Modeling, Simulation and Optimization of Piezoelectric Bimorph Transducer For Broadband Vibration Energy Harvesting

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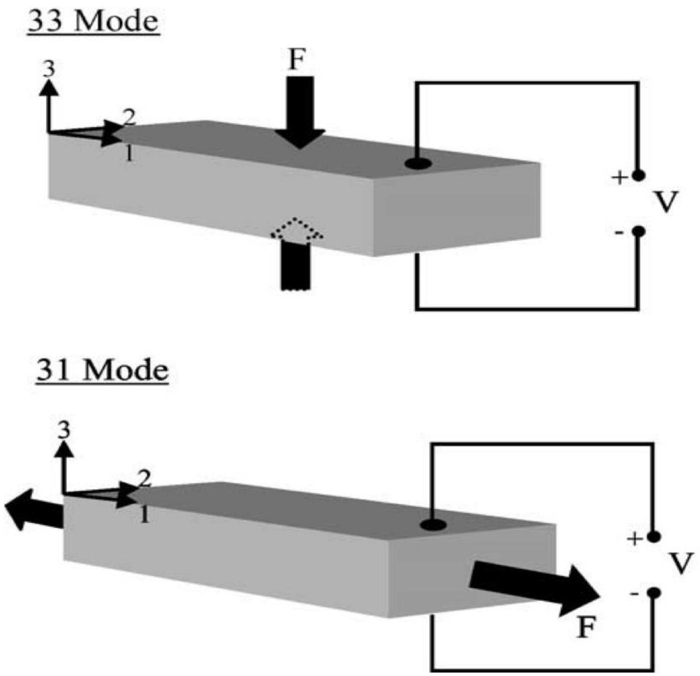
Research

- 1. Find the best beam geometry for best performance
- 2. Maximize Broadband response
- 3. Maximize power under natural vibration frequency by tuning external R

Operation mode



[8]Although the electrical/mechanical coupling for 31 mode is lower than for 33 mode, there is a key advantage to operating in 31 mode. The system is much more compliant, therefore larger strains can be produced with smaller input forces. Also, the resonant frequency is much lower. suitable for lower frequency energy harvesting applications.

Bimorph connection

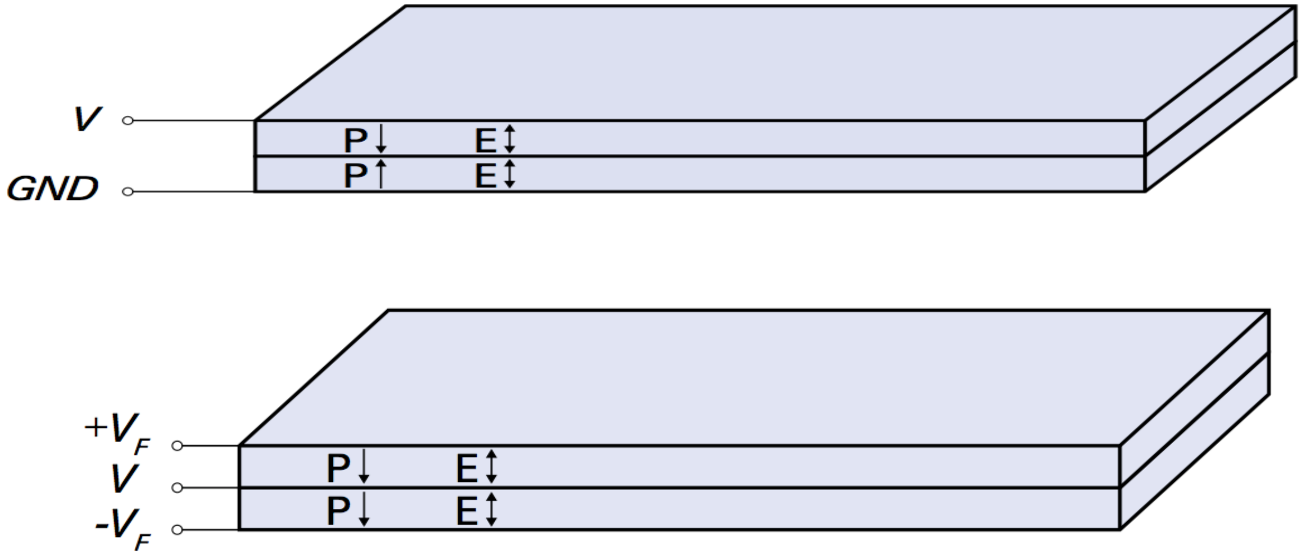
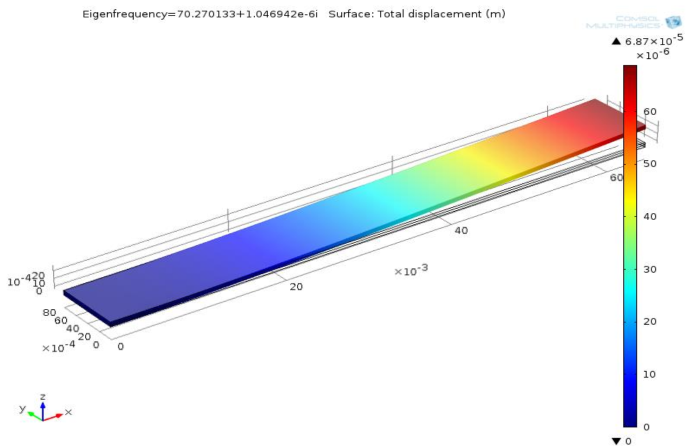


figure (upper) shows series connection ;figure (lower) shows parallel connection. series connection is simpler that parallel connection due to it only has two electrodes while parallel connection has 3 electrodes

We did not use one-layer beam because voltage cancels out on the surface of the beam

Boundary condition



Boundary load

Fixed constraint

Ground

Terminal (connect to AC circuit)

Piezoelectric material

Gravity

PZT-PZN material compositions

Sample 1:

$0.9\ (Pb(Zr_{0.52}\ Ti_{0.48})O_3) – 0.1(Pb(Zn_{1/3}\ Nb_{2/3})O_3)$

Sample2:

$0.9\ (Pb(Zr_{0.52}Ti_{0.48})O_3) – 0.1(Pb(Zn_{1/3}\ Nb_{2/3}\ )O_3)$

$+\ 2$ mol% MnO_2

Material property definition

k_{31}: electron-mechanical piezoelectric coupling factor $= \frac{E_e}{E_M}$

ε_{33} : dielectric constant

d_{31} : piezoelectric charge constant (C/N)

g_{31}: piezoelectric voltage constant(Vm/N)

v: poisons ratio (negative ratio of transverse strain to axial strain)

tanδ: dissipation factor. ratio of active power to reactive power

S_{11}: Compliance (Pa^{-1},inverse of stiffness)

PZT-PZN Material property

	k_{31}	ε_{33}	**Cp**(nF)	g_{31}(Vm/N)	**v**
Sample1	0.3101	7e-9	5.5	0.0129	0.34
Sample2	0.2995	4e-9	3.15	0.0151	0.35

PZT Material property

	d_{31}(C/N)	ρ (kg/m3)	d_{33}(pC/N)	ε_r	tanδ	S_{11} (Pa^{-1})
Sample1	8.62e-11	7850	290	757.735	0.00241	1.01e-11
Sample2	6.02e-11	7880	198	449.992	0.00572	1.15e-11

ε_0=8.85e-12 F/m

Conversion

- Mechanical Energy $W_M = F\,\Delta Z/2$
- Electrical Energy $W_E = Q^2/(2C_p)$
- $k_{33} = \sqrt{\frac{W_E}{W_M}} = \frac{V\sqrt{C_p}}{\sqrt{F\Delta Z}} = 0.42$
- $\varepsilon_{33}^T = 6.71e\text{-}9$ F/m $\varepsilon = \frac{\varepsilon_o A}{\Delta C d} + 1$ [16]
- $d_{33} = 2.9e\text{-}10$ C/N (d_{33} meter)
- $S_{33} = \frac{d_{33}^2}{k_{33}^2 \varepsilon_{33}^T} = 1.07e\text{-}11\,Pa^{-1}$

Conversion of compliance matrix using material properties

Sample1

$S_{11}, S_{22} (Pa^{-1})$	$S_{13}, S_{31}, S_{32}, S_{23} (Pa^{-1})$	$S_{12}, S_{21} (Pa^{-1})$	$S_{33} (Pa^{-1})$	$S_{44}, S_{55} (Pa^{-1})$	$S_{66} (Pa^{-1})$
1.15e-11	-1.152e-11	$-3.91e$-12	1.07e-11	0	$1.518e$-11

Sample2:

$S_{11}, S_{22} (Pa^{-1})$	$S_{13}, S_{31}, S_{32}, S_{23} (Pa^{-1})$	$S_{12}, S_{21} (Pa^{-1})$	$S_{33} (Pa^{-1})$	$S_{44}, S_{55} (Pa^{-1})$	$S_{66} (Pa^{-1})$
1.01e-11	-1.013441935 e-11	$-3.535e$-12	1.578e-11	0	$1.313e$-11

Coupled equation(Strain-Charge)

Mechanical property and Electrical property are dependent on each other and can not be separated

$$D_i = d_{ijk}\ T_{jk} + \varepsilon_{ij}\ E_j$$

$$S_{ij} = s_{ijkl} T_{kl} + d^T\ E_k$$

D: electrical charge displacement
d_{ijk}: piezoelectric moduli
T: stress
ε: dielectric constant (F/m)
E: electric field (v/m)

S: mechanical strain
s: compliance

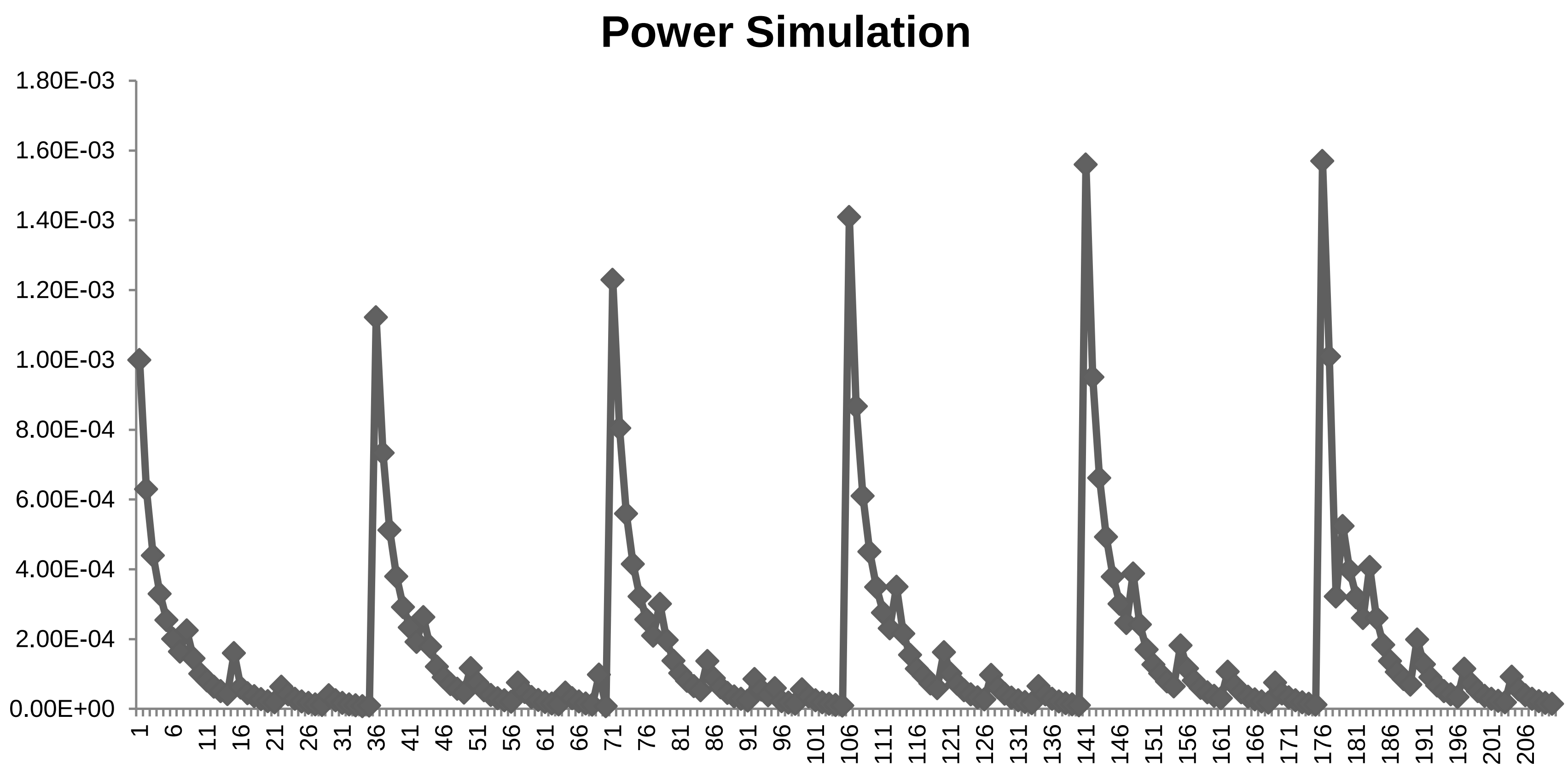
Parametric Sweep

Length [40mm 44mm 48mm 52mm 56mm 60mm]

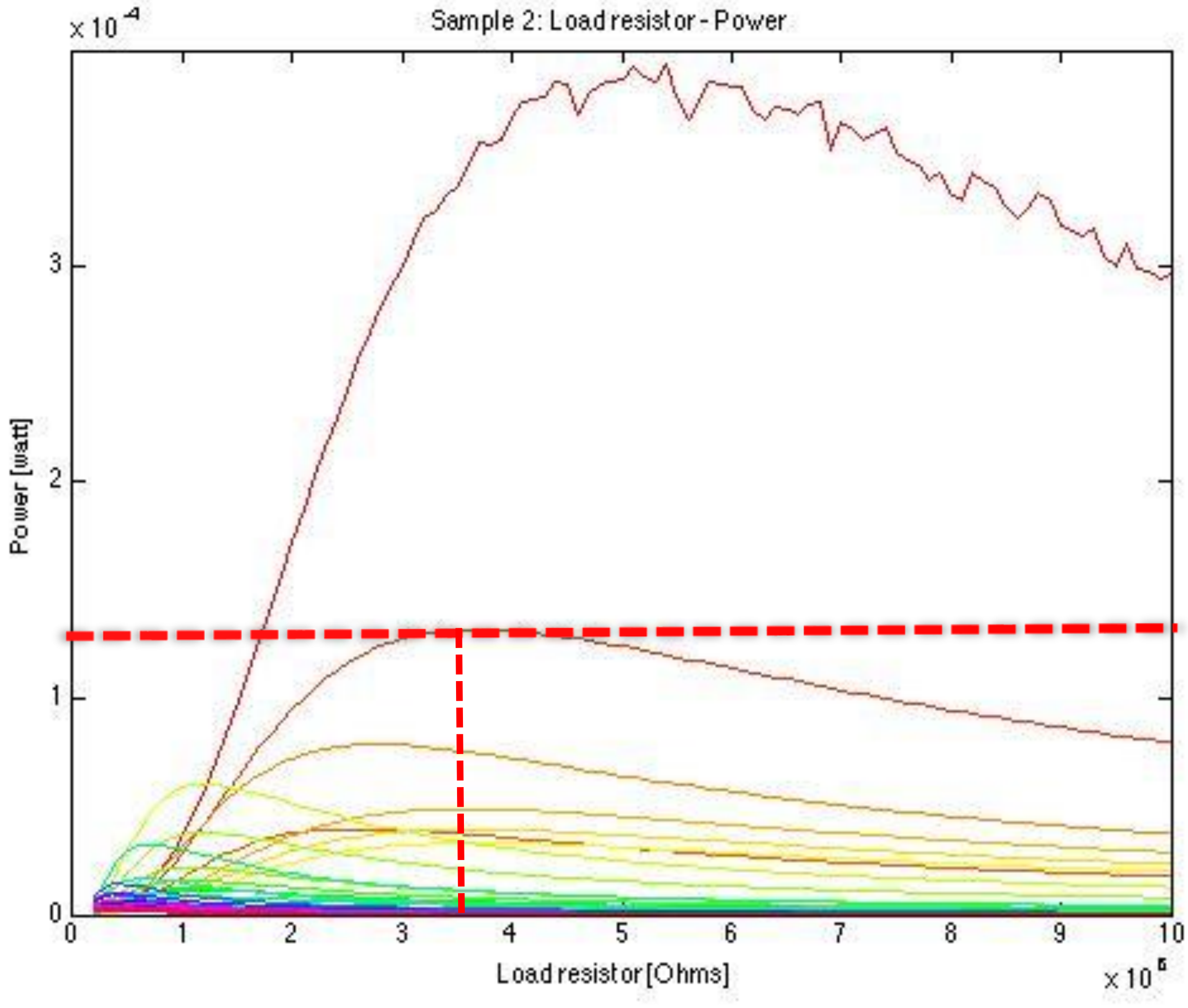
Width [2mm 6mm 10mm 14mm 18mm]

Thickness [0.2 0.25 0.3 0.35 0.4 0.45 0.5mm]

Parametric Sweep

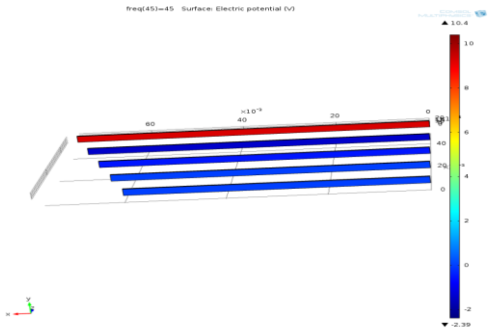


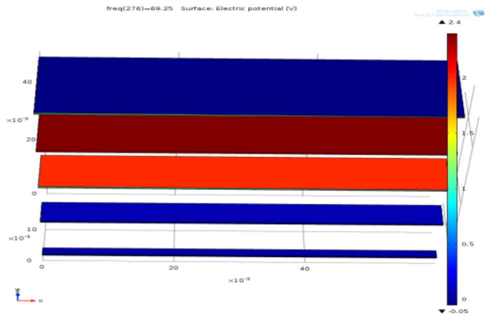
Power-Resistor relation

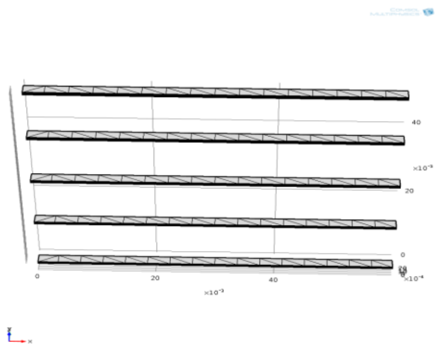


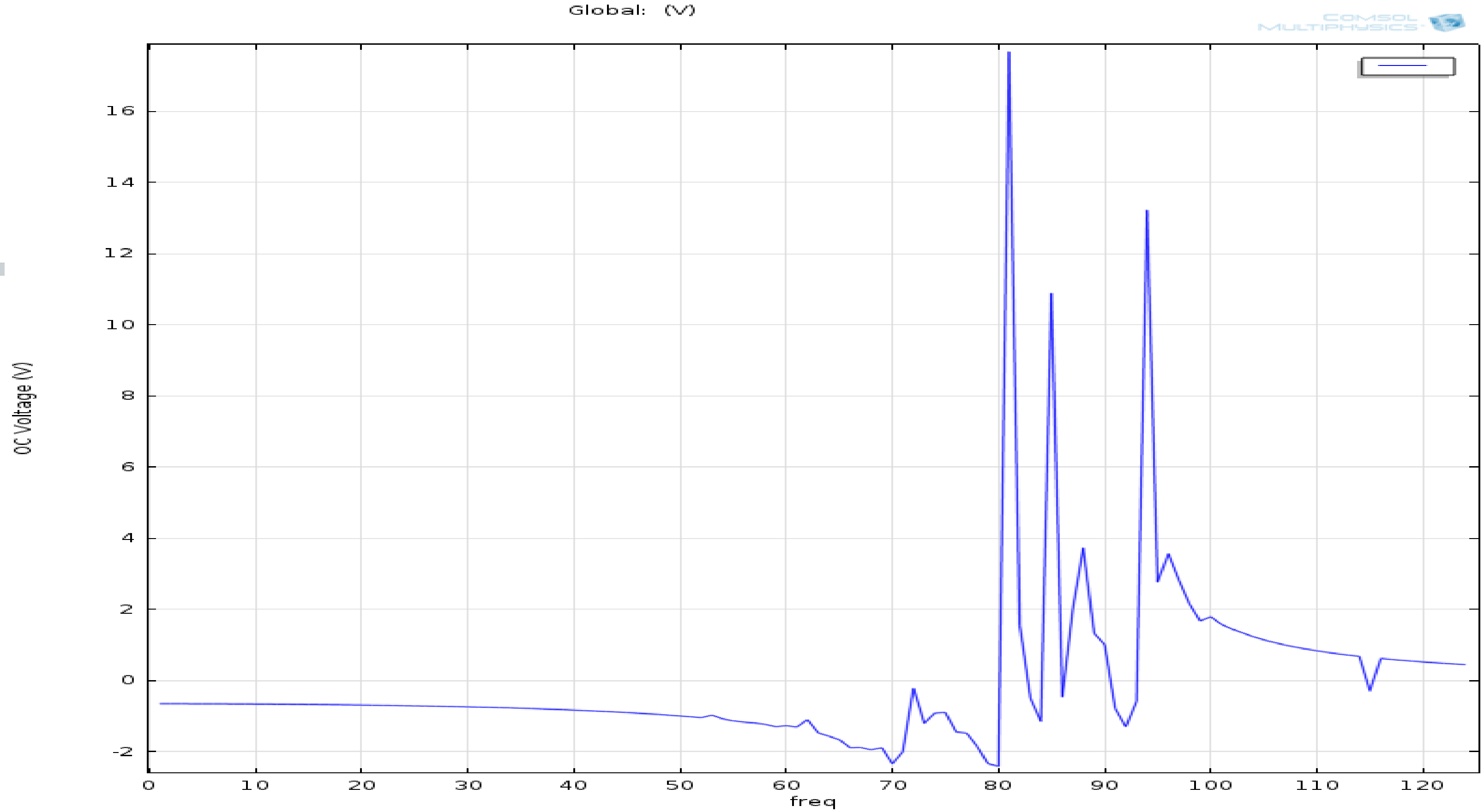
Multi-beam

- Simulation of multiple cantilever beam connected in series circuit. We set the number of beams to 5. Two parameters are kept constant and vary the other one parameter. The plan is divided to 3 cases for each sample,









Length	Width	Thickness	OC Voltage	fr
60mm	10mm	0.25mm	9.59V	68.9Hz
60	10	0.3	9.45	82.64
60	10	0.35	9.18	96.34
60	10	0.4	8.93	110.03
60	10	0.45	8.93	123.7

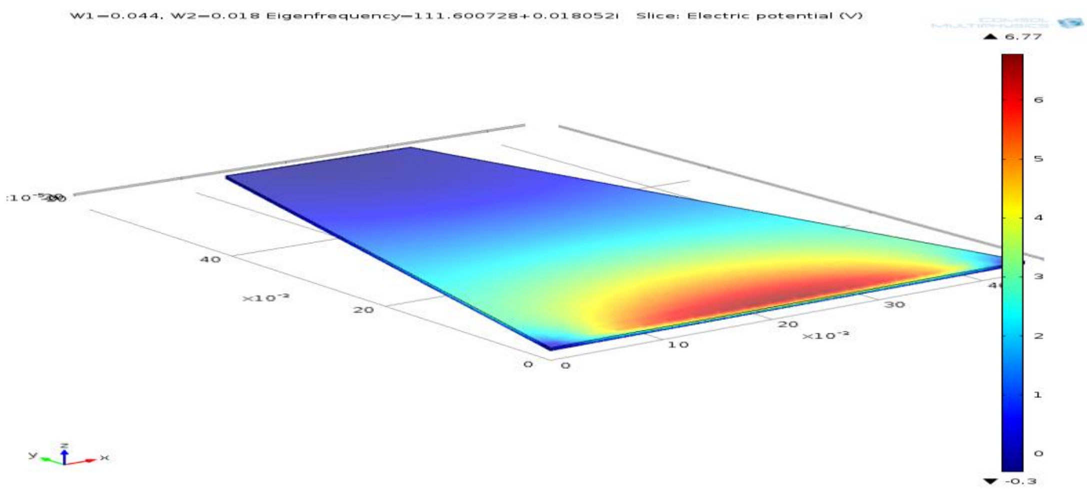
Comparison between materials(bimorph)

L: 60mm ;W:2mm ;T:0.2mm

Name	Power	optimal resistance(ohm)	voltage (v)
Sample1	0.404 mW	4900000	44.5
Sample2	0.394 mW	5400000	46.2
PZT5A	0.206 mW	3500000	26.9
PZT5H	0.144 mW	1800000	16.1

Future work

- 1. Multi-beam
- 2. Trapezoidal
- 3. Magneto-electric + Electromagnetic + Piezo



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