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Fabrication of New Actuator based on Flexoelectric Effect

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INTRODUCTION

- Novel methodology towards analysis, and fabrication of actuator based on converse flexoelectric effect
- Alignment of nano particles within a closed medium such as vacuum
- Electrode configuration on the boundary surface has been utilized
- Perovskite dielectrics with higher relative permittivity has been utilized such as Barium Strontium Titanate

THEORY

PIEZOELECTRICITY:

Upon the application of uniform strain will lead to sublattice shifts within the unit cell of a non-centrosymmetric dielectric crystal resulting in the appearance of a net dipole moment. Such a phenomenon is called piezoelectricity.

FLEXOELECTRICITY:

A macroscopic strain gradient can induce polarization in dielectrics of any crystal structure, even for a centro-symmetric lattice crystal. Such a phenomenon is called Flexoelectricity or the gradient induced polarization effect.

THEORY (cont..)

Mechanical strain can generate electric polarization in a deformable dielectric material through the two mechanism described below

$$P_i = d_{ijk}\varepsilon_{jk} + \mu_{ijkl}\frac{\partial \varepsilon_{jk}}{\partial x_l}$$

d_{ijk} = piezoelectric co-efficient (a third rank polar tensor)

μ_{ijkl} = flexoelectric co-efficient (a fourth rank polar tensor)

$\partial\varepsilon_{jk}/\partial x_l$ = flexoelectric polarization induced by strain gradient

NOTE: The flexoelectric co-efficient, which determine the strength of the flexoelectric response, which is non-zero for all dielectric materials,(i.e.) all dielectrics are capable of producing polarization.

FLEXOELECTRICITY

In a deformable crystalline dielectric material, flexoelectricity is composed of four components:

a. Bulk static

b. Bulk dynamic

c. Surface flexoelectric

d. Surface piezoelectric effect.

First three were estimated of the order of 10^{-10} C/m, while the magnitude of surface piezoelectric effect depends on the surface characteristics of the selected material

PROBLEM DEFINITION

Barium Strontium Titanate (BST):

Material proportion : $Ba_{0.67}Sr_{0.33}TiO_3$

Temperature : 25 °C curie point

Size (thin layer) : (100 x 100 x 50) μm

Material Properties*:

$\mu_{11} = 115 \times 10^{-6}$ C/m

$\varepsilon_r = 16000$ (Relative Permittivity)

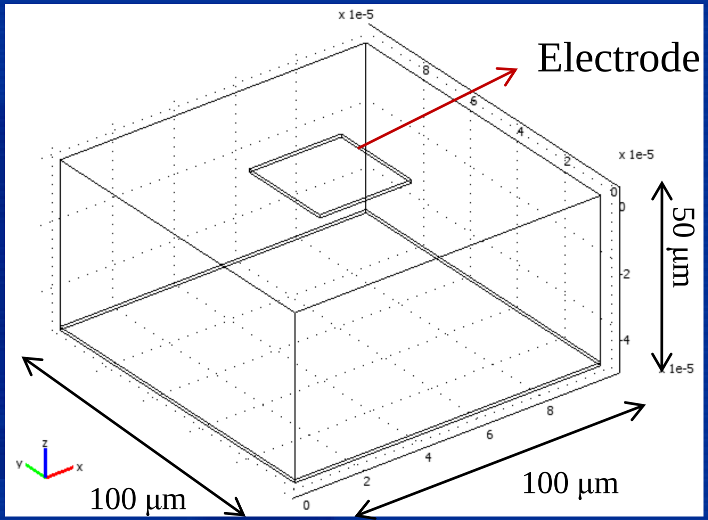
$d_{33} \simeq 10^{-10}$ C/m (Approx. range)

Electrodes : Silver layer (1 μm)

*(Based on Experimental Results from Ref. 2)

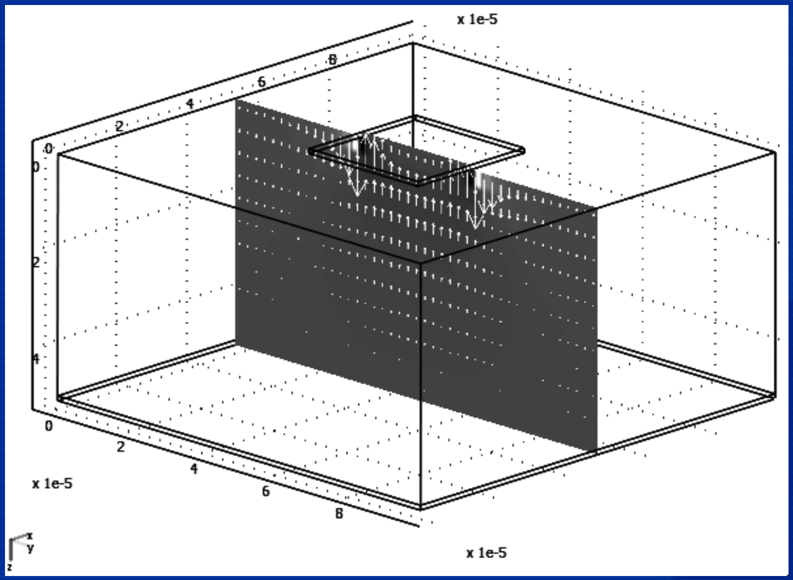
FEM MODEL (COMSOL)

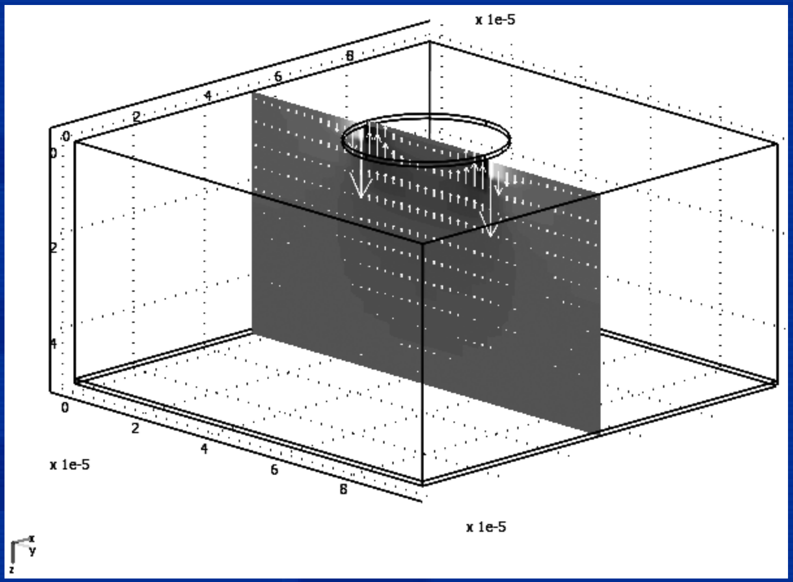
- Finding the best electrode shape for BST at 25°C.
- For comparison thickness of both the model are kept constant.



1. SQUARE ELECTRODE:
   - considered 9 BST model by varying the top square electrode area.
2. CIRCULAR ELECTRODE:
   - considered 9 BST model by varying the top circular electrode area.

SELECTION OF ELECTRODE





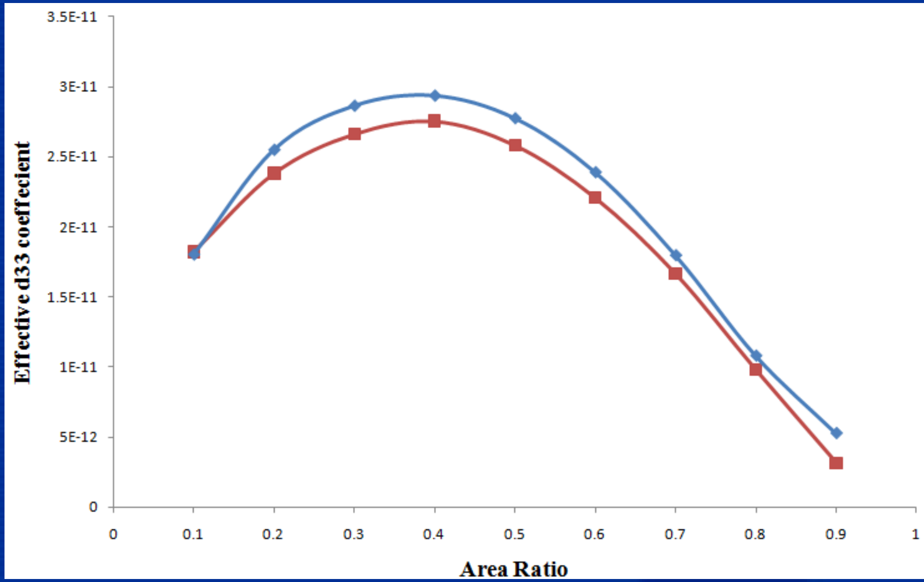
Area ratio = Upper Electrode / Lower Electrode

Calculated Result:

Gradient of the Electric Field $\simeq 10^{-8}$ -10^{-9}C/m

From the calculated Gradient of the electric field, the effective d_{33} ratio for each square and circular electrode model was plotted with area ratio.

INITIAL RESULT



From the graph:

- Area ratio of 0.4 shows higher d_{33} value.
- Square electrode has $\simeq$ 30 $\times 10^{-10}$m (effective displacement)
- Square electrode is chosen for further study.

AC CURRENT

AC current with the following formula

$$V_A = V_0 \cos\left(\omega_t + \phi_A\right)$$
$$V_B = V_0 \cos(\omega_t + \phi_B)$$

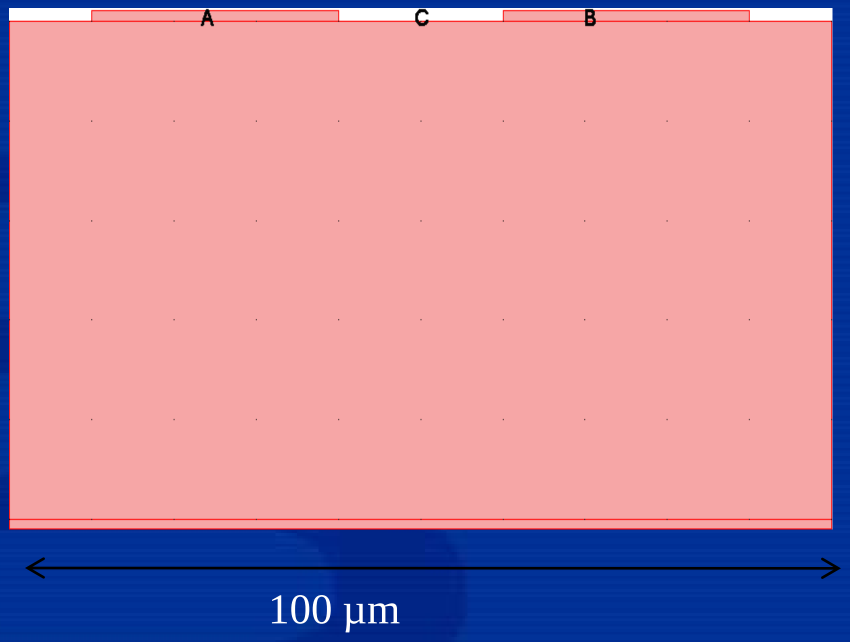
V_A and V_B = instantaneous voltage of A and B electrode

ϕ_A and ϕ_B = Phase angles of A and B electrode

ω_t = Angular frequency

Natural frequency of 1 kHz is used for simulation

FEM MODEL



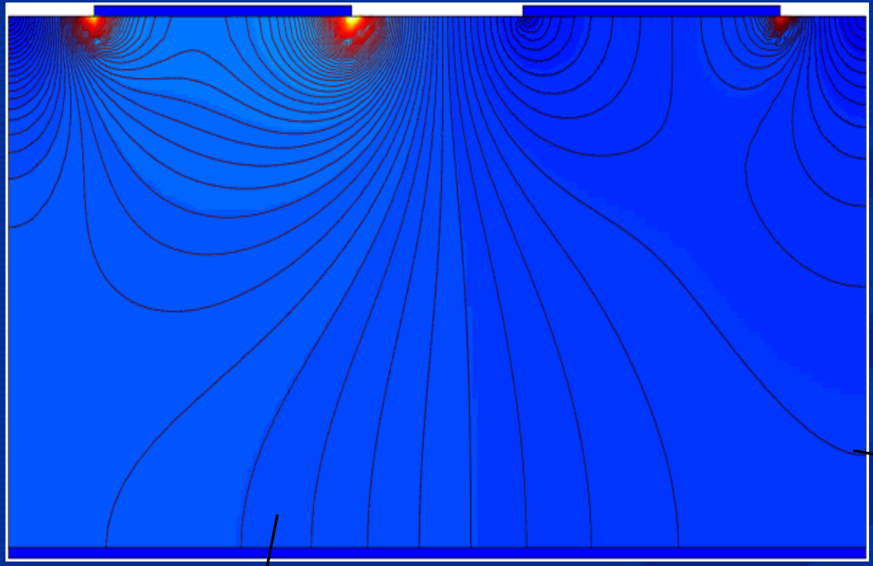
A and B are Electrodes
C – nano particles are placed

- Electrodes A and B with a thickness of 1 µm.
- Area ratio of 0.4 is maintained

Note: Interference will occur if the frequency of both the electrodes remain same.

$$\vec{E}(\vec{r},t) = \mathrm{Re}\,\underset{\sim}{\vec{E}}_0 \exp\left[i\left(\vec{k}\cdot\vec{r}-\omega t\right)\right]$$

CONSTRUCTIVE INTERFERENCE



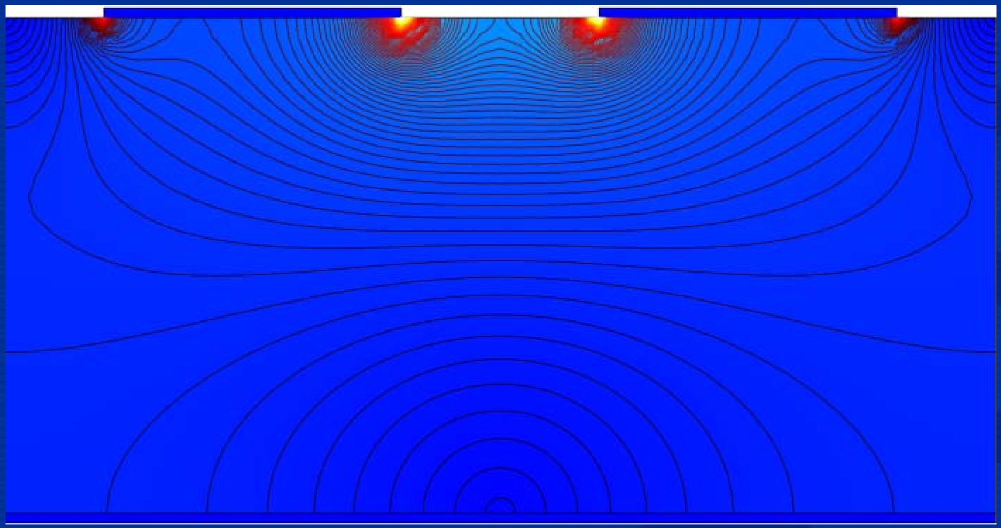
Zone B

Zone A

Constructive Interference:

- Phase angle at B is 45 deg.
- It helps to move the nano-filaments in one direction as we want.

DESTRUCTIVE INTERFERENCE



Destructive Interference

- For a phase angle of 180 deg. at electrodes
- It can be used as a method to stable the actuator during actuation.

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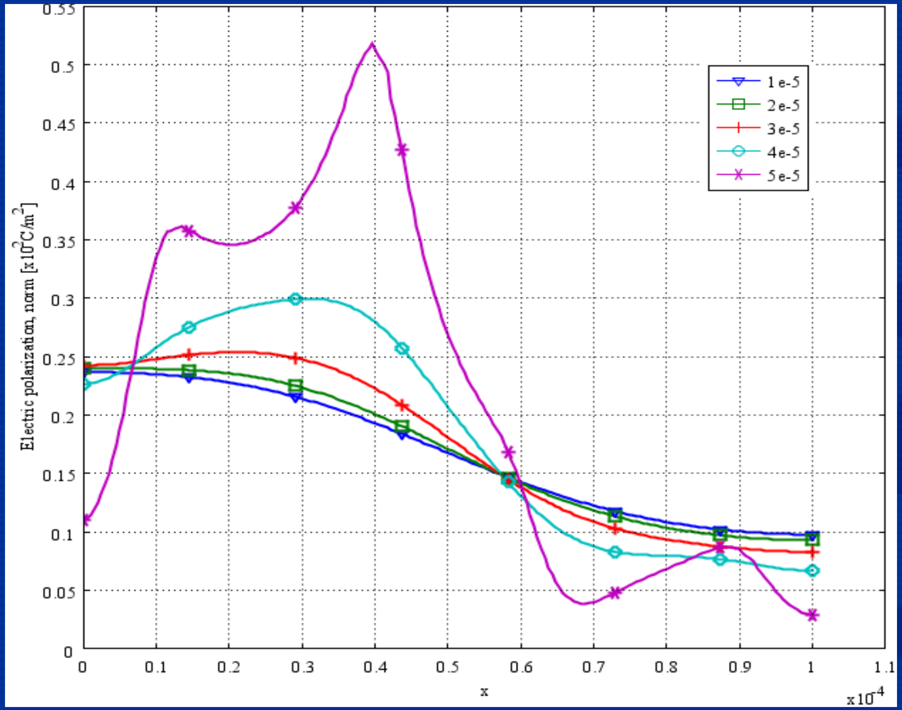
RESULTS



Graph:
Represent the Surface Flexoelectric effect of the actuator

CONCLUSION

- Indirect method to fabricate the actuator with the basis of flexoelectric effect.
- Present simulation results predict the flexoelectric coeffecient in the range of 10^{-9} C/m
- We are in process of testing the actuator.
- The fabrication method is based on the previous research papers published.
- Actuators

QUESTIONS