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Inventiveness and Estimation of MEMS Constructed Appliance for Healthcare and Ecological Intensive Care

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This research work is based on MEMS (Micro-Electro-Mechanical Systems) technology which includes even the concept of Bio-MEMS and Microfluidics.MEMS is very useful for physical, chemical, and biomedical applications and it can be integrated with VLSI chips. The major focus is to study and analyze the various physical, mechanical and biological behaviors of MEMS-based devices in the presence of different parameters for diverse sensing and environmental monitoring-related applications. Some MEMS-based devices like Microcantilever and Pressure sensors are the major part of this research work. Due to the flexibility and versatility of these devices, they are useful for a variety of applications (e.g. environmental monitoring, biomedical, consumer products, etc.). Apart from microcantilever and pressure sensors, design and analysis of some other MEMS-based structures like Accelerometers, Actuators, Electric Sensors, Micro heaters, Electrodes, etc. have also been done to understand the depth of the research work and able to understand the Analytical and Numerical Models. Additionally, several MEMS-supported materials have been analyzed to have a better understanding of more suitable materials for fabricating MEMS/BioMEMS devices. Several MEMS materials were examined based on their mechanical and electrical characteristics to select the best sensing materials. During this process Metals, Semiconductors, Insulators, and Polymers are considered and it was found that Silicon is one of the most common apart from that usage of polysilicon and silicon dioxide is more considerable. Several other materials like gold, zinc oxide, PMMA, PDMS, and Nylon including other materials showed great response while mechanical and electrical properties were analyzed. After all the major concentration was given for a microcantilever and pressure sensor device and its sensing ability in a different medium (environmental monitoring). This work has been done with some essential modifications for diverse environments like in presence of gas, water, and biomolecules. At last, the outcome of this section of work provides that using microcantilever-based structures different bio or chemical molecules can be detected which is helpful for environmental monitoring and healthcare. As per requirements virtual labs and different tools like TinkerCAD, MATLAB R2015a, LTspice XVII, Solve Elec: Circuit 1, COMSOL Multiphysics 5.3a, and Proteus 8 Professional were used for modeling, simulation, and analysis.

Keywords: MEMS, Healthcare, Environmental Monitoring, Multiphysics, Comsol, Sensors.

1. Introduction

In our day-to-day life electrical, electronic and mechanical devices are very important because they are playing a critical role in our life. One common technology which is associated with all these kinds of devices is referred to as MEMS Technology[1]. MEMS means Micro-Electro-Mechanical-Systems. In a very simple way, we can say that it is an association of very small (µ) devices which may be electrical, electronic, or mechanical devices integrated using a single chip. The component size in the case of a microelectromechanical system is between one micrometer to 1 millimeter and 1mm is equal to 1000 micrometers.Fig.1.1 shows the block diagram and basic principle of this MEMS technology.

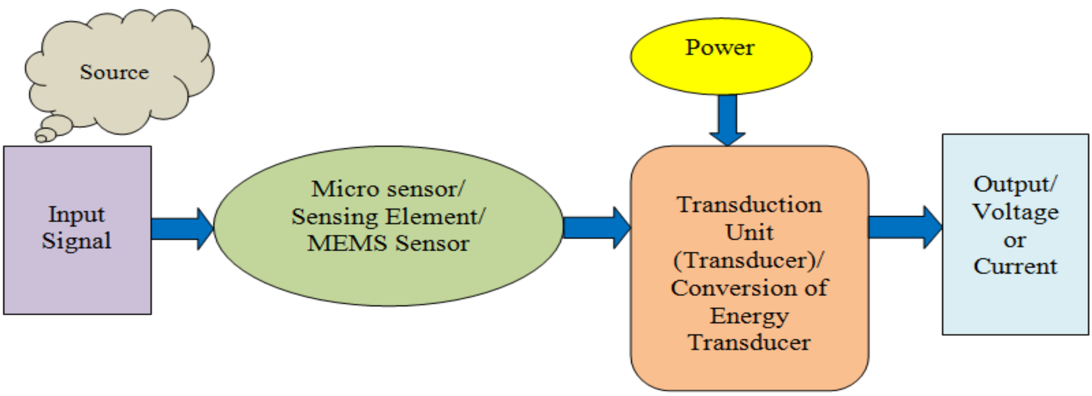


Fig.1.1 Block diagram of MEMS

There is a variety of changes in the field of MEMS because of the enlargement of silicon technology[2]. There are a lot of features and capabilities of MEMS-based devices, they can think, sense or even act also. MEMS-based devices add sensing and it can be measured in terms of movement, vibration, pressure, temperature, or light. One very common thing in all these kinds of MEMS is the use of transducers, microsensors, and microactuators, without these devices, we cannot even imagine MEMS. In the field of MEMS, there is an essential role of machine control systems. Generally, machine-controlled systems are referred to as mechatronic systems. Mechatronics, which blends mechanical, electrical, electronic, computer, and control engineering, has significant advantages for MEMS technology. A mechatronics system's main functions are depicted in Fig.1.2

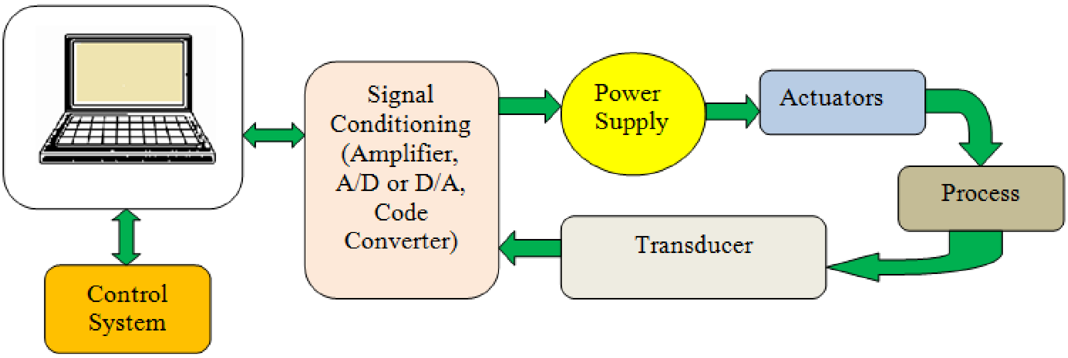


Fig.1.2 Block diagram of a Mechatronics System

The primary function of a sensor or transducer in this system is to give electrical signals for many parameters, including displacement, acceleration, pressure, velocity, force, and flow. The signal from a transducer connected to a computer is enabled under signal conditioning with the aid of an amplifier, an A/D or D/A, or using a code converter. Control systems build and embed control logic as software in a microprocessor or computer. Mechatronics has distinctive applications, such as process control, environmental studies, power generation, etc.[3]. The two basic classes of miniaturizing devices are microsystem technology and nanotechnology. In the case of microsystem technology, bulk micromachining devices can be obtained via a top-down technique, with sizes ranging from 0.1m to a few m. In nanotechnology, the bottom-up method, also known as surface micromachining, is more prevalent. This method yields fabricated devices with a size range of 0.1nm to 0.1m. With the use of integrated electronics and a batch production technique, MEMS can be used to develop and build complicated mechanical devices. Smaller systems have less mechanical inertia, making it easier for users to start or stop a device quickly. As a result, smaller devices are highly recommended. Apart from that, when compared to larger components, smaller components suffer from reduced thermal distortion and mechanical vibration due to their lower mass. As a result, these facts provide advanced features for using MEMS-based devices in various domains[4].

1.1 SENSORS

In a very simple language, we can understand the concept of a sensor. It is a device receiving a signal and according to the received signal, it will respond. This signal must be energy, heat, light, motion, or electrical or chemical reaction. Generally, the sensor takes the output of the transducer and converts it either into voltage or current. The primary work of a transducer is to convert one form of energy into another form. From a control point of view, the purpose of a sensor is to sense the signal while actuators are useful to activate a control action. There are certain things which is very much essential when selecting any sensor like environmental factors- temperature range, size, humidity effects, power consumption, self-test capability, etc.

1.2 TRANSDUCERS

A transducer is a device or it can be also referred to as a basic element that is especially much useful to convert one form of energy into another form (mostly electrical energy). A major requirement of conversion is sometimes the available form is not suitable or operation is not possible so for observation, required measurement, quantification, or manipulation according to the situation and related application energy conversion is required with the help of a transducer. Transducers are capable to perform the sensing operation as well as quantify the physical, electrical, mechanical, and fluidic variables like temperature, pressure, vibration, flow of voltage, radiation, and many more. The major difference between a transducer and a sensor is a transducer is enough capable to convert the energy from one form to another form but it is not possible to quantify the conversion through a transducer but in the case of a sensor it is enough capable to quantify the energy level. So according to this basic principle transducers and sensors are applicable for different applications[5].

1.3 ACTUATORS

An actuator is a device that is much utilized to accomplish the alteration. It has a huge role in the field of automation as well as control. Some of the popular and very common actuators are mechanical actuators, thermal actuators, electrostatic actuators, and magnetic actuators. Mechanical actuators are mainly classified into two types, Mechanical Structure based microactuators and Active material-based microactuators. Mechanical Structure based microactuators are available in different shapes like beam type, cantilever type, plate type including others. The diaphragm-type microactuators are nothing but a plate or membrane-type microactuators. One very notable point is actuators are working on the principle of the properties of the materials from which that particular actuator was constructed. Even active materials also play a reasonable role.

1.4 MICROCANTILEVER

Microcantilever refers to a device that is fixed on one end and free on the other. Micro beams and cantilever constructions are essentially very valuable transducer elements that can be used to measure a wide range of physical events.

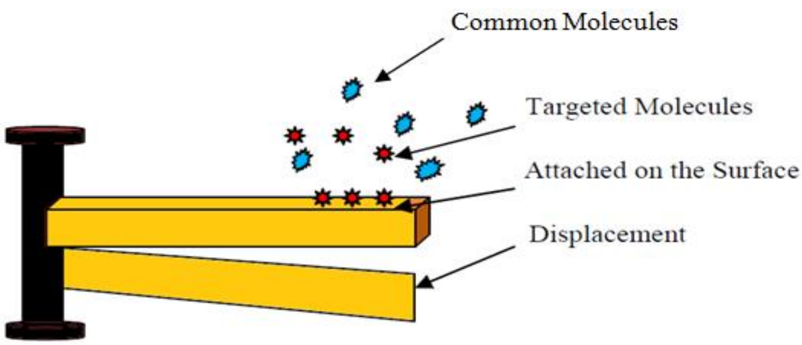


Fig.1.3 Micro Cantilever Setup

It can be utilized as sensors, transducers, probes, needles, transport mechanisms, and switches in various industries due to its simplicity, flexibility, versatility, and distinctiveness. Fig.1.3 shows the setup of a microcantilever structure. Microcantilever is capable of high and fast measurement of mechanical movements and also it works with less power consumption. So, it can be used for multipurpose. Through Fig.1.4 detecting principle of a microcantilever is represented. In short, it detects the analytes (bio analytes or chemical analytes) and provides a measurable signal. Micro cantilevers come in a variety of shapes, including rectangular, paddle-shaped, triangular, trapezoidal, V-shaped, step profile, I-shaped, T-shaped, and many others. It can be used for pH Sensing, Sensor for DNA, Electronic Nose, Prostate Cancer, and many more. It is an ideal device mostly for the applications like environmental monitoring and healthcare.

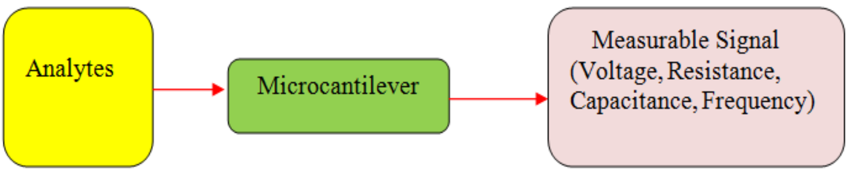


Fig.1.4 Detecting principle of a microcantilever

1.5 PRESSURE SENSOR

The central idea of a system is to analyze the responses between input and output. In the case of a pressure sensor, it senses the pressure that is input and converts it as an analog electrical signal which is the output of the pressure sensor concerning the given input. Another notable point is the magnitude of the analog electrical signal depends on the pressure applied to that particular surface. There are mainly three different principles of sensing Piezoelectric, Piezoresistive, and Capacitative pressure sensing.

$$\text{Pressure(P)} = \frac{\text{Force(F)}}{\text{Area(A)}} \quad \text{-----} \ (1.1)$$

The key reason for the occurrence of Force is because of applied pressure on the surface. So, pressure is the ratio of the Force (F) to the Area (A) which has been shown in equation-1.1. Pressure can be measured by measuring the deflection of the diaphragm which occurs due to applied pressure to the diaphragm. In fig.1.5 shows the very basic phenomenon of a pressure sensor device.

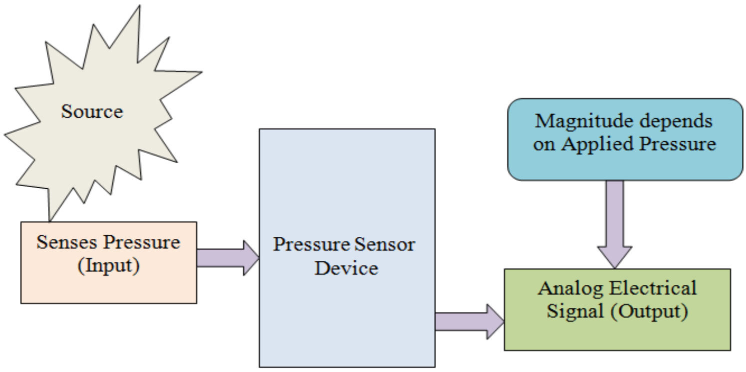


Fig.1.5 Phenomenon of a Pressure Sensor Device

1.6 MULTIPHYSICS FOR MEMS-BASED RESEARCH

In this research work to achieve the goal mainly COMSOL 5.3a multiphysics software has been utilized. This tool can add more than one physics for the same structure and also it can be analyzed in different environments.

1.7 PRIMARY OBJECTIVES OF RESEARCH

1. To understand MEMS technology and learn the different properties of materials with the help of a multiphysics-based concept. The major finding, in this case, is to get knowledge of different sensing materials to have a better understanding of more suitable materials for fabricating MEMS/BioMEMS devices.[Available in section 4.4 and 4.7]

2. To study the various effects due to dimensions, shapes and material changes for microstructure devices in a multiphysics environment. A major study to concentrate on different properties like capacitance, electrical voltage, displacement, stress, strain, velocity, etc. [Available in section 4.5,4.6 and 4.7]

3. Design and study of a MEMS-based Microcantilevers device for the best sensitivity. The major study, in this case, is the static and dynamic modes of the microcantilever. Additionally, expose microcantilever as a biosensor and its different roles in healthcare under different environmental aspects. [Available in section 4.2,4.3 and 4.8]

4. Test and evaluate the MEMS-based pressure sensor in a variety of environments. (This study is much useful, especially for healthcare and environmental monitoring systems). [Available in section 4.9 and 4.12]

5. Analysis of reliability, sensitivity, and performance concerning sensing layer and device response. As an example, design and investigations of temperature effeteness applied voltage with temperature, Characteristics of heat flow in 3D structures, etc. [Available in section 4.10]

2. REVIEW OF LITERATURE

The present demand of the world is to have some latest technology through which one can monitor and detect the desired things at the initial position itself, to have further control and safety in life. The major aim of this research work is to achieve the same thing using MEMS technology[6].One of the well-known American Electrical engineers his name is Harvey C.Nathanson invented the very first Micro-Electro-Mechanical System (MEMS) device. In the year 1958 silicon strain gauges were available as a commercial product. Later during the year, 1959 Feynman stated that MEMS can integrate both electrical and mechanical components. After a few years in 1961 first silicon-based pressure sensor was presented. Later in the year, 1970 first silicon accelerometer was introduced. During the 1980's huge research has been done about understanding the concept that how silicon can be a mechanical material, the LIGA Process, and techniques of micromachining. After a few years during 1990's Bio-MEMS got more concentration because of its healthcare-related applications, especially in the year 1995 onwards Bio-MEMS has a rapid development and became popular.

2.1 KEY POINTS OF THE LITERATURE SURVEY

MEMS-based literature survey and analysis is one of the very difficult tasks because of its involvement in different fields like a multidisciplinary kind of research work[7]. The entire literature survey and relevant essential work have been summarized, which is given below:

Table 2.1 Summary of Literature Survey

S.No.	Year	Authors	Inferences
1.	1995	Chen, G. Y., T. Thundat et al.	Molecule adsorption on cantilever surfaces causes bending and resonance frequency shifts[8].
2.	1999	Britton, C. L. et al.	Microcantilever array for mercury and hydrogen detection[9].
3.	2000	Raiteri, R et al	Surface stress variations were measured by bending microfabricated silicon nitride cantilevers[10].
4.	2001	Lang, H. P et al.	The array of cantilevers is a selective, ultrasensitive, quantitative, and chemical sensor[11].
5.	2001	Wu, Guanghua	Antigen and PSA antibodies were immobilized on the cantilever's bottom gold surface[12].
6.	2002	Arntz, Y et al.	Micro cantilevers array with functionalized anti-creatin kinase and anti-myoglobin antibodies to detect cardiac biomarker proteins[13].
7.	2003	Khaled et al.	Deflection is due to the chemical reaction between analyte molecules and receptor coating, which causes surface tensions on the receptor side[14].
8.	2004	Zhang, et al.	Using polymer material, developed a microcantilever platform to achieve high-sensitivity biosensors[15].
9.	2005	Hopcroft et al.	SU-8 was used to make cantilevers for atomic force microscopes[16].
10.	2006	Carrascosa, Laura G et al.	Sensors were reviewed, Apart from that fabrication, uses based on chemical and biological analysis, and trends in cantilever fabrication were also discussed[17].

11.	2007	Gino Rinaldi et al.	The microcantilever has been designed and its dynamic behavior was analyzed [18].
12.	2007	Sandeep Kumar Vashist et al.	Done a detailed review of the microcantilever and its diverse applications[19].
13.	2008	Ansari, Mohd Zahid, et al.	Sensitivity and its effecting parameters of a microcantilever as a biosensor[20].
14.	2009	Monika Chaudhary et al.	Design of U and V-shaped microcantilever for better sensitivity[21].
15.	2009	Sree Vidhya et al.	Analysis of geometric alteration, T-shaped Micro cantilever designed and applied the piezoresistive method for the detection of stress[22].
16.	2009	Boisen, Anja, et al.	Microfabricated cantilever arrays for multiplexed detection of biomarkers in real time[23].
17.	2009	Madhu Santosh Ku et al.	Discussed the mechanical, electronics, and fabrication approaches to enhance the sensitivity[24].
18.	2010	Alvarez, Mar, and Laura M. Lechuga	Analysis of small sensor area, fabrication, mass production, and compatibility using CMOS [25].
19.	2012	L.Sujatha et al.	Designed a micro-heater and studied the temperature variation around it. Helpful to monitor the surrounding environmental temperature[26].
20.	2013	Subhashini. S et al.	Investigation for the Presence of CO2 Gas molecules in the atmosphere. The notable point is with increased mass of carbon dioxide resonant frequency decreased. The process was tested with the help of the ZnO Sensing layer[27].
21.	2013	Sandeep Arya et al.	Shown that microcantilever is sensitive to a dynamic viscosity of the different Gases[28].
22.	2013	Anchit J. Kaneria et al.	Performed Static analysis using Galerkin and behavior of the microcantilever beam's interplay of nonlinear electrostatic force and linear restoring force[29].
23.	2013	A.Mirza et al.	Suggested CMOS-MEMS-based microcantilever sensor as capnometer. It’s possible with low cost, less power consumption, and small size[30].
24.	2014	A.Nallathambi et al.	A T-shaped micro cantilever was designed for environmental applications using a Polysilicone sensing layer. A presser that is equivalent to humidity applied on the surface of the microcantilever and analyzed [31].
25.	2014	Gopinath. P.G. et al.	Suggested microcantilever-based arrays with high sensitivity and selectivity[32].
26.	2014	Anuj Kumar Goel et al.	Suggested the mechanical behavior of different structures including microcantilevers under applied pressure and materials properties[33].
27.	2014	Sandeep Arya et al.	Designed a low-frequency signal generator that is based on the MEMS microcantilever concept and did the analytical analysis[34].
28.	2015	Ashwini Kaveeshwa et al.	Has modeled a self-actuating pyroelectric energy conversion which is based on a microcantilever[35].
29.	2015	A. Acheli et al.	Modeling and simulation of the microcantilever. Analysis was made depending on different factors like time, temperature, and materials[36].
30.	2015	P. Graak et al.	Provides how a MEMS-based smart device can be designed and also discussed the methodology of energy harvesting [37].
31.	2016	Murthy, K. S. N et al.	MEMS Biosensor for Tuberculosis Detection was proposed, using a rectangular cantilever[38].
32.	2016	Nikhilendu Tiwary et al.	Characterization of microcantilever through the growth of ZnO nanowire on microcantilever surface[39].
33.	2016	M. Ahsan Saeed et al.	MEMS-based bio-sensor for detection of biomolecules and Analyzed Eigen frequency in static mode[40].

34.	2016	Deep Kishore Parsediya et al.	A common mechanical element for sensing higher and lower mass is a rectangular microcantilever [41].
35.	2016	A. Nallathambi	A pressure sensor is based on the piezoresistive concept for environmental monitoring and so on[42].
36.	2016	Aishwarya Maheshwari et al.	Stepped cantilevers in which by introducing the electrets with steeped microcantilever they had obtained the maximum voltage at the output, by utilizing this several battery related issues can be resolved[43].
37.	2017	N.Siddaiah et al.	Designed a triple coupled microcantilever which is known as a U-shaped micro cantilever[44].
38.	2017	Nitesh Kumar Dixit et al.	Designed a power harvester using the principle of piezoelectric with the help of a microcantilever[45].
39.	2017	Sridevi Gugulothu et al.	Estimated the displacement using MEMS simulator and compared it with the result obtained by COMSOL [46].
40.	2017	Amit Md. Estiaque Arefin et al.	The authors of this article have shown that the Length and thickness of a microcantilever have a continuous effect but the width has a discontinuous effect on the Eigen frequencies. Overall dimensional effect on Eigen frequencies was carried out through this paper[47].
41.	2017	A Panahi et al.	Suggested how an air leakage can be identified in the airplane using the microcantilever concept[48].
42.	2017	Pallavi Sajjan et al.	Explained about microcantilever as a biosensor and also modeled a device that was capable to detect tuberculosis by using gold as an upper layer[49].
43.	2017	Gopinath. P.G.et al.	Provides a paddle microcantilever with improved deflection and better sensitivity, which is very useful for biomedical applications[50].
44.	2017	D. S. Bhade	Review of MEMS and the key methodologies useful for designing MEMS devices [51].
45.	2017	U. G. Phonde et al.	Suggested the different applications and future scopes of MEMS-based devices almost in all the fields[52].
46.	2017	Hiroshi Yanazawa et al.	Gave his opinion and analysis of the growing market, latest trends, and future applications of the MEMS [53].
47.	2017	Harini Mathur et.al	Designed the DTF deposited microcantilever structure pressure sensor on a silicon base[54].
48.	2017	Cheng-liang PAN et al.	Explained how to capture wind energy as a power source for a remote wireless sensor network using a right-angle piezoelectric cantilever beam[55].
49.	2017	Dong LI et al.	The resonance frequency and sensitivity of the piezoelectric vibration energy harvester are affected by increasing mass or modifying the length [56].
50.	2018	F.R. Munas et al.	Analyzed three different geometries (square, circular, cross-sectional) of a diaphragm and concluded that square-type geometry is more sensitive[57].
51.	2018	Yang Hong et al.	Exhibits the effect of the neutral plane's position on the output power of piezoelectric cantilevers, they also explain possible techniques to improve the output power of piezoelectric [58].
52.	2018	Bindu A Thomas et al.	Properties of different materials were analyzed under different conditions in multiphysics[59].
53.	2018	Anuj Kumar Goel et al.	Sensitivity improvement is done by making holes nearby the fixed end of the micro cantilever[60].
54.	2018	Iraj S. Amiri et al.	Investigation using SEM and AFM to examine the microstructure of the constructed microcantilever [61].

55.	2018	I. Mala Serene et al.	Suggested the use of MEMS-based microcantilever to identify various diseases. They also discussed different materials and dimensions which are used to detect various diseases are also summarized[62].
56.	2018	Dinesh R. Rotake et al.	A Microcantilever study has been done using surface modifications mainly for BioMEMS applications[63].
57.	2019	Devin Kalafut et al.	Tristable behavior has been analyzed and some future work has been suggested[64].
58.	2020	Madzhi et al.	Suggested how to improve the sensitivity of piezoresistive microcantilever and sensitivity of the microcantilever depends on materials, its geometrical dimensions, and shapes of the micro cantilever[65].
59.	2020	Tasnim Sarker et al	Presented slotted microcantilever using P-24 Antigen, through simulation they presented a microcantilever based biosensor which is useful for detection of HIV(Human Immune Deficiency Virus)[66].
60.	2020	Dinesh Rotake et al.	Presented the optimization techniques of a microcantilever by single and multi-arm [67].
61.	2021	Daniel Mamou et al.	A variety of parameters about Surface Modification of Cantilever for Industrial Gas Sensors[68].
62.	2021	Hao Jia et al.	Done a major research work on Bio/Chemical Detection in Air and Liquid Using Integrated Resonant Micro/Nano Gravimetric Sensors[69].
63.	2021	Miranji Katta et al.	Identification of many tropical diseases simultaneously using PZT-5H piezoelectric material and microcantilever, with the help of molecular mass[70].
64.	2021	S Akshya et al.	The concept uses a piezoelectric microcantilever to detect the different molecules[71].
65.	2022	Joachim Frühauf et al	Analysis of Silicon Cantilever for Micro and Nano force as well as Stiffness Calibration[72].
66.	2022	Shervin Foroughi et al.	Microcantilevers with Various Stiffnesses for different Sensing Applications[73].

In addition, more persons have newly made some further noteworthy contributions. Y. Li et al. (2022) investigated the Sensitivity improvement of piezoelectric concept-oriented MEMS Acoustic Emission sensors by utilizing Multi-Cantilevers. S. Shi et al. (2022) suggested the enhancement of sensitivity by changing the shapes and materials of a microcantilever. Jae-Hoon Choi et al. (2022) provided the evidence and suggestions for the testing of the bending operation of microcantilevers and their different applications. Finally, it has been stated that it is one of the most fascinating fields to study and that there are several opportunities for environmental monitoring and research focused on healthcare.

3. ASSESSMENT METHODS AND MATERIALS

The major finding of this investigation is to detect the bio analytes and chemical analytes for the detection of different diesis at their early stages. Additionally, protecting the environment through environmental monitoring is much useful for healthcare.

3.1 PROCESS AND METHODOLOGY

To achieve the targeted goal of the research there are a lot of steps and observations which are listed below, it provides the path on which research work has been carried out.

- First of all, concentration was given to understanding the emerging trends and ongoing research works in the field of MEMS, BioMEMS, and Microfluidics to investigate the unknown facts through the mechanical, chemical, and biological behavior of Microstructures using multiphysics concepts with the help of a majorly used software COMSOL5.3a.

- To understand multiphysics, modeling, and design in a multiphysics environment using FEM (Finite Element Method) and find more suitable sensing Materials for MEMS/BioMEMS-based devices. Additionally, Sensitivity, overall optimization, reliability, and Performance analysis concerning different sensing materials using modeling and simulations.

- To Design MEMS-based devices like Microcantilever and pressure sensors as well as understand the concept of surface chemistry, dimensional variations, changes made in shapes, and the role of sensing materials for different microstructures which is working on the principle of microcantilever or pressure sensor.

- To design and analyze Analytical, Numerical, Prototype, static and dynamic Models to understand the concept of MEMS-based devices, Microcantilever bending, piezoresistive and piezoelectric effects, self-heating, selection of the superior type of power supply, etc.

- Design of overall MEMS-based device under different environmental conditions or under different effecting parameters, which is useful for environmental monitoring and healthcare. Additionally, Justification for the whole research work through study, analysis, optimization, modeling, and simulation results.

3.2 RESOURCES AND TOOLS

To achieve the goal of the research during the circuit level analysis used software are TinkerCAD, MATLAB R2015a, LTspice XVII, and Solve Elec: Circuit 1, but during device level modelingCOMSOL Multiphysics 5.3a, TinkerCAD and Proteus 8 Professional were used. Additionally, virtual labs are also used to do the proper justification for this research work.

3.2.1 Comsol multiphysics 5.3a: This multiphysics tool provides the user to analyze different physics even more than one physics to obtain a unique result that may use for several applications[74]. Finite element analysis plays an important role in this multiphysics environment[75]. This software is majorly used for this research work apart from this other software used as a supporting software[76].

3.2.2 Tinkercad: This is a well-liked free accessible web app. It is much helpful to design 3D structures, electronics, and different kinds of coding from the basic to research level. In this research work, tinkercad tool has been used especially to design the 3D structures and to understand the virtual experiments in the absence of physical laboratories in a virtual manner.

3.2.3 Matlab (used version-Matlab R2015 a): MATLAB is a tool and it is a common platform that all the researchers, scientists, academicians, industrialists, and interested people are making use of it according to their applications. MATLAB R2015 has been used for this research work especially for analyzing the graphs by comparing them with Comsol.

3.2.4 LTspice XVII: LTspice is one of the best schematic-driven tools as a circuit simulation program. It is an open-access tool that is freely available. Using this tool circuit level analysis was obtained, Another great advantage of making use of this tool is without much coding circuit analysis can be performed with the help of some proper steps.

3.2.5 Solve Elec: Circuit 1: This tool is very easy to use and much fruitful. It is freely available and the beauty of this tool is input coding is not required. Thus according to the targeted applications if the circuit diagram is correct then one can be able to obtain the correct value and even dc as well as analysis can be done very effetely using this tool.

3.2.6 Proteus 8 Professional: This is a very powerful tool and because of this tool PCB design and circuit simulation became very easy and user-friendly. Broadly it has three different sections or features which helped process the research workflow.

3.2.7 Virtual Labs: It is much more difficult to fabricate the micro or nanodevices due to the unavailability of lab facilities almost everywhere but without doing some kind of experimental studies one cannot complete the research work. Thus, one of the most suitable ways was chosen to achieve the goal of this research work i.e. by making use of virtual labs.

3.3 PURPOSE AND USE OF VARIOUS MATERIALS

In the process of the research work under a multiphysics environment using MEMS technology, there is a huge role of materials[6]. Most important materials have been studied through the literature survey, tested through the simulation, and compared the performance with one another among the material itself [77]. As a whole, it is found that the following materials play a leading role in this research work, Silicon Oxide (SiO_2), Aluminum (Al), Gold (Au), Silver (Ag), Gallium Arsenide (GaAs), Polysilicon, Silicon, Zinc Oxide (ZnO), Silicon Nitride (Si_3N_4)and several polymers. Additionally, Silicon Carbide material is very popular for harsh environment analysis processes. Apart from that three most important properties of materials are Piezoelectric, Ferroelectric, and Pyroelectric which provide fruitful results. In addition, the smart materials can be employed as sensors, converting the strain placed on them into an electrical signal that can be utilized to calculate the system's strain levels. Similar to actuators, they produce strain in response to stimuli like voltage. The major mechanical properties considered in this research are elasticity, plasticity, ductility, brittleness, hardness, toughness, stiffness, resilience, endurance, strength, etc.

4. DESIGN AND ANALYSIS

The microcantilever, as well as pressure sensor principles, have been used in modeling and simulation for a variety of prospective and novel constructions to achieve the goal of the study effort. Numerous good outcomes were reached in the analysis and simulation of the pressure sensor as well as microcantilever in both of its modes-static and dynamic.

4.1 ANALYSIS OF CANTILEVER USING VIRTUAL LAB

This section is providing information about 3rd research objectives. Understanding cantilever behavior requires some sort of experimental inquiry. Taking into account that such research and analysis can only be carried out with very restricted resources. This led to the deployment of a platform known as the virtual lab (A MOE Government of India Initiative), which is open to all researchers.

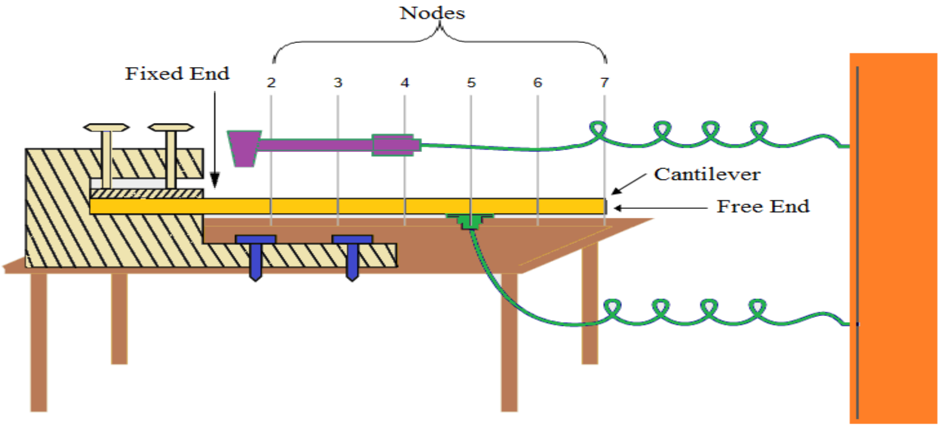


Fig.4.1 Experimental setup of a cantilever

(Source: https://va-coep.vlabs.ac.in/exp/cantilever-modal-analysis/simulation.html)

In this analysis shown in Fig.4.1, dimensions are taken as Width=4.5e-5 µm, Height=1.5e-5 µm, Length=0.000325 µm.Just by hitting the hammer one by one concerning modes (2, 3, 4, 5, 6, and 7) responses have been analyzed. Fig.4.2 and 4.3shown the response of mode-2.

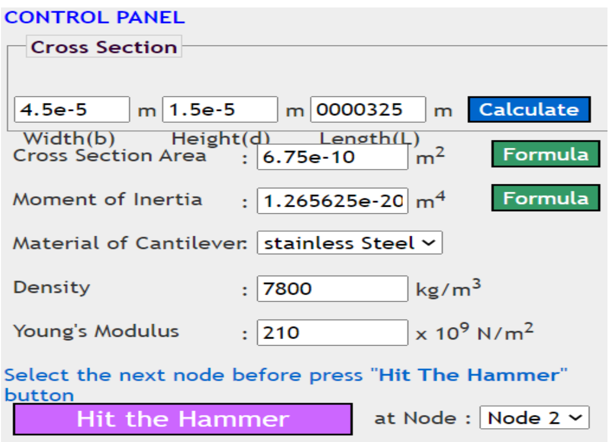


Fig.4.2 Response of cantilever at mode-2

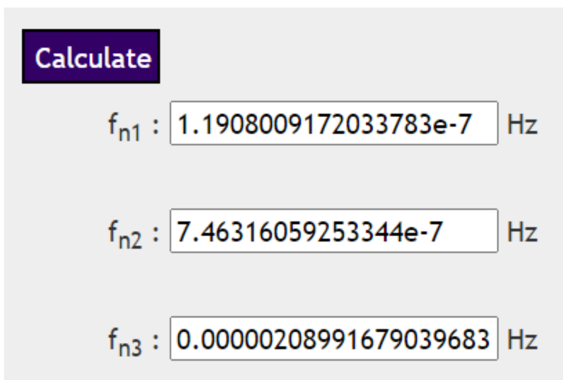


Fig.4.3 Obtained frequencies due to deflection

4.1.1 Use of Strain gauge sensor for Cantilever Analysis

An electrical resistivity changes as a result of mechanical tension (strain gauge). A strain gauge is a tool that measures stress in a material at any position. The strain it causes is typically used to evaluate stress. A strain gauge is a long-length conductor which may place in a zigzag pattern on a membrane. Even according to the finding parameters it may place at different areas on the surface of microstructures like microcantilevers and required values may obtain. Mechanical elongation and compression are converted into quantifiable values via a strain gauge transducer. A strain gauge property mainly depends on Poisson's ratio, Gauge factor, and Young's modulus. The sensitivity of the strain gauges is used to define their features (gauge factor). According to the working principle mainly there are three types of gauge factors i.e. Mechanical, electric and piezoelectric. The gauge factor is one unit change in resistance for every one unit change in strain gauge wire length.

$$\text{Gauge Factor}(\text{G. F.}) = \frac{\frac{\Delta R}{RG}}{\varepsilon} \quad \text{---------- (4.1)}$$

Where, ΔR– Change in Resistance, R_G-Resistance of Unreformed Gauge, ε-Strain. To proceed further the same principle has been tested which has been shown in Fig.4.4 and 4.5. By doing the analysis, major observations using this virtual pattern are, that it has limited materials and even new materials cannot be added by the user. Apart from that Shape of the cantilever cannot be changed only dimensions can be changed; Deflections concerning different modes can be seen easily.

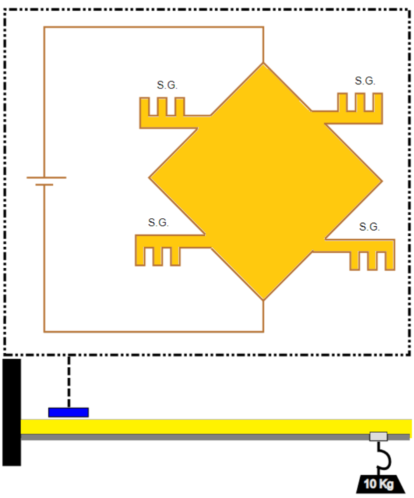


Fig.4.4 Full Bridge

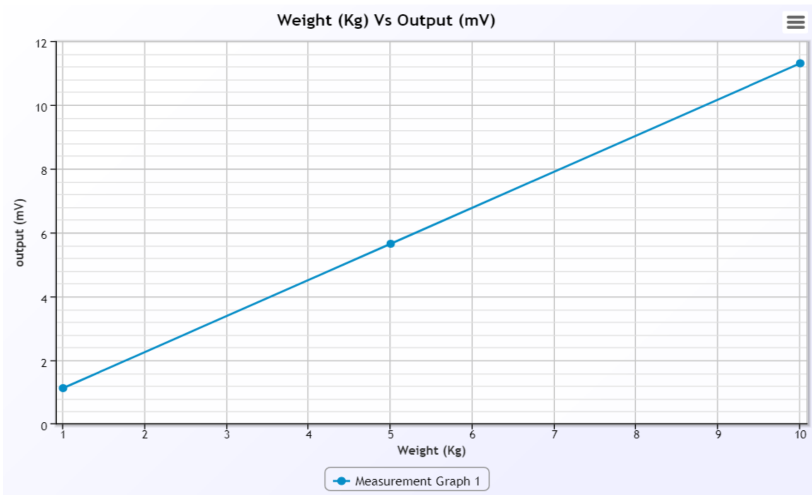


Fig.4.5 Weight versus Voltage

4.2 MODELING AND SIMULATION OF MICROCANTILEVER

This section is satisfying 3rd Research objective about design and study of microcantilever.At the initial level simulation of the microcantilever in both modes has been done using the tool COMSOL 5.3a, which is a multiphysics software with great features.

4.2.1 Micro Cantilever in Dynamic and Static Modes

Taken the dimensions such as Width=45 µm, Depth=325 µm, height=15 µm, and using silicon material modeling and simulation have been done. Modeling and Simulation have been done for a microcantilever with the same dimensions, shape, and material. Through this analysis, it has been noticed that while the microcantilever is working in dynamic mode it's providing total displacement very high (shown in Table 4.1) as compared to its working mode in static mode. Another notable point is during dynamic mode displacement occurs due to mass at the free end of the microcantilever but in the case of static mode, displacement is because by stress. So in the case of static mode, effective values of stress and strain have been calculated.

Table 4.1 Comparison of Displacement

Working Modes of Micro Cantilever	Total Displacement	Effecting Parameters
Dynamic Mode	3.56×10^{6}µm	Eigen Frequency=2.4803E6 Hz
Static Mode	1.95×10^{4}µm	Stress=9.25×10^{11}(Maximum Value) Strain=4.71(Maximum Value)

Finally, it is clear that the microcantilever is more sensitive in dynamic mode but this mode of analysis is not suitable for liquid medium. It has been also pointed out that a change in resonance frequency is due to mass, if the mass increases resonance frequency decreases.

4.3 IMPACTS OF CHANGE IN MATERIALS OF A MICROSTRUCTURE

This section is the outcome of 1st research objective about the material properties. Through literature survey, it has been found that few materials are providing maximum displacement while applying force on the surface of microcantilever and it has been analyzed in the FEM-based multiphysics environment under stationary studies by applying -7N force.

Table 4.2 Maximum displacement(case-I)

Dimensions	Materials	Maximum Displacement(µm)
	Silicon	1.37×10^{4}
	Silicon Nitride	9.37×10^{3}
	Polysilicon	1.39×10^{4}
L=325 µm W=45 µm H=15 µm	Silicon Oxide	3.37×10^{4}
	Gold	3.15×10^{4}
	Polyimide	7.29×10^{5}
	PDMS	2.79×10^{9}
	Silicon Carbide	2.93×10^{3}
	Zinc Oxide	1.63×10^{13}

Table 4.3 Maximum displacement(case-II)

Dimensions	Materials	Maximum Displacement(µm)
	Silicon	3.79×10^{6}
	Silicon Nitride	3.79×10^{6}
	Polysilicon	3.79×10^{6}
L=355 µm	Silicon Oxide	3.78×10^{6}

W=30 µm H=5 µm	Gold	3.8×10^6
	Polyimide	3.79×10^6
	PDMS	3.81×10^6
	Silicon Carbide	3.8×10^6
	Zinc Oxide	3.79×10^6

MEMS materials are primarily available in three different categories as Metals, semiconductors, and Insulators. From each category, a few relevant materials have been chosen and as a whole total of 9 materials have been tested and it has been found that Zinc oxide and Gold are more suitable materials which provide maximum displacement at different Eigen frequencies with load or under without load conditions. The same thing has been shown with the help of Table-4.2 and 4.3 by changing the dimensions. Somehow since gold is very costly so in some places we may use Zinc oxide instead of gold but not suitable for all cases.

4.4 INVESTIGATIONS THROUGH DIMENSIONAL VARIATIONS

Case-I: This is the 2nd research objective in which, dimensional variations and their effects on Eigen frequencies and displacement has been considered and studied. Material is Silicon and dimensions are taken as Length L is varying while W=30µm and H=5µm is constant. In the next step width (W) is varying while L=355µm and H=5µm is constant. Again Height (H) is varying while L=355µm and W=30µm is constant. Analyzed under Eigen Frequency Study without applying any load or pressure. This analysis and the result are concluded in Table-4.4.

Table 4.4 Analysis of Eigen frequency effects on displacement

Parameters		Displacement	Eigen frequencies
Length	Increasing	Continually Decreasing	Continually Decreasing
Width	Increasing	Not Increasing Continually, at some particular Eigen frequencies it was decreasing also. So it's a random increment and decrement in displacement.	Random increment and decrement.
Height	Increasing	Continuously Increasing and then started decreasing.	Continually Increasing

Case-II: Dimensional variations under constant applied force -7N in the Z direction and its effects on displacement under stationary study have been considered (shown in Table 4.5).

Table 4.5 Displacement under stationary

Parameters		Displacement
Length	Increasing	Continuously Increasing
Width	Increasing	Continually Decreasing
Height	Increasing	Continually Decreasing

4.5 INVESTIGATIONS THROUGH SHAPE VARIATIONS

In this section 2nd point of research objective has been considered. Here, Pi, N, and H shapes of a microcantilever have been designed and analyzed for total displacement. Apart from that other shapes like rectangular, paddle, triangular, trapezoidal, V-shaped, step profile, I-shaped, and T-shaped were also simulated and tested.

4.6 PIEZOELECTRIC PHENOMENA

This section is based on the 1st as well as 2nd research objective. Initially Vibration Characteristics of Aluminium Cantilever Beam using piezoelectric-ceramic sensor has been studied (Fig.4.6) using a virtual lab[78].

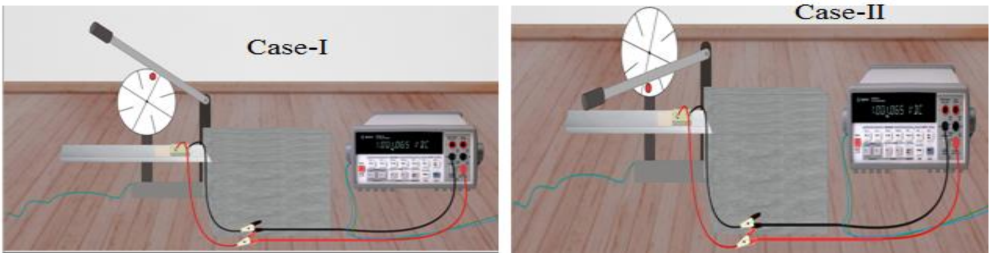


Fig.4.6 Study of Piezoelectric phenomena with the help of virtual lab

(Source:https://vssd-iitd.vlabs.ac.in/exp/piezoelectric-sensors/simulation.html)

4.6.1 Vibrations control of the micro-cantilever

It is very essential to add layers of the piezoelectric actuator to the microcantilever to control or at least reduce the modal vibrations. Here ZnO and PZT-5H are used as a piezoelectric actuator layer. Design and analysis have been done using both the materials and comparisons have been made between them. The piezoelectric actuator is built of ZnO and PZT, while the microcantilever beam is composed of polysilicon, silica, and platinum.

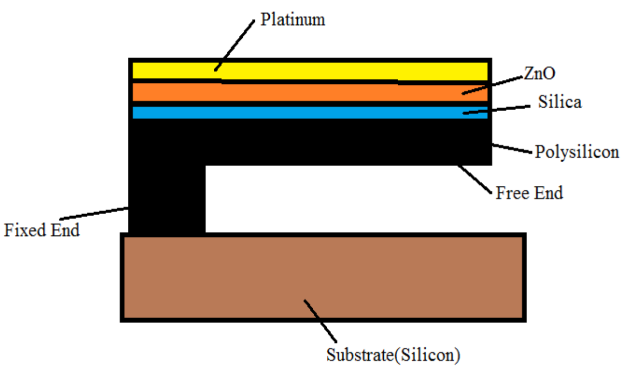


Fig.4.7(a) Piezoelectric(ZnO) layered Microcantilever

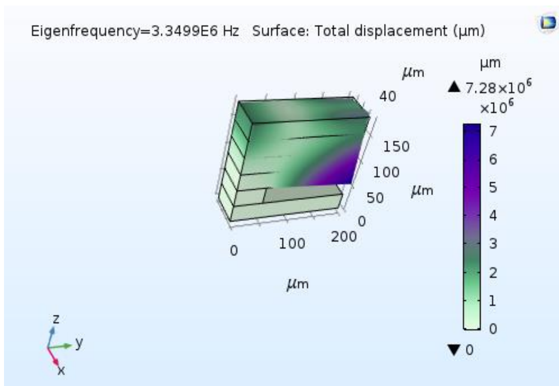


Fig.4.7(b) Displacement Using PZT-5H

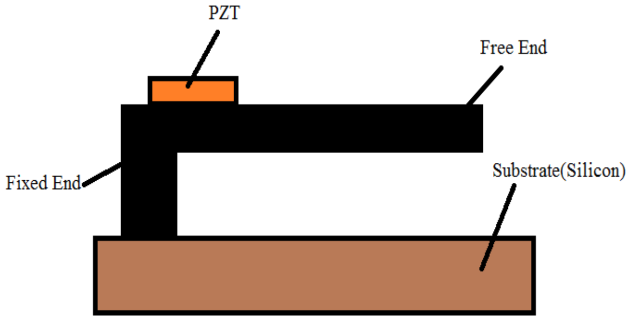


Fig.4.7(c) PZT (Piezoelectric) material analysis

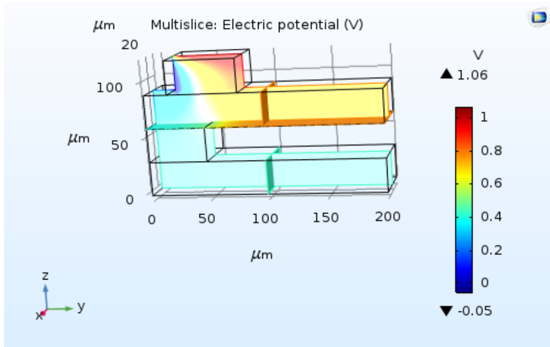


Fig.4.7(d) Increase in electrical potential(Case I)

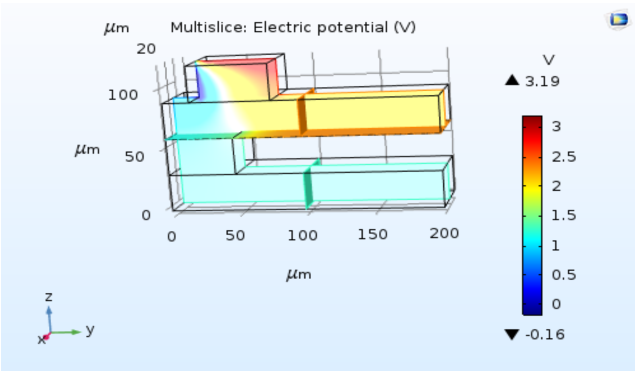


Fig.4.7(e) Increase in electrical potential(Case II)

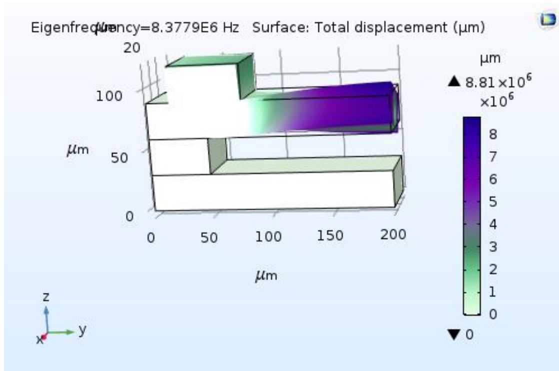


Fig.4.7(f) Displacement Using PZT-5H

It is possible to eliminate the undesirable vibrations of the micro-cantilever and enable the cantilever to deflect by the intended mode of vibration by including a piezoelectric layer, which is PZT; at the near end of the fixed micro-cantilever beam. The same process has been done which is shown in Fig.4.7 (a) to 4.7(f). Node movement is prevented by a lack of voltage for the piezoelectric actuator. Furthermore, as the voltage is raised, the node displacement will rise as well. Finally, it was noticed that the cantilever length and voltage supplied to the piezoelectric actuator can both be altered to get the ideal resonance frequency.

4.6.2 Micro battery

By making use of piezoelectric material ZnO and additional suitable materials a micro battery has been designed in which by providing a less input voltage to piezoelectric material greater potential can be generated. It is shown in Fig.4.8 and Table-4.6.

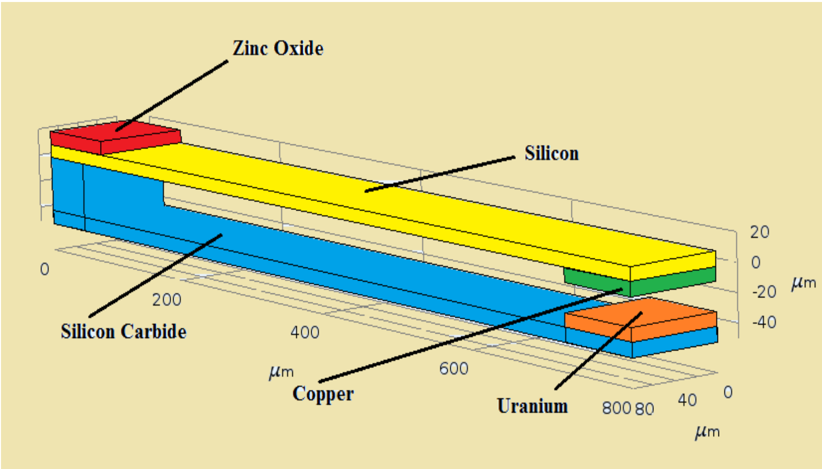


Fig.4.8 Design of a micro battery

Table 4.6 Electric Potential(V)

Input Voltage	Output Voltage
3	3.22
5	5.37
10	10.7
15	16.1
25	26.9
50	53.7
100	107
200	215

4.7 ARRAY OF MICROCANTILEVERS ANALYSIS

This design procedure is shown in Fig.4.9 and Table-4.7. In this section, nine different materials were shortlisted based on various factors and properties, and it was discovered that SiO_2 can achieve maximum displacement. Another fact has been highlighted: by drilling two circular holes from the fixed end, the effective area of microcantilevers can be reduced, resulting in a higher displacement. This is one of the outcomes of 3rd research objectives.

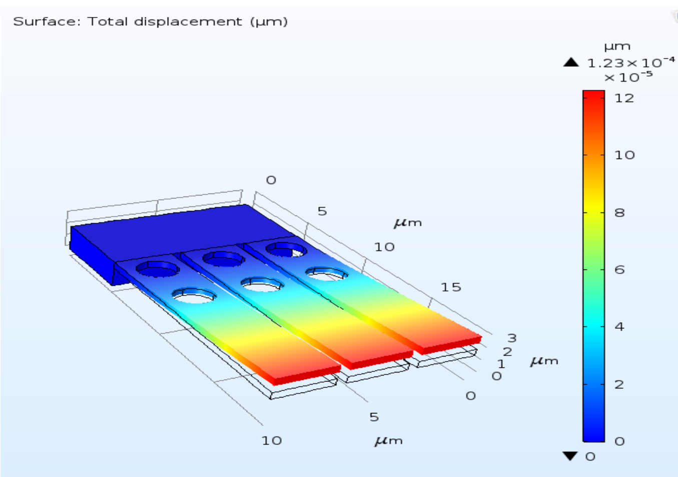


Fig.4.9.Maximum displacement using 2 holes

Table:4.7 Maximum displacement concerning holes

Number of Circular Holes	Maximum Displacement
Without Hole	6.78×10^{-5}μm
2 Holes	1.23×10^{-4} μm
3 Holes	1.17×10^{-4} μm
4 Holes	9.98×10^{-5} μm

4.8 DESIGN AND ANALYSIS OF A PRESSURE SENSOR

This section is satisfying the major outcomes of 4th research objectives. Displacement, pressure, and other various physical parameters can be measured using capacitive transducers[79]. As square typed diaphragms are preferred and when comparing our result to similar kinds of previously contributed[80] works (circular typed diaphragms), our study is incremental research by enhancing the mechanical parameters.

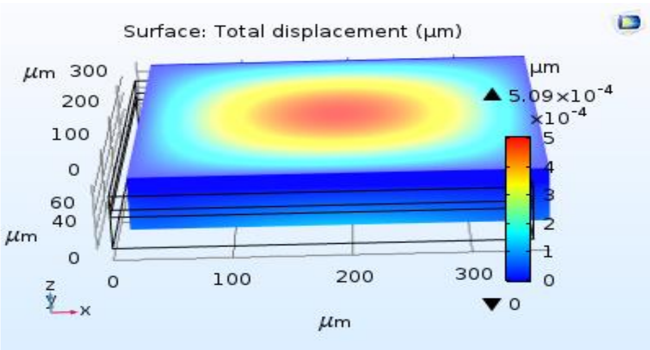


Fig.4.10 (a) Total displacement (surface) due to pressure

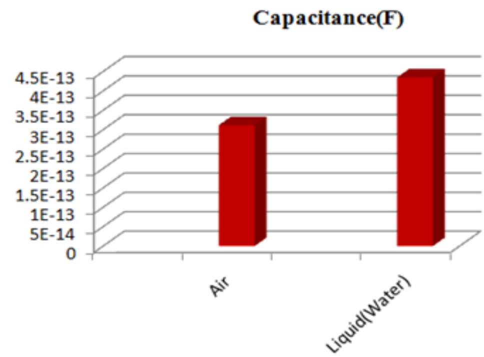
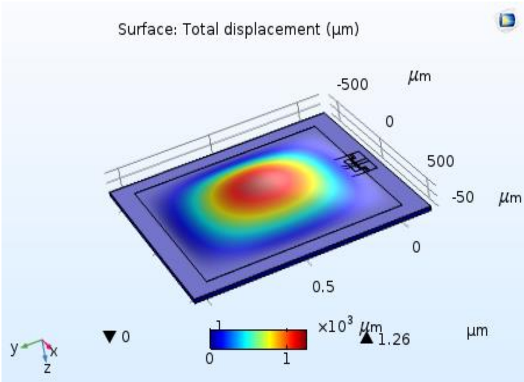


Fig.4.10 (b) Capacitance in air and liquid

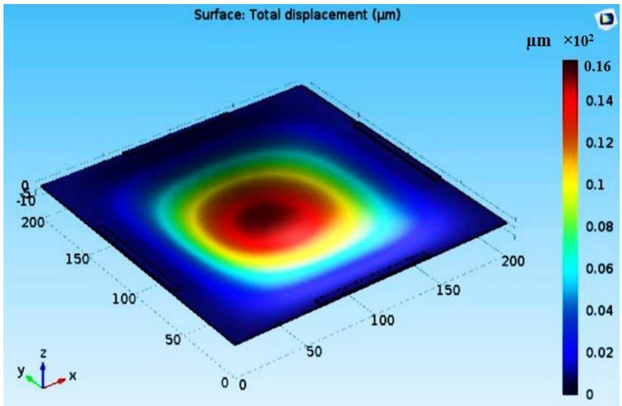
Additionally, the modeled device in this study has a displacement of 5.09×10^{-4}μm, as shown in Fig. 4.10(a), which is greater than the displacement of the previously designed devices, which are 1.5484×10^{-5}μm[81], 2.18×10^{-6}μm and 1.95×10^{-6}μm[82]. Since here the aim is to study the different environments, so in between the gap air and liquid (water) was considered by choosing the appropriate values from the properties of the materials as well as a literature survey. By doing the same in the case of air as a medium obtained capacitance is 3.12×10^{-13} F and for liquid(water) the obtained capacitance is 4.35×10^{-13} F shown in Fig.4.10(b).

4.8.1 Intracranial pressure (ICP) Measurement

An abnormal increase in intracranial pressure (ICP) brought on by an excessive deposit of cerebrospinal fluid (CSF) in the brain is the hallmark of the medical condition known as "water on the brain," or hydrocephalus. The main objective of this simulation is to estimate the magnitude and location of the maximum stress produced by the mechanical force acting on the graphene membrane surface. The next objective is to validate the displacement and strain values, with the expectation that the outcomes will result in a band gap in a graphene-based piezoresistive pressure sensor. Through modeling and simulations is noticed that Graphene based Intracranial Pressure Sensor is much better than a conventional one which has been shown in Fig.4.12 (a) and 4.12(b).



4.11(a) Conventional Pressure Sensor



4.11(b) Graphene-Based Intracranial Pressure Sensor

4.9 HEATING EFFECTS AND MONITORING

A thorough analysis has been done on the property of heat conduction, temperature impacts, material properties, and heat propagation method. Now it is clear that selecting the ideal membrane material is one of the crucial secrets, in addition to the choice of sensing material, which is essential. Surface emission (€) values have been taken into account as 0, 1, and it was shown that surface radiosity is the same in both situations, at 519 w/m^2(max.), while the surface temperature has varied from 293K to 309K (max.) accordingly. The diffuse irradiance (I_{diff}) value for a diffuse surface is 100[W/m^2] and for a diffuse mirror is 0.5[W/m^2]. Through surface temperature study, it has also been discovered that slower heat propagation occurs when thermal conductivity is lower, whereas faster heat propagation occurs when thermal conductivity is higher, which is incredibly helpful for heat transfer and environmental monitoring. This section provides some major outcomes of 5th research objectives.

4.10 ENVIRONMENTAL ANALYSIS AND MONITORING

In the case of gas monitoring, the investigation has been done to directly measure the deflection using a piezoelectric crystal rather than a Wheatstone bridge. When stress is applied to a piezoelectric it generates voltage. Based on its maximum displacement, the proposed sensor must be considered the best and most recommended model for gas sensing properties. Similar to that, the substrate and active layers of the sensor can be adjusted to suit a certain target gas[83]. Additionally, When compared to a multi-layered sensor made from the same volume of zinc oxide, the multistep arrangement showed an increase in sensitivity of almost 90% over a range of applied pressures[84]. Finally, it is determined that the cantilever's dimensions should be tiny for a high-quality factor and higher sensitivity[85].On the other hand liquid, medium-level measurement has been done using a virtual lab to understand the facts. Level-monitoring sensors measure the fluid concentration. It can be used in a variety of high-pressure industrial processes. This is one of the outcomes of 4th research objective.

As a real-time analysis one example of the blind cave, fish has been taken. Due to a network of neuromasts(sensory organ/ part of the lateral line) called lateral lines that are dispersed throughout their bodies, blind cave fish can detect flows and movements of nearby objects even in situations of dark and muddy water. Similarly, an array of adjustable pressure sensors put on underwater vehicles allows for the detection, recognition, and tracking of underwater obstructions as well as the transmission of information about the surrounding flows that may help in reducing the hydrodynamic (motion of water and the forces acting on water /power consumed by the vehicle to move) drag of the Vehicle. Due to the flow, a pressure difference is set between the atmosphere and membrane, resulting in the bending of the diaphragm. The change in resistance can be read out as voltage. With the help of PMMA, PDMS, and Nylon material made the analysis but it is found that PDMS is more suitable (provides maximum displacement) shown in Fig.4.12(a) and 4.12(b).

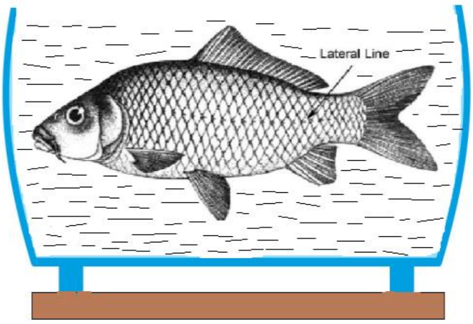


Fig.4.12(a) Blind cave fish with lateral line

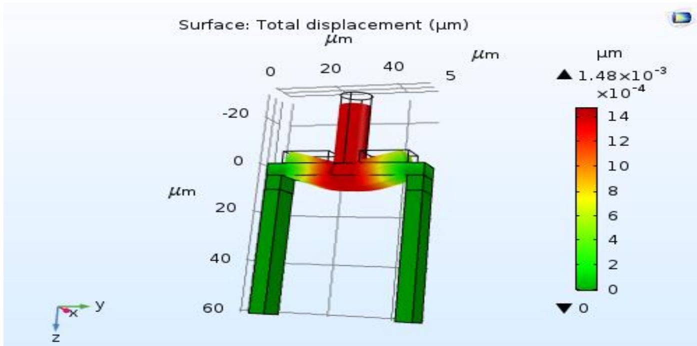


Fig.4.12(b) Maximum displacement using PDMS

4.11 BIOMEDICAL AND HEALTHCARE MONITORING

In this section, a suitable microcantilever has been constructed by using the dimensional values as width= 80 μm, Depth=800 μm, and Height=10 μm. Additionally, Out of 19 different materials, PDMS(Polydimethylsiloxane) provides the greater displacement. Thus, referring to it microcantilever has been designed and tested. Finally, it was exposed that the highest displacement is 1.17×10^{-7} μm, which was achieved using the PDMS (Polydimethylsiloxane) material. There are several tests, but three main shapes have been created and through analysis, it was found that the largest displacement is 1.81×10^{-6} μm, it was obtained when producing round holes on the micro cantilever's surface from the fixed side employing 2D to 3D conversion through extruding. By stacking and coating various materials, sensitivity has been targeted at the third stage. This analysis have been shown in Fig.4.13(a) and 4.13(b).

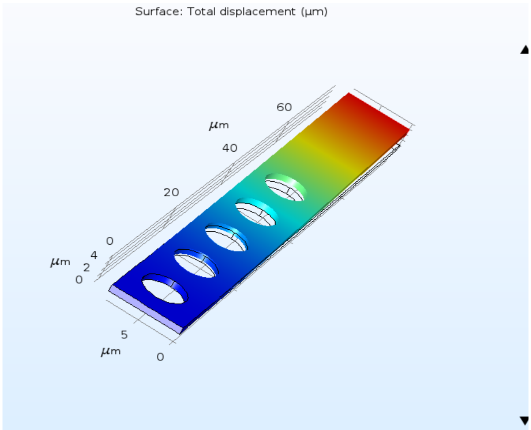


Fig.4.13(a) Circular holes at microcantilever

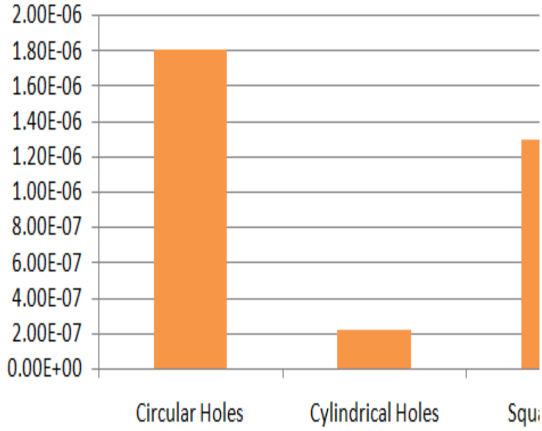


Fig.4.13(b) Maximum displacement through circular holes on microcantilevers

Since DNA (Deoxyribonucleic acid), as well as the image-based cancer detection process, is very expensive and complicated so instead of that using Micro Cantilevers are making the detection process very easy and enough capable to work in a diverse environment. Thus, an analysis has been done for the single, double, and triple strip microcantilever and by analyzing the bending it was noticed that the double strip is more suitable and more sensitive, as shown in Fig.4.14 (a) and 4.14(b).This is one of the outcomes of 4th research objective.

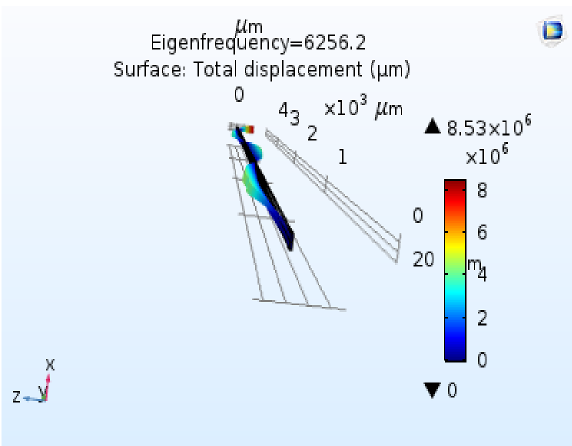


Fig.4.14(a) Total displacement(double strip)

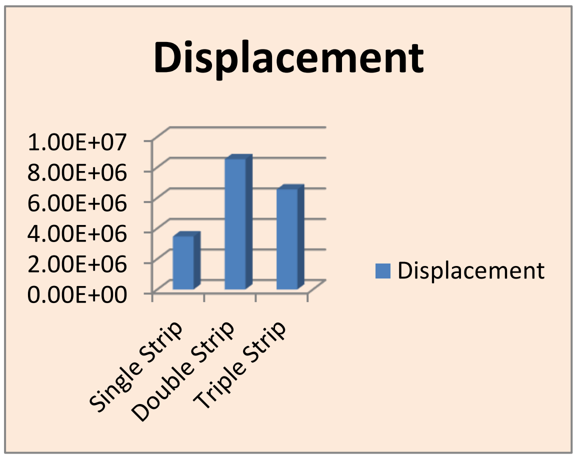


Fig.4.14(b) Analysis of obtained displacement

5. RESULTS ANALYSIS AND DISCUSSIONS

This section's primary objective is to effectively convey all the numerous discoveries from Chapter 4. This division makes an effort to highlight all the significant computed values and offer comparisons between various structures to assist in selecting the best microstructure device [86].

5.1 OUTCOME ANALYSIS OF MATERIALS

Metals, semiconductors, and insulators are the three main kinds of MEMS materials. It is noticed that majorly Silicon Oxide (SiO_2), Aluminum (Al), Gold (Au), Silver (Ag), Gallium Arsenide (GaAs), Polysilicon, Silicon, Zinc Oxide (ZnO), Silicon Nitride (Si_3N_4), PDMS(Polydimethylsiloxane), Graphane are more suitable materials for this research work. Since gold is so expensive, we sometimes utilize zinc oxide in place of gold, however, this is not always appropriate. Additionally, Silicon Carbide material is very popular for the harsh environment analysis process.

5.2 OUTCOMES OF NOVEL MEMS-BASED DEVICES

In the case of dynamic mode, there are six sets of Eigen frequencies obtained through the simulation and concerning every Eigen, frequency obtained displacement, shown in Table 5.1. Further by modifying in dimensions displacement, improved which is shown in Table 5.2

Table 5.1 Maximum displacement

Eigen Frequency (Hz)	Total Disp. (µm)
2.4803E6	3.56×10^6

Table 5.2 Maximum displacement (changing dimensions)

Eigen Frequency(Hz)	Total Displacement (µm)
1.0265E6	3.78×10^6
2.6671E6	5.56×10^6
6.0057E6	6.47×10^6

In the case of static mode, the same dimensions and materials were taken only the study type selected as stationary. Through this the obtained parameters like Total Displacement=1.95×10^4µm, Stress=9.25×10^{11}(Max. Value), and Strain=4.71(Max. Value). Finally, it is clear that the microcantilever is more sensitive in dynamic mode but this mode is not suitable for liquid medium. The beam deflection, Eigen frequencies, and structures serve as the foundation for the analysis of shape variations. Through shape variations and analysis the maximum displacement is obtained through Pi-shape which is equivalent to 4.09×10^{-5}µm. Different geometrical structures and shapes have been modeled and analyzed as a result of which it has been determined that, with proper adjustment and construction, we may use only 2 micro-cantilever based arrays instead of 3 microcantilevers in a microcantilever array, which will significantly reduce costs, use less power, simplify the structure, and be portable. Major results obtained through the modeling and simulation of the pressure sensor are Variation of displacement with pressure is linear. The primary foundation stone of sensitivity improvement is the placement of piezoresistive materials or structures (Piezoresistors) at the location of highest stress. Additionally, by modeling the microcantilever, it was found that a double strip is more appropriate and sensitive for early-stage cancer detection. Apart from these results, several notable results were obtained in chapter 4, which were not included here to avoid repetition.

5.3 SUMMARY OF RESULT ANALYSIS

Microcantilever is a very versatile sensor. It is giving better response as a physical, chemical, or even biological sensor by detecting the changes (if any) like bending in microcantilever or vibration frequency. To increase the overall sensitivity of the microcantilever, deflection and resonant frequency of the microcantilever have to be increased. If Eigen frequency is higher, stress will be higher and if stress will be higher then the microcantilever will be more sensitive. So making the microcantilever more sensitive one can improve the stress by applying different techniques. It is also noted that if Eigen frequency is higher then displacement of microcantilever will be high. By Increasing the length of the microcantilever its sensitivity can be improved. By reducing the thickness of the microcantilever its stiffness will get decrease and sensitivity will get increase. By using materials which has lower young's modulus sensitivity of the micro Cantilever can be improved. It means choosing a proper sensing material to make the device more sensitive. Additionally, with the help of microcantilever and pressure sensors, different kinds of environments can be analyzed as well as these devices are much helpful for biomedical applications.

6. CONCLUDING INTERPRETATION

To obtain the goal of research many modeling and analysis has done by using different tools and virtual labs. The major study done in this research work is based on microcantilever, pressure sensor, mechanical, electrical, and biological properties, heat transfer analysis, MEMS materials, surface chemistry for different microstructures, piezoresistive and piezoelectric effects, selection of the superior type of power supply, reliability of structures and devices for healthcare and environmental monitoring. Many 2D and 3D microstructures were created at the most fundamental level by adhering to material qualities. The characteristics of a microcantilever and pressure sensor were then examined using various mechanical and electrical qualities in various media as well as by altering various parameters, such as modifying the size, shape, and material composition, among many other potential things. These tasks were all completed utilizing a variety of technologies, including virtual labs, COMSOL 5.3a multiphysics, etc. and some solutions have been investigated.

One technique for reducing microcantilever vibrations is suggested. In addition, a micro battery has been created using ZnO through which by supplying less input voltage a larger potential can be produced. Another point that has been brought up is that the effective area of microcantilevers can be lowered, leading to a higher displacement, by drilling two circular holes from the fixed end. Another development is the creation of a piezoresistive pressure sensor based on graphene for ICP monitoring. In addition, the bending of the single, double, and triple strip microcantilevers was studied, and it was shown that the double strip is more suited and sensitive. One example of a blind cave fish has been used for real-time analysis. PMMA, PDMS, and Nylon materials were used in the analysis, however, it was exposed that PDMS is best since it offers the maximum displacement. Thus, monitoring the environment and human health requires this kind of effort.

FUTURE SCOPES

However, it is crucial to keep an eye on microcantilever testing for a range of applications in different scenarios. Analysis based on fabrication may be done for the good of society.

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