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Directional Optimization of MEMS Piezoelectric Hydrophone for Underwater Application

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Abstract

As the globalization forward the world need high accurateness and reliable devices are indeed. So directional optimization of MEMS piezoelectric hydrophones area of research works are got concentrated in underwater application for ocean research works.Directional optimization and to get landscape the sensitivity and increase the output voltage for that choose rectangular, square and circular diaphragm. Theobjectives of proposed work are is to selecting the proper design for MEMS Piezoelectric hydrophone to improve the sensitivity for different structures like rectangular, circular and square diaphragm and optimizing the high sensitive frequency response by comparing the results obtained from Simulation and analytical validation. Materials considered for this work is PZT, PVDF and ZnO and all properties of the material taken from materials standards, boundary condition is stiffly fixed at the boundaries, load will be applied on the diaphragms as constant pressure of 1 Pascal and variable pressure of 1pa to 10pa. Modelling and directional optimization of piezoelectric hydrophone has been done by using COMSOL Multiphysics software. Interpretation of numerical values like electric voltage (V), Mechanical displacement and Vonmises stress. These outputs from COMSOL Multiphysics are compared with theoretical results to get landscaped sensitivity, Frequency analysis is done from varying pressure values. The optimized results from testing are suggest that this device could be used to detect underwater sounds in various applications.

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Keywords:"MEMS, PZT, PVDF, ZnO, COMSOL Multiphysics"

1. Introduction:

Micro-electromechanical system (MEMS) is a technology system that combines mechanical and electrical components [1]. By adopting this technology assist in order to get landscaped sensitivity from diaphragms is tedious in pressure sensor of hydrophone transducers.

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Hydrophones are made up of piezoelectric materials like silicon and natural piezoelectric material quartz these hydrophones indeed to perceive the sounds in underwater so called these are microphones and underwater sound waves may turn as variable pressure on diaphragms of piezoelectric material will output the voltage when mechanical force applied on the body[2]. This scenario is to output the voltage but landscape sensitivity requires proper placing of piezoelectric patches and orientations of patches and physical configuration of patch also matter. Placing of patches on silicon diaphragm purely depends on the maximum stressed zone in the diaphragm there can place the patch can do the directional optimization of patches. These patches are made up of PVDF, ZnO, and PZT by placing these patches it will assist to in order to get landscape sensitivity this work helps to improve performance of the hydrophone transducers [3].The design for diaphragm includes design in three different structures rectangular, square, and circular among these three structure one most suitable structure is optimized for piezoelectric hydrophone through analytical calculations. Simulation work carried out in COMSOL Multiphysics solver tool reported results of Vonmises stress.

Nomenclature

MEMS	Microelectromechanical system
PZT	Lead Zirconium titanium
PVDF	Polyvinylidene Fluoride
ZnO	Zinc oxide
Wmax	Maximum displacement of diaphragm
σvm	Vonmises stress
V	Electric voltage
D	Charge density
C	Dielectric constant
σ	Mechanical stress
d33	Piezoelectric strain
€o	Absolute Permittivity of force space
€r	Relative permittivity

1.1 Piezoelectric Material:

Piezoelectric materials have a property of change their shape, much like a lattice, and convert the remaining mechanical energy into electrical energy. The most commonly used piezoelectric materials are [4],

Polyvinylidene Fluoride (PVDF) is a polymer (Polyvinylidene Fluoride), includes of lengthy chains of the repeating monomer (—CH2—CF2—). The hydrogen atoms are absolutely charged and the fluorine atoms are harmfully charged with admiration to the carbon atoms and this passes every monomer unit with an intrinsic dipole moment. PVDF film is pretend by solidification of the film from a molten phase, which is then tense in a meticulous path and ultimately poled in the liquor phase, the personality polymer chains are open to take up several orientation and so a given quantity of liquid has no lattice dipole moment. Later than solidification, and stretch the layer in one direction, the polymer manacles are predominantly associated along the path of stretching. This, joint with the poling, imparts an enduring dipole instant to the film, which then behaves similar to a piezoelectric material [5].

Lead Zirconate Titanates (PZT) is the most generally used kind of piezoceramic. This is hard solutions of lead zirconate and lead titanate, habitually doped through other elements to attain definite properties. These ceramics are pretend by mixing jointly relative amounts of lead, zirconium and titanium oxide powders and heating the combination to about 800–1000°C. They then respond to form the perovskite PZT powder. This fine particle is assorted with a folder and sintered hooked on the required shape. Throughout the cooling process, the material undergoes a par electric towards ferroelectric phase evolution and the cubic piece cubicle becomes tetragonal. Since a result, the unit cubicle becomes lengthened in one path and has an enduring dipole instant oriented all along its extended axis (*c*-axis). The UN poled ceramic includes of many arbitrarily oriented domains and therefore has no lattice polarization. Relevance of an elevated electric pasture has the effect of aligning largely of the unit cells as intimately equivalent to the applied position as possible. This procedure is called poling and it imparts an enduring net divergence to the ceramic. The material in this state exhibits together the straight and chat piezoelectric affect. PZT sensors show generally of the description of ceramics, explicitly an elevated expandable modulus, brittleness and low tensile strength. The material itself is automatically isotropic, and by asset of the poling process, is supposed diagonally isotropic in the flat usual to the poling path as distant as piezoelectric properties are concerned. This means that for PZT sensors, $s11 = s22$, $s13 = s23$, $s44 = s55$, $d31 = d32$ and $d15 = d24$ [5].

Zinc oxide (ZnO)is the most generally used kind of piezo ceramics. this are hard solutions of zinc nitride and lead oxide, habitually doped through other elements to attain definite properties. These ceramics are pretend by mixing jointly relative amounts of lead, zirconium and titanium oxide powders and heating the combination to about 800–1000°C. They then respond to form the perovskite ZnO powder. And it has more advantage over PZT and PVDF, fabrication of this piezo ceramic is easy and piezoelectric properties. [5]

2. Modelling and simulation:

Modelling of piezoelectric diaphragm for three different structure and different material of patches where placed on silicon diaphragm, these material chosen are PZT-5H, PVDF and ZnO the simulation has been done in COMSOL Multiphysics for different structure has been materialised[6]. Figure1 shows the total displacement obtained by the square structure of silicon diaphragm with piezoelectric patches.

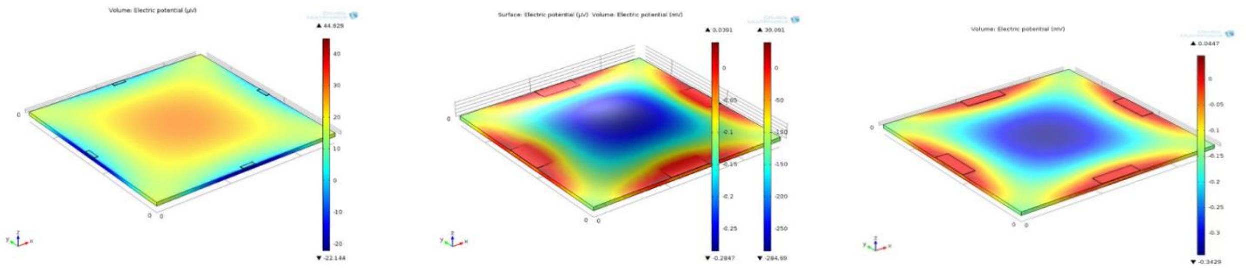

Fig: 1 landscaped sensitivity of square structure (a) PZT (b) PVDF (c) ZnO

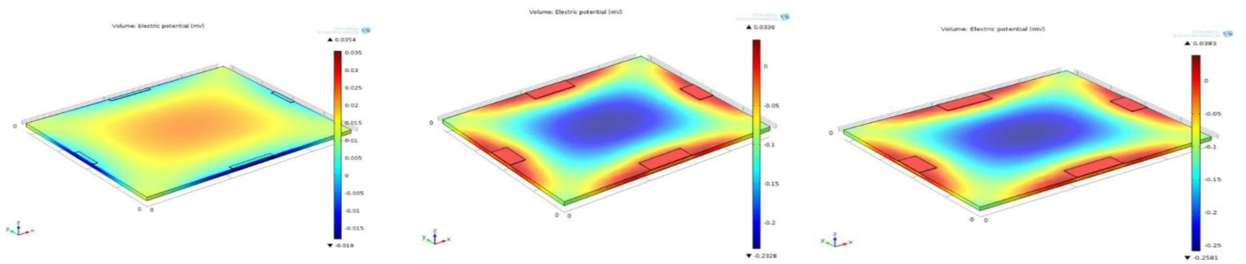

Fig: 2 landscaped sensitivity of rectangular structure (a) PZT (b) PVDF (c) ZnO

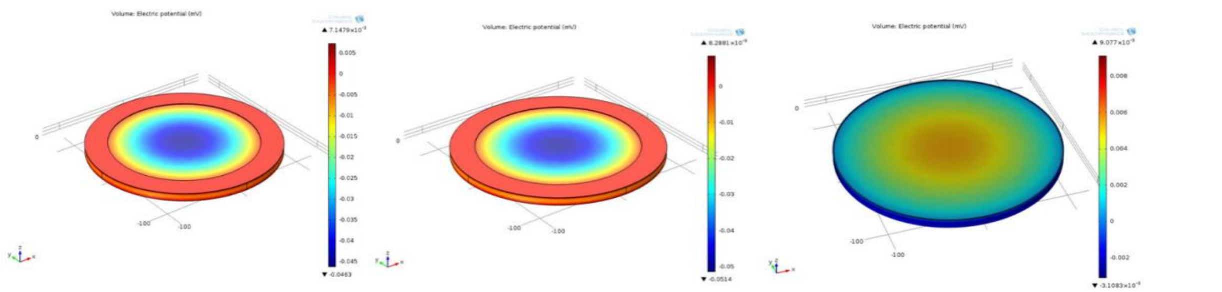

Fig: 3 landscaped sensitivity of circular structure (a) PZT (b) PVDF (c) ZnO

Figure 2 shows the designed structure for rectangular plate with piezoelectric materials and rectangular plates fixed with all the boundary edges and tetrahedral messing is used to compute for 1bar pressure. Similarly Fig 3 indicates the simulated results for circular diaphragm with different piezo electric materials.

Directional optimization of Piezoelectric patches of all kind of structure are performed and the output sensitivity getting high. but it does not make any sense, also the Resonant frequency will not produce in simulation and even less stressed zone areas also having the output of maximum sensitivity it is shown in the figure 4. Hence it is decided to place the piezo electric patches at maximum stress induced areas.

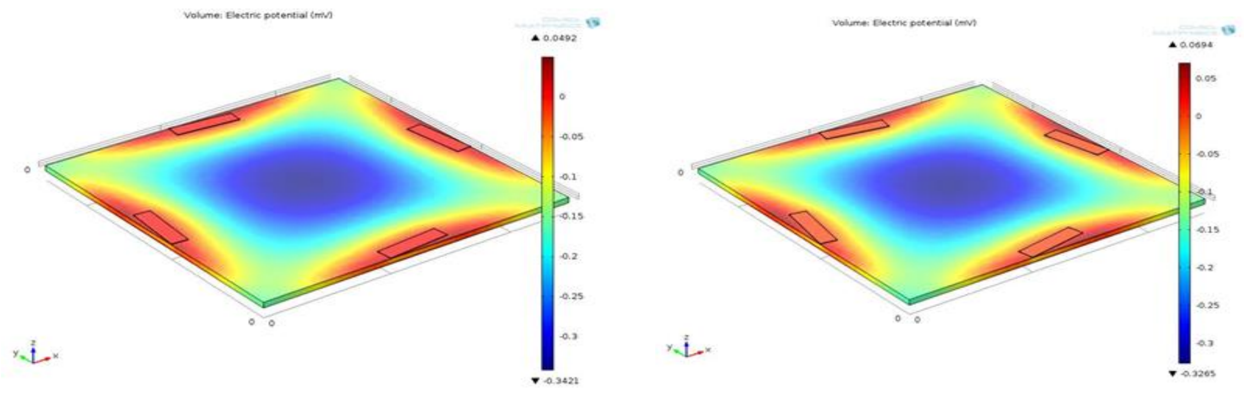

Fig 4: Angle optimization of ZnO patch for (a) 5degree (b) 10degree

Table1: properties of the piezoelectric materials

Material	**PZT**	**PVDF**	**ZnO**
Absolute Permittivity	8.854x10^-12	8.854x10^-12	8.854x10^-12
Relative Permittivity	1200	12	2859
D33	500x10^-12	33x10^-12	11.7x10^-12

Table 1 shows the properties of the materials used to find out the induced potential voltage from the different structural materials.

The Maximum displacement of diaphragm with optimized ZnO patch is found by

$$Wmax = \frac{-3\,W\,[m^2-1]\,a^2}{16\pi E m^2 h^3} \quad \text{... (1)}$$

$$W = (\pi a^2)\,p \quad \text{... (2)}$$

$W = 4.90625 \times 10^{-8}$ N

$m = 1/0.25 = 4$

$Wmax = -7.88\times10^{-6}$ µm

Stress tensor:

$$Vm = \begin{matrix} 127.28 & 28.75 & 72.649 \\ 28.75 & 127.71 & 87.831 \\ 72.679 & 87.831 & 56.005 \end{matrix}$$

$\sigma_{VM} = 215.81$ N/m^2

Voltage induced

Potential (v) = $\frac{D \times A}{C}$, D= d33 x σ , C= $\frac{€o \times €r \times A}{d}$ …. (3)

Where €o = Absolute Permittivity of force space = 8.854 x 10^{-12}

€r= Relative permittivity of Zn0 = 2859

Area of patch = 2.89 x 10^-8 m^2

C= 7.32 x 10 ^ -10

$$\sigma\ max = \frac{3 \times v \times W}{8 x \pi \times h^2}$$ …. (4)

W = [π x a^2]ρ

W= 4.90 x 10^-8

σ max = 14.60 N/m^2

D= d33 **x** σ

d33 of ZnO = 11.7 x 10^-12

D = 1.7082 x 10^{-10}

Voltage (V) = 6.17 µv

3. Results and Discussions:

For the varying pressure deflection of the optimized ZnO structure and its extracted voltage are shown in the figure5. Both the theoretical and Simulated result using Comsol Multiphysics are considerably nearer to each other hence whatever the simulated results gives good performance while fabricating the device using above standards.

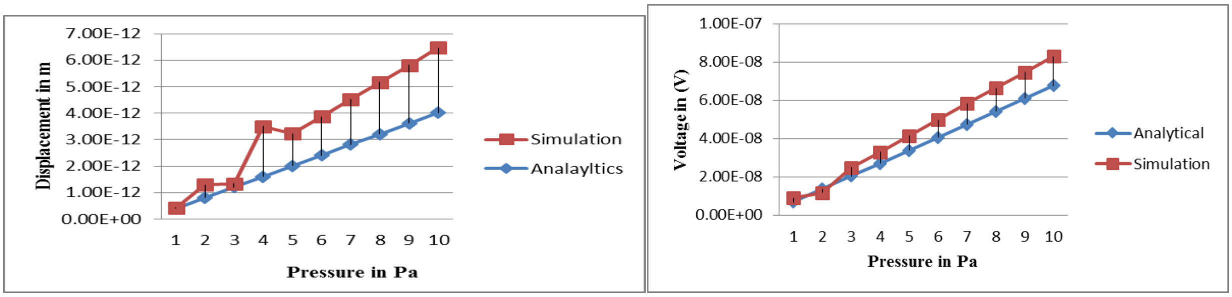

Fig 5: Analytical v/s simulation results of ZnO Circular Structure (a) Pressure v/s Displacement (b) Pressure v/s voltage.

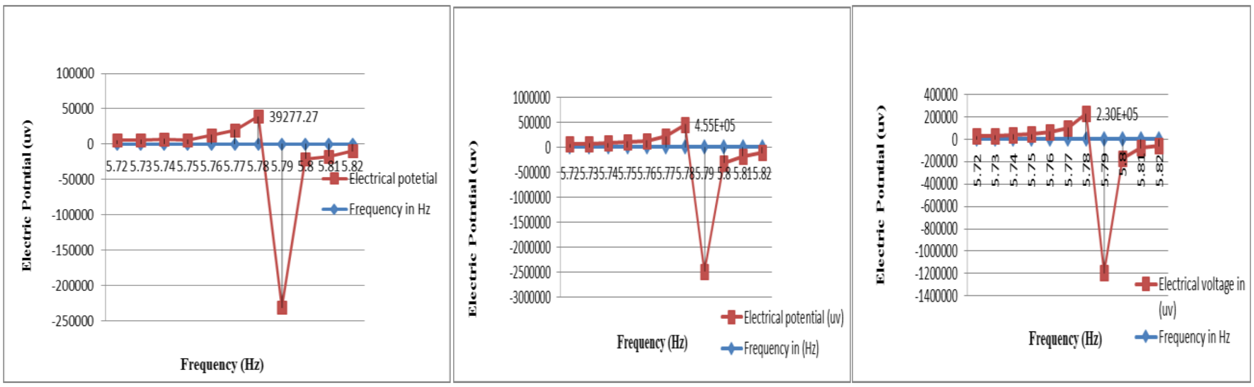

Fig 6: Frequency response of the ZnO Patches For (a) 1 Pascal (b) 5 Pascal (c) 10 Pascal

Table2: Theoretical results

SI. No	Theoretical Results					
	Structure	**Material**	**Applied Pressure in N/m/^2**	**Displacement In µm**	**Vonmises Stress in N/m^2**	**Electrical Voltage in V**
1	**Square**	PZT	1	5.48e-6	1.19e4	3.64e-5
		PVDF	1	6.16e-6	1296.02	2.40e-5
		ZnO	1	5.48e-6	1285.52	3.56e-6
2	**Circular**	PZT	1	5.01e-14	1201.4	6.95e-7
		PVDF	1	4.01e-14	2165.10	4.55e-6
		ZnO	1	4.01e-14	215.81	6.77e-9
3	**Rectangular**	PZT	1	3.57e-12	7588.52	3.09e-5
		PVDF	1	4.11e-12	1009.70	2.04e-5
		ZnO	1	4.11e-12	1012.33	3.04e-7

Table 3: Simulation results

SI. No	Simulation Results					
	Structure	**Material**	**Applied Pressure in N/m/^2**	**Displacement In µm**	**Vonmises Stress in N/m^2**	**Electrical Voltage in V**
1	**Square**	PZT	1	9.59e-6	1.73e4	4.46e-5
		PVDF	1	6.16e-6	1152.1	3.91e-5
		ZnO	1	5.32e-6	1141.3	4.50e-6
2	**Circular**	PZT	1	4.73e-14	1045	9.08e-7
		PVDF	1	2.44e-14	1804.4	7.17e-6
		ZnO	1	2.44e-14	179.58	8.83e-9
3	**Rectangular**	PZT	1	6.14e-12	6952.9	3.54e-5
		PVDF	1	3.50e-12	1253.36	3.43e-5
		ZnO	1	3.45e-12	1153.65	3.96e-7

From the above two tables it is clearly indicates the analytical calculation results, total displacement of structure, vonmises stress and electrical potential with simulation results presented in validation of results for three structure and three piezoelectric patches in that PZT and ZnO produced landscaped sensitivity. Hence for the design of MEMS piezo electric Hydrophone PVDF with circular structure is most suitable.

4. Conclusions:

In This work directional optimization of piezoelectric diaphragm for three different piezoelectric material PZT, PVDF and ZnO in underwater application to produce enhanced sensitivity of hydrophone for different structure like square, rectangular and circular these structures optimized physical configuration of piezoelectric material in COMSOL Multiphysics software compared results with analytical calculation. From this witnessed the proper placing of piezoelectric patches and exact specification of patches as per results obtained for constant pressure 1pa and variable pressure 1 to 10 pa achieved landscaped sensitivity for all three structures. Comparison of Analytical calculation results total displacement of structure, vonmises stress and electrical potential with simulation results presented in validation of results for three structure and three piezoelectric patches in that PZT and PVDF produced landscaped sensitivity. Frequency simulation of three structure of three patched piezoelectric material in all ZnO has been output the resonant frequency compare to PZT and PVDF patches. Comparing all three structures results circular structures has output the high sensitivity over square and rectangular structure. Comparing PZT and ZnO patched results PVDF output the landscaped sensitivity by having the patches at Maximum stress area along the direction of stress induced. Hence this work concluded that PVDF more suits for underwater application MEMS piezoelectric pressure sensor.

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