International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-4, April 2019

Simulation and Comparison of Various Cantilever Beam For Pressure Sensor

R. S. Ernest Ravindran, P. Mukul Sai, R. Ajay Kanth, K. Rajesh, R. N. R. C. Tejaswini, A. Panduranga

Abstract*: *Micro cantilever used for detecting the changes due to the cantilever bending and from it, vibrational frequencies can be analyzed. In this investigation, various materials like Silicon, Gold, Bismuth and Platinum were used to simulate cantilever beam. The simulation is carried out by using comsol multi physics. Each cantilever were characterized by various parameters such as Force, Displacement, Relative permittivity, Young's modulus and Poisson's ratio. Bismuth material is observed to have high sensitivity that is due to the properties of the material. Cantilever simulated using Bismuth material can be applicable for pressure sensor applications.

Index Terms*: *Cantilever beam, COMSOL Multiphysics, Displacement, MEMS

I. INTRODUCTION

A sensor is a device that is utilized to identify and reacts to some kind of input from the physical environment. The predetermined input may be light, heat, moisture, pressure or any other environmental phenomena. The output signal is generally a signal that is converted into human-readable display at the sensor location. A good sensor must have to compile with the following rules. They are sensitive to the property measured and not affect the property measured. A pressure sensor normally consists of a pressure sensitive element which is used to detect the pressure and changes over it into a simple electric signal whose magnitude relies on the pressure applied [1]. Since they convert pressure into an electric signal, they can also be referred as pressure transducers. Pressure Sensors are again classified into three types like capacitive, piezo electric and piezo resistive pressure sensors.

A capacitor has two metal plates in between a dielectric material is placed like a sandwiched. In capacitive pressure sensor, one of metal plates is allowed to move in and out so the capacitance between them changes because of differing separation between the plates. The movable plate is associated with a diaphragm, which is used to generate and detect the changes in electro static field [2-4]. The development of the diaphragm would influence the connected metal plate's position and capacitance would fluctuate. These sensors however much inadequate at high temperatures are generally utilized at surrounding temperature because of the linear output. Piezo is a greek word which means press, here piezoelectric effect is used so that they can easily measure the differences in temperature, pressure, strain etc. Piezoelectric crystals build up a potential contrast at whatever point they are exposed to any mechanical weight. When a piezo electric material is deformed then an electric charge will be generated [5]. These sensors have the precious stone mounted on a dielectric base so that there is no flow leakage. At whatever point the diaphragm detects pressure, it pushes the shaft down and pressurizes the crystal and voltage is created [6].

Piezo resistive sensors are as of now the most broadly utilized sensors in mechanical applications. These sensors have impressive favourable circumstances over different sensors, for example, high affectability, low nonlinearity mistake, ease, high effectiveness, small size [7]. The imperative pieces of a piezo resistive pressure sensor are the piezo resistors and the diaphragm. At the point when a pressure is applied at the diaphragm, stresses are produced. Piezo resistive pressure sensors work dependent on the piezo resistive impact, so the piezo resistors are situated at the top of the diaphragm [8].

A cantilever is one that is mounted at one end and the alternate end is liberated to move once it experiences some stress. A micro cantilever could be a device that may be used as physical, chemical or biological device for detecting the changes in cantilever bending or wave frequency [9]. It is the miniaturized duplicate of a springboard that moves up and down at regular intervals. This deflection of small cantilever modifications once a particular mass of an analyte is specifically absorbate on its surface like change once an individual step onto the spring board. However, the micro cantilevers are 1,000,000 times smaller than the springboard having dimensions in microns. The materials that are used for designing of cantilever are silicon, gold, bismuth and platinum.

Poisson's ratio defined as the ratio of transverse contraction strain to longitudinal extension strain in the stretching force direction. The Poisson's ratio will have a negative sign so that it indicates that the materials are having positive ratio. It uses Poisson effect so that it can tends the material to expand in different directions perpendicular to the direction of compression. Young's modulus is a mechanical property, which measures the stiffness of the solid material. It also describes the relationship between stresses with the help of linear elasticity.

Manuscript published on 30 April 2019.
***** Correspondence Author (s)
R.S.Ernest Ravindran*, E.C.E, KLEF(Deemed to be University), Guntur, India.
P. Mukul Sai, KLEF(Deemed to be University), Guntur, India.
R. Ajay Kanth, KLEF(Deemed to be University), Guntur, India.
K. Rajesh,KLEF(Deemed to be University), Guntur, India.
R. N. R. C. Tejaswini, KLEF(Deemed to be University), Guntur, India.
A. Panduranga,KLEF(Deemed to be University), Guntur, India.

This principle states that when a small load is applied on the solid material then the material will undergo deformation and when the load is removed then the material will again regain its original shape.
Density is the mass per unit volume, where the density of material varies with temperature and pressure applied. When the pressure increases then the volume of the material decreases thus it will increase the density of the material. The density will use the intensive property so that it can easily measure the changes that occur in the material. Relative permittivity also need to be analyzed which defined as the ratio of absolute permittivity to the permittivity in free space. Permittivity is the property of the material, which is used to affect the columbic force between the two point charges in the material.
Micro cantilevers have been employed for physical, chemical and biological sensing. They also have wide applications in the field of medicine, specifically for the screening of diseases, detection of point mutations, blood glucose monitoring and detection of chemical and biological warfare agents [9]. These sensors have several advantages over the conventional analytical techniques in terms of high sensitivity, low cost, simple procedure, low analyte requirement (µl), non-hazardous procedures and quick response. This development has increased the sensitivity limit up to the extent that researchers can now visualize the counting of molecules. With the ability of high throughput analysis of analytics and ultra-sensitive detection, this technology holds tremendous promise for the next generation of miniaturized and highly sensitive sensors.

II. COMSOL MULTIPHYSICS

COMSOL Multi physics is a cross-platform finite component analysis, solver and multi-physics pose software. It allows approved physics-based freak interfaces and coupled systems of a set of teeth differential equations (PDEs). COMSOL provides an IDE and undivided workflow for electrical, factory made, running, and chemical applications. An API for Java and Live Link for MATLAB manage be secondhand to get a handle on something the software superficially, and the agnate API is beside secondhand by the Method Editor.
COMSOL contains an App Builder which cut back be used to develop individualistic domain-specific apps by the whole of law of the land user-interface. Users manage to handle drag-and-drop tools (Form Editor) or programming (Method Editor). Specific features take care of being included from the exemplary or polished features may be introduced at the hand of programming. It furthermore contains a Physics Builder to create custom physics-interfaces evident from the COMSOL Desktop mutually the related look-and-feel as the chronic physics interfaces.
The primary advantage of comsol multi physics is that it can be used to solve problems like structural mechanics, heat transfer, fluid flow and electro magnetics etc either if only single set of physics is imported or the multiple set of physics are imported [10]. COMSOL Server is the software and iron horse for one after the other simulation apps and the statement of belief for covering their deployment and distribution. Comsol multi physics is very reliable because it can be used to implement advanced methods

III. DESIGN AND METHODOLOGY

Comsol multi physics is used for designing of the cantilever because it is a very flexible platform so that it can allow all the relevant physical aspects of our design and it is one of the most widely used software for developing and optimizing new products [4]. It is an ideal software so that it can have the possibility of adding physical effects to our design and while compared to other commercial packages comsol is very easy for combining the physics.
In order to design the cantilever beam in comsol multi physics, firstly, selection a new model is necessary and then a block of dimensions has to be taken. After that selection of the material based on the required parameters has to be chosen and then doing meshing to that particular model and after that results are been analyzed. For the formation of the block, the parameters that are going to be used are like length, width and thickness and after that selecting a material that the block should be made off.
After the completion of the block design, the one end of the box is fixed and the other end is deformable or movable. After the block design setting of the parameters that are required for, user, and we can get an packed structure by applying mesh to the design. Now the pressure has to be applied on the cantilever so that the changes in displacement and frequency from metal to metal has been observed.
The materials that are used for the designing of the cantilever are silicon, gold, bismuth and platinum. Therefore, for all these four materials the identification of the changes in parameters has to be noticed. The parameters that are going to notice are density, young's modulus, poisson's ratio and relative permittivity. In order to identify the material which has high sensitivity the graph between displacement and force is plotted. The designing of the mems cantilever using comsol is shown in fig 4.

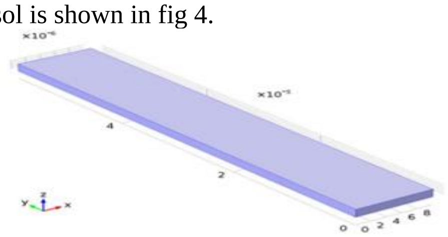

Fig4. Structure of MEMS cantilever beam using COMSOL

IV.RESULTS AND DISCUSSIONS

Materials used for simulating the cantilever are Silicon, Gold, Bismuth and Platinum. For the simulation of the cantilever, the physical parameters such as Width, Length and Thickness of the material are kept constant as shown in table 1.

Table 1.Parameters of a cantilever beam

Name	Expression	Value (µm)
Width	10 e^{-6}	10
Length	100 e^{-6}	100
Thickness	1 e^{-6}	1

Published By:
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International Journal of Engineering and Advanced Technology (IJEAT)
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4.1 SILICON CANTILEVER BEAM

Silicon is the best material mostly used in all electronic applications even in sensors due to its high electrical, mechanical and other properties. Silicon material is used for real time measurements of physical parameters such as pressure, flow rate, temperature, moisture etc. and it is highly used in MEMS for its material properties and at room temperatures when we apply some pressure it will elongates. Fig 6 indicates the simulated model of the silicon cantilever beam using comsol multi physics. By considering the values from Table 1 the above silicon cantilever beam has been simulated.

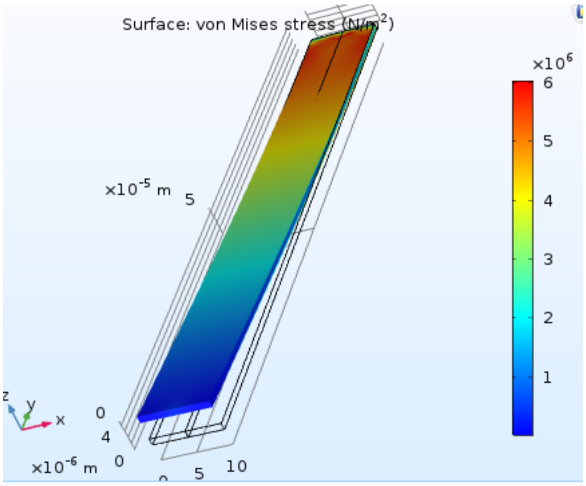

Fig 6 Simulated model of silicon beam

Table 2 Force and displacement calculations of silicon

Force (µN)	Displacement (µm)
0.1 e-6	2.4419 e-7
0.5 e-6	1.02209 e-6
1 e-6	2.4419 e-6
1.5 e-6	3.6628 e-6
2 e-6	4.883 e-6
2.5 e-6	6.1047 e-6
3 e^{-6}	7.3256 e^{-6}

Various forces were explored on the cantilever beam such as 0.1µN, 0.5 µN, 1µN, 1.5 µN, 2 µN, 2.5 µN, 3 µN and the displacement obtained is shown in table2 i.e., at 3 µN the displacement is 7.3256 e^{-6} which is very high when compared to other values.

Table 2.1 parameters of silicon cantilever beam

Parameters	Values
Density	2.3290g/ cm^3
Young's Modulus	47GPa
Poisson's Ratio	0.265
Relative Permittivity	11.68

An increasing force is applied on the beam. After 1µN i.e., from 1.5 µN to 3 µN there is a sudden change in displacement which is from 3.6628 e-6 to 7.3256 e^{-6} as shown in fig 6.1.

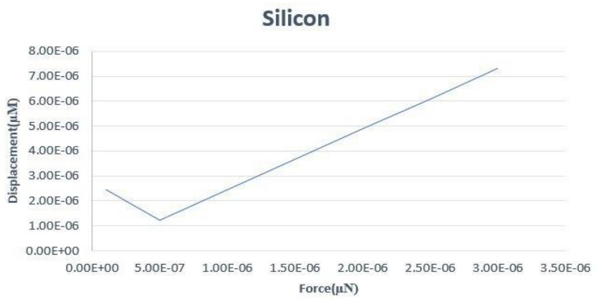

Fig 6.1 Graph for silicon beam

4.2 GOLD CANTILEVER BEAM

Gold material is used for the physical measurement of pressure, temperature, moisture etc. It is a good conductor of electricity and it is very essential in electronics because gold materials does not tranish easily. So, it is more sensitive and it has high reliability when compared to the silicon and it remains conductive for more time. Fig 7 indicates the simulated model of the gold cantilever beam using comsol multi physics. By considering the values from Table 1 the above gold cantilever beam has been simulated.

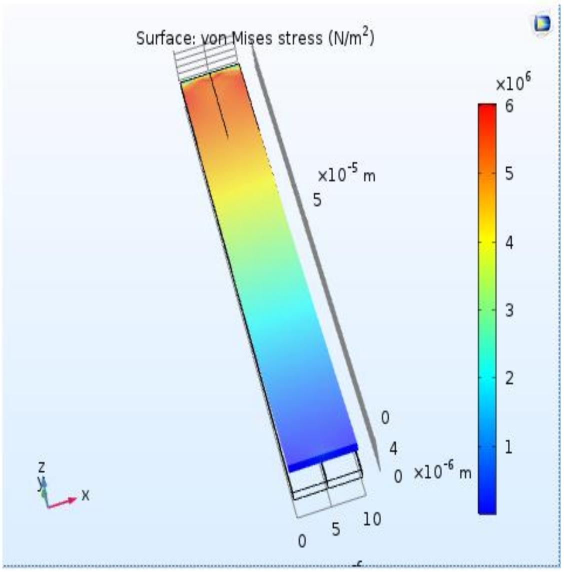

Fig 7 Simulated model of gold beam

Table 3 Force and displacement calculations of gold

Force(µN)	Displacement(µm)
0.1e^{-6}	5.1255e^{-7}
0.5 e-6	2.5628 e-6
1e^{-6}	5.1255e^{-6}
1.5 e-6	7.6883 e-6
2 e-6	6.012 e-5
2.5e^{-6}	1.2814e^{-5}
3 e^{-6}	1.5377 e^{-5}

Various forces were explored on the cantilever beam such as 0.1µN, 0.5 µN, 1µN, 1.5 µN, 2 µN, 2.5 µN, 3 µN and the displacement obtained is shown in table3 i.e., at 3 µN the displacement is 1.5377 e^{-5} which is very high when compared to other values.

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Table 3.1 parameters of gold cantilever beam

Parameters	Values
Density	19.3g/ cm^3
Young's Modulus	78GPa
Poisson's Ratio	0.44
Relative Permittivity	1.6239

Gold is quite responsive when compared to silicon, its displacement is proportional to force as shown in fig 7.1 i.e., from 5.1255 e^{-7} to 1.5377 $e^{-5}$the displacement is proportional to the force applied. It is a good conductor of electricity and its base in piezoelectric yet to be observed.

4.3 BISMUTH CANTILEVER BEAM

Bismuth is a material, which is having low electric and thermal conductivity. It is one of the material which is having high sensitivity and high electrical resistance compared to other materials. It is nontoxic to the nature and industrially less toxic. Fig 8 indicates the simulated model of the bismuth cantilever beam using comsol multi physics. By considering the values from Table 1, the above bismuth cantilever beam has been simulated.

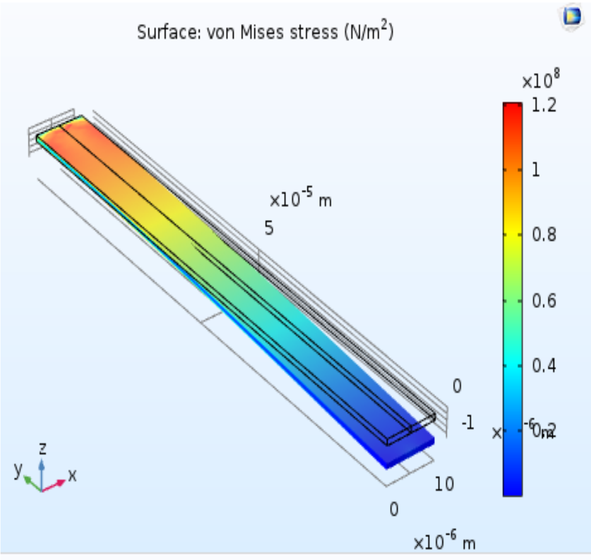

Fig 8 Simulated model of bismuth beam

Various forces were explored on the cantilever beam such as 0.1µN, 0.5 µN, 1µN, 1.5 µN, 2 µN, 2.5 µN, 3 µN and the displacement obtained is shown in table 4 i.e., at 3 µN the displacement is 3.1634 e^{-6} which is very high when compared to other values.

Table 4.1 parameters of bismuth cantilever beam

Parameters	Values
Density	9.78 g/ cm^3
Young's Modulus	32 GPa
Poisson's Ratio	0.325
Relative Permittivity	12.820

Best sensitivity is observed in bismuth when compared to silicon and gold. Its displacement is linear and quick with respect to the force applied as shown in fig 8.1 i.e., from 1.054 e-6 to 3.1634 e^{-6} the displacement is linear to the force . However, its sensitivity property has a good potential.

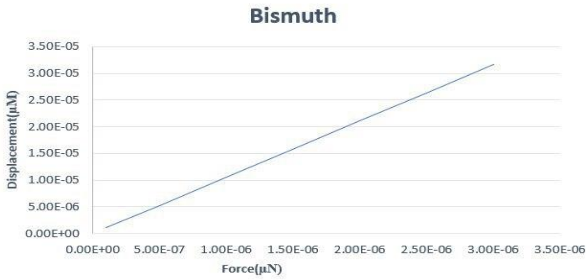

Fig 8.1 Graph for bismuth beam

4.4 PLATINUM CANTILEVER BEAM

Platinum is a thick, costly and relatively rare material. It has best tensile and ductile property that means it is not only easy to shape but also it is easy to work. The main advantage of platinum material is that it will not rust easily because it is un reactive. The Fig 8 indicates the simulated model of the platinum cantilever beam using comsol multi physics. By considering the values from Table 1 the above platinum cantilever beam has been simulated.

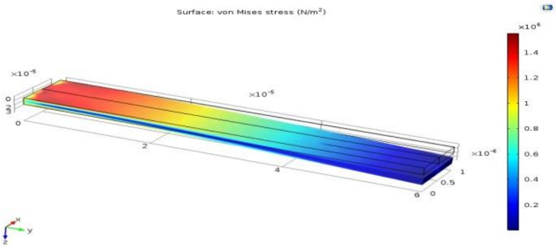

Fig 8 Simulated model of platinum beam

Table 5 Force and displacement calculations of Platinum

Force(µN)	Displacement(µm)
0.1e^{-6}	2.3341e^{-7}
0.5 e^{-6}	1.1671 e^{-6}
1e^{-6}	2.3342 e^{-6}
1.5 e^{-6}	3.5012 e^{-6}
2e^{-6}	4.6683 e^{-6}
2.5 e^{-6}	5.8353 e^{-6}
3 e^{-6}	7.6024 e^{-6}

Various forces were explored on the cantilever beam such as 0.1µN, 0.5 µN, 1µN, 1.5 µN, 2 µN, 2.5 µN, 3 µN and the displacement obtained is shown in table 5 i.e., at 3 µN the displacement is 7.6024 e^{-6} which is very high when compared to other values.

Table 5.1 parameters of platinum cantilever beam

Parameters	Values
Density	21.45g/ cm^3
Young's Modulus	168GPa
Poisson's Ratio	0.38
Relative Permittivity	2.7604

When compared to bismuth, platinum is not having the best sensitivity because from 2.5µN to 3µN the displacement is non-linear with respect to the force applied i.e., from 5.8353 e^{-6} to 7.6024 e^{-6} the graph is nonlinear to the force. So platinum cannot be used for future purposes.

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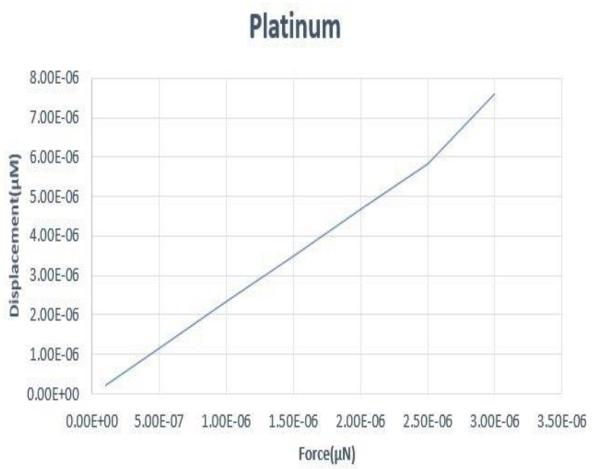

Fig 8.1 Graph for platinum beam

COMPARITIVE ANALYSIS

The cantilever beam has been designed by using four materials like silicon, gold, bismuth and platinum. All the materials are put under same pressure loads. There is not much difference in displacement in unit observation. But even that plays a major in micro level sensing. The applied pressure is in micro newtons. The observed displacement is also in micro meters. Among all silicon is not no sensitive even though is highly used in mems for its material properties. Gold is good conductor of electricity, this might be consider for piezo resistive sensing which is good for blood pressure sensors. Bismuth is more sensitive when compared to silicon and gold. But platinum has very less displacement however, its usages are not known to us at present.

COMPARISION GRAPH OF VARIOUS MATERIALS FOR THE SIMULATION OF CANTILEVER BEAM

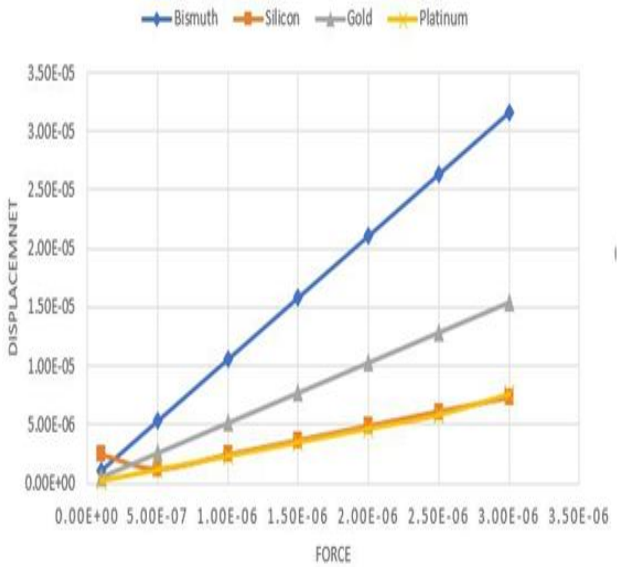

Fig 9 Comparison graph

The graph between force and displacement has been plotted for silicon, gold, bismuth and platinum and by comparing all those four materials the best sensitivity is observed in bismuth material because when the force is applied on bismuth the displacement is very linear and it is increasing with respect to the force applied by comparing with other materials. So that bismuth has been chosen for future applications.

CONCLUSION AND FUTUREWORK:

Simulation and comparison of various cantilever beams of different materials and their displacement as well as their material properties have been analyzed and compared when the small amount of force is applied. It has also found that the beam designed with bismuth is more efficient and preferable as material which has more response when a force is applied on it. Cantilever beam acts as a base in bio medical industries for highest research activities such as cardiovascular, Drug delivery, Endocrinology, Gastroenterology, Neurology and Surgery as bio medical purposes

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