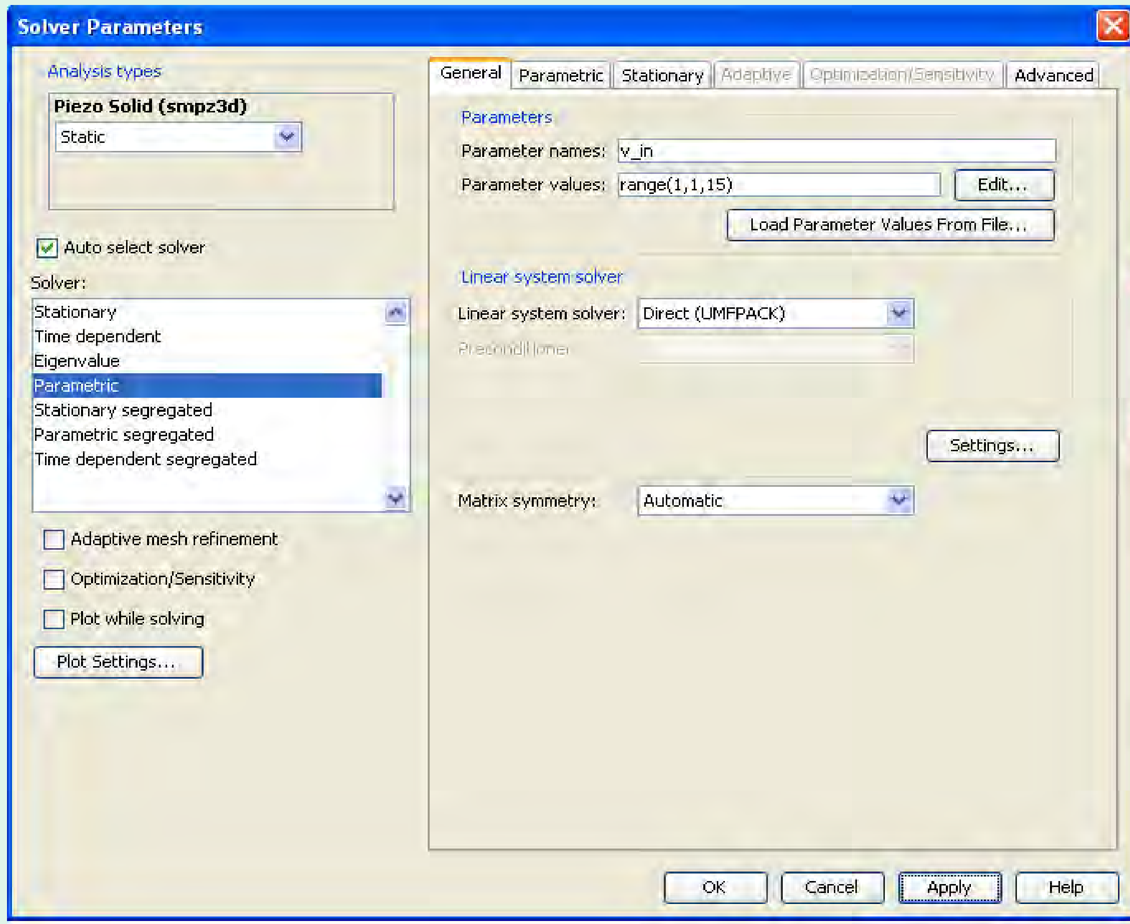
– other surfaces: zero charge

Solver Parameters

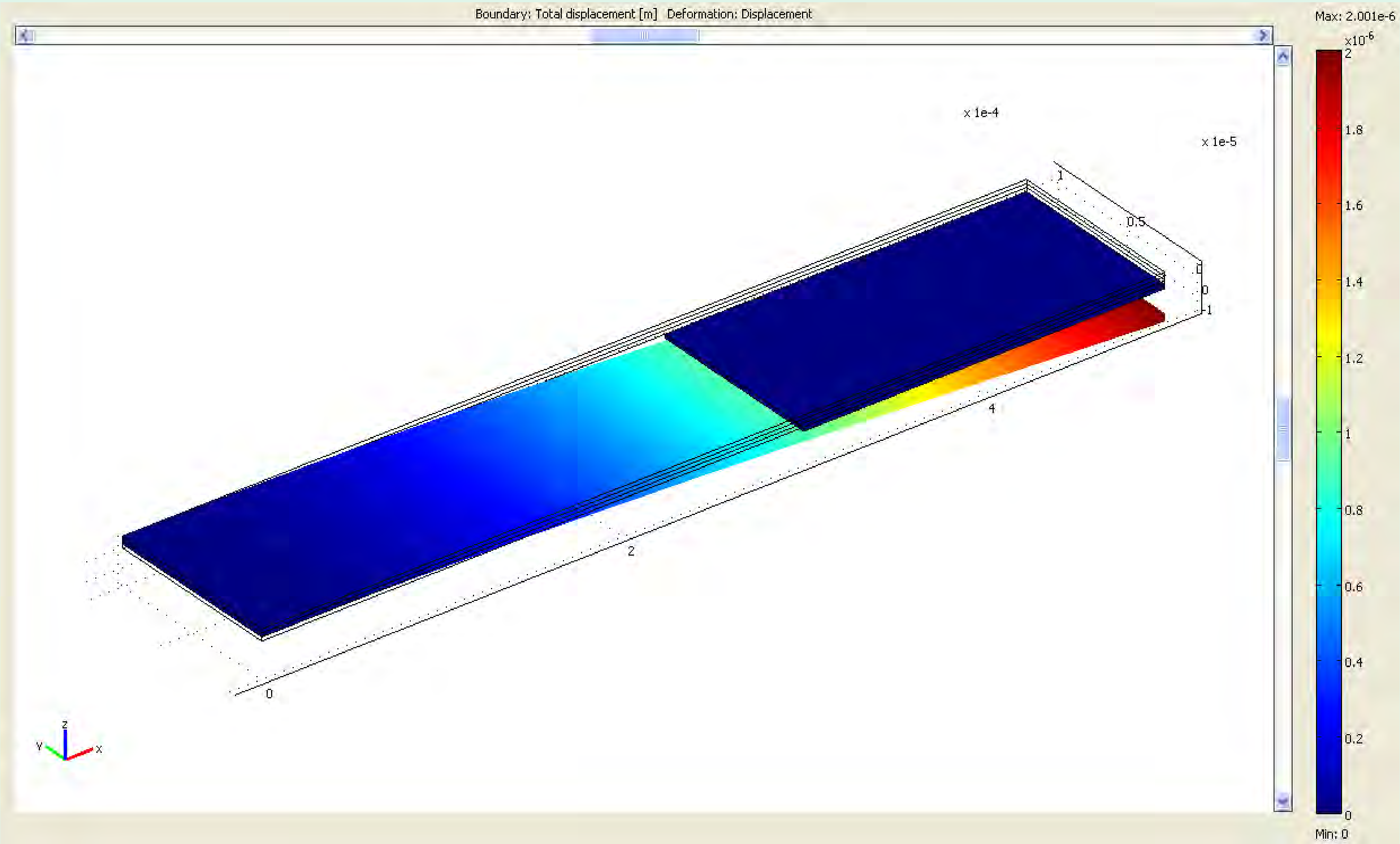
group 1: stationary solver

group 2:Parametric solver:

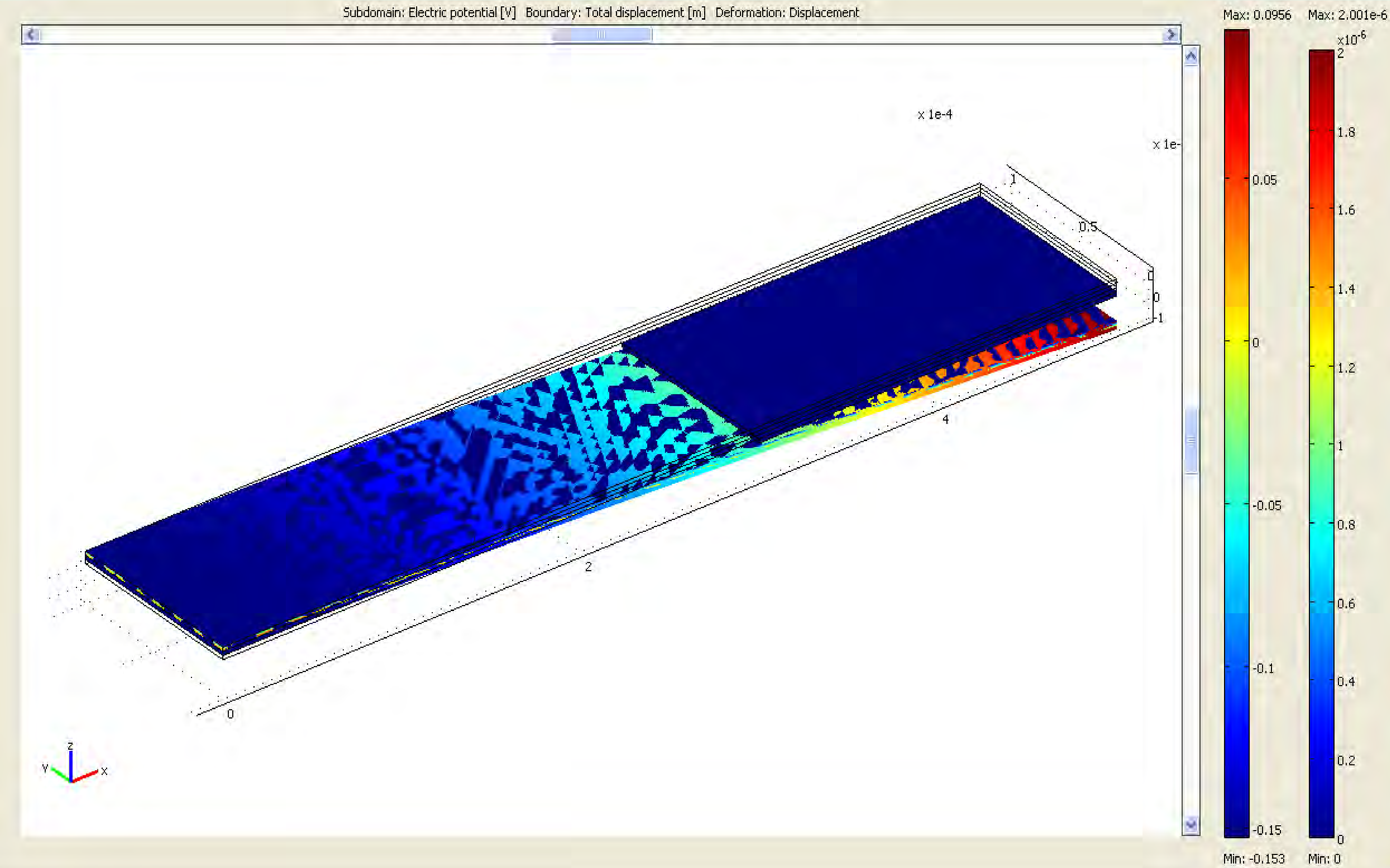
voltage v_in:1v ⟶15v



Simulation Results Z-Displacement



Voltage developed



Voltage developed

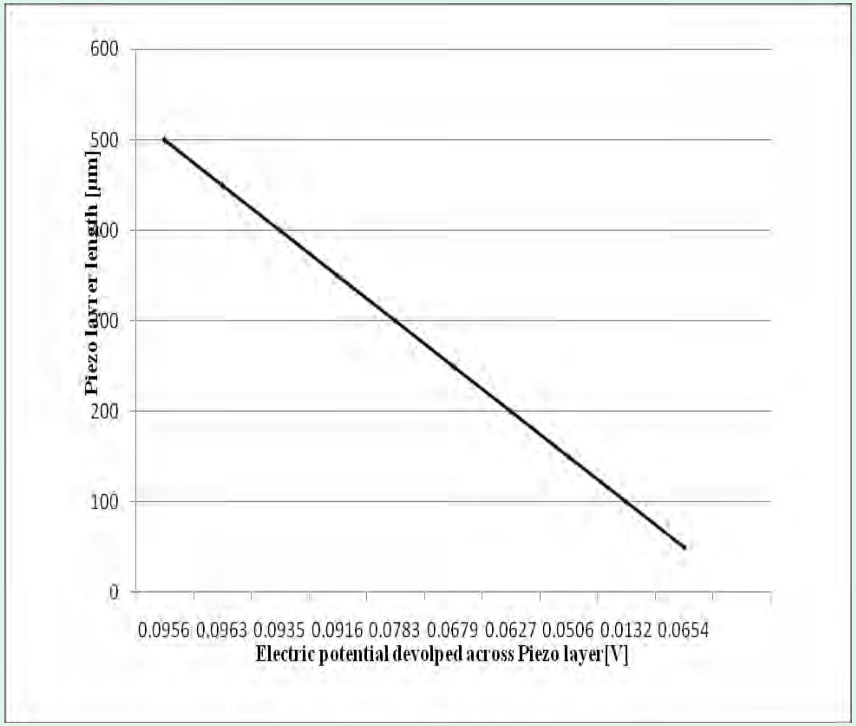
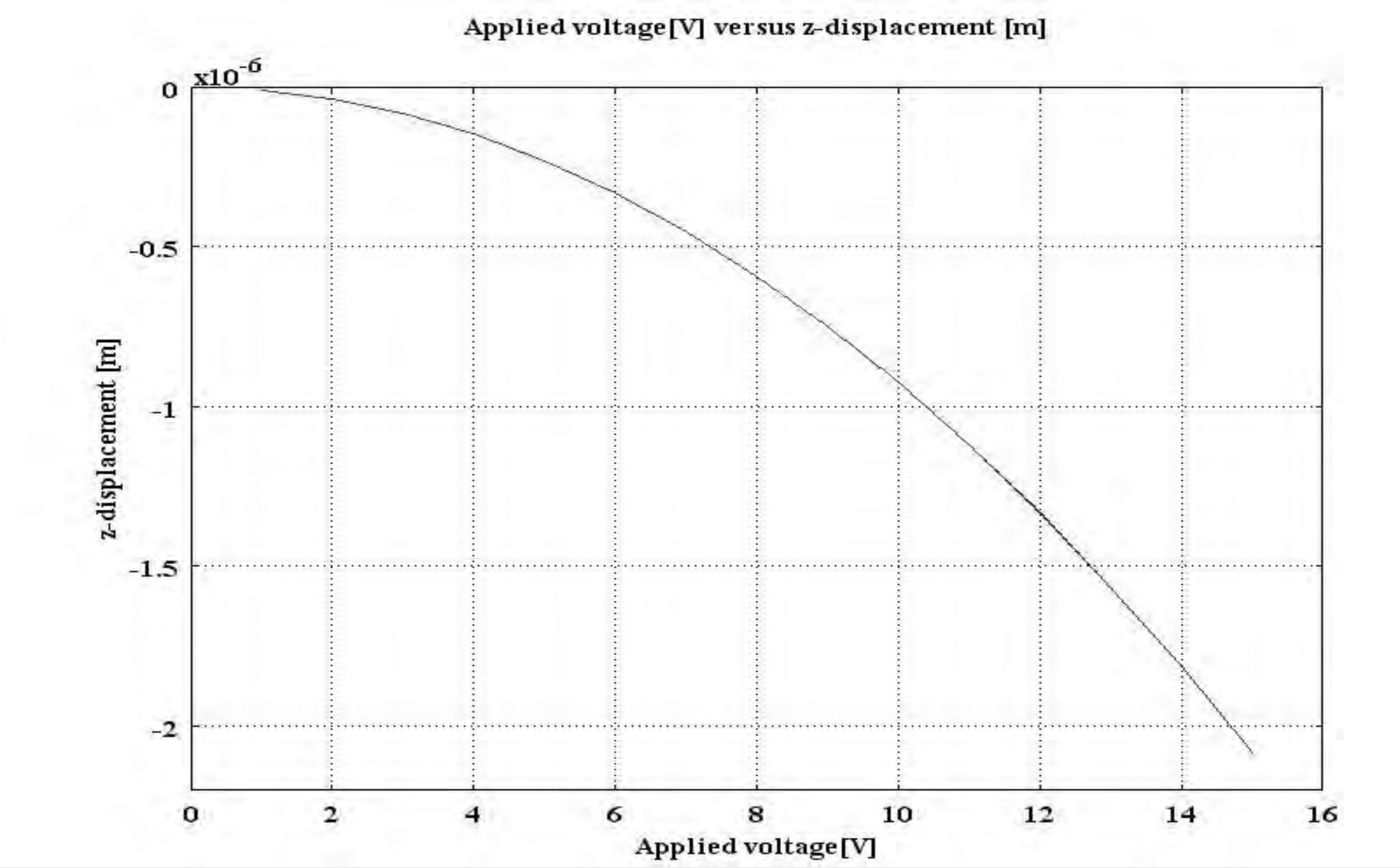


Figure : plot of electric potential developed versus length of piezo layer.

SL. no	Length (μm)	Voltage (V)	deflection (μm)
1.	500	0.0956	2.001
2.	450	0.0963	2.011
3.	400	0.0935	2.036
4.	350	0.0916	2.149
5.	300	0.0783	2.477
6.	250	0.0679	3.092
7.	200	0.0627	4.214
8.	150	0.0506	6.125
9.	100	0.0132	8.539
10.	50	0.0654	12.05

Table 1: Voltage developed across piezoelectric material and deflection observed at the tip (for a fixed length of micro cantilever and varying piezo length)

Plot of Applied voltage vs z-displacement



Conclusion

- An energy harvester based on piezoelectric self-reciprocating radioisotope powered cantilever was designed and simulated in Comsol MultiPhysics.
- This model can be used for future optimization of the generator design.
- Generated voltage can be increased by Geometry Optimization techniques using moving mesh application mode

References

1. Hui Li, Amit Lal, James Blanchard, Douglass Henderson, “Self reciprocating radioisotope powered cantilever”, journal of applied physis, volume 92, and no.2, 15 July 2002, pp-1122-1127.

2. Amit Lal & James Blanchard, “The Daintiest Dynamos”,IEEE Spectrum, sept.2004,pp-38-41.

3. Brian.D. Hahn. Daniel T.Valentine “essential Matlab for engineers and scientists”, pp-309-311.

4. Suyog N Jagtap and Roy Paily, “Geometry Optimization of a MEMS-based Energy Harvesting Device” Proceeding of the 2011 IEEE Students' Technology Symposium 14-16 January, 2011, IIT Kharagpur.

5. M. Guizzetti, V. Ferrari, D. Marioli and T. Zawada, “Thickness optimization of a piezoelectric converter for energy harvesting,” *Proceedings of the COMSOL Conference*, 2009

6. W. Liao and T.H.NG, “Sensitivity analysis and energy harvesting for a self powered piezoelectric sensor,” *Smart Structures Laboratory University of Hong Kong*, vol. 16.

7. Rajesh Duggirala, Ronald G. Polcawich, *Member, IEEE*, Madan Dubey, and Amit Lal, *Member, IEEE* “Radioisotope Thin-Film Fueled Microfabricated Reciprocating Electromechanical Power Generator” Journal of micromechanical systems, VOL. 17, NO. 4, AUGUST 2008

Thank you.