International Journal of Engineering Sciences Paradigms and Researches (IJESPR)
Vol. 48, Special Issue, (TAME-2019, April 4-5, 2019)
(An Indexed, Referred and Impact Factor Journal approved by UGC- Journal No. 42581)
ISSN (Online): 2319-6564
www.ijesonline.com

Structural Analysis of Micro Electro-Mechanical Systems for Different Substrate Materials.

Harshul Mahendroo[1], Dr.Sonia Bansal[2], Munish Vashistha[3], Amir Mansoori[4] and Vinod Chacko[5]
[1,2,3,4,5] J.C.Bose University of Science and Technology YMCA, Faridabad, Haryana, India
Email: harshul.mahendroo@gmail.com

Abstract

The paper deals with the structural analysis of Micro-electro-mechanical Systems (MEMS) on different substrate materials. MEMS are often considered as a bridge between Very Large Scale Integration (VLSI) and macro mechanics. They offer an opportunity to apply VLSI structured design methods and VLSI fabrication process to mechanical systems. The diversity in different materials of microelectronics are exploited in order to study the recent developments in this genre. Although MEMS have the similar fabrication process with VLSI system but the technology faces many challenges.
Future MEMS will be developed with greater functionality, higher electronic-mechanical integration. In turn, future MEMS will be driven by new materials, system design methods, fabrication techniques and packaging tools. With these essentials, this process technology is swiftly asserting itself as a potential stretch with high performance, miniaturized size and cost effectiveness with its new trends.

Keywords— Micro Electromechanical Systems, ANSYS 18.1, MEMS, VLSI.

I. INTRODUCTION

Micro-electromechanical systems (MEMS) are the process technology that is used to miniaturize the devices or systems that comprise both electrical and mechanical components. MEMS are the combination of semiconductor processing and mechanical engineering but at a smaller scale. MEMS are fabricated using IC batch process techniques [1]. These MEMS devices comprise of a sensor that senses the stimuli and an actuator that controls and moves the system upon stimuli.

MEMS have been acknowledged as the most promising technology as they have known to have a potential to refashion both industrial as well as customer products by combining micromachining technologies with silicon based microelectronics. The complexity of these devices can be seen in the extensive range of markets and applications which incorporate MEMS devices[2].

II. A WAY AHEAD : FUTURE OF MEMS

The MEMS market is still in the developing phase. The comparison between MEMS and metal-oxide semiconductor industry will always sustain as there is no other technology that has evolved the digital electronics industry. The devices in market are currently being manufactured by both conventional bulk and surface micromachining process in spite of a volume is produced by adapting surface micromachining, it will take a few more years for this approach to make a huge impact [1][2].

In past few decades, MEMS has been an enabling technology for the development and production of new industrial and customer products. To attain effectiveness in commercialization in MEMS, foundries must overcome bottlenecks of critical technologies, economical feasibility in integrating components based on MEMS, also the market uncertainty for the devices and their applications [2]. There is a great demand in reducing cost of these devices which will ultimately affect the availability of the device structures. More reliable manufacturing processes must be brought to practice; technical awareness with new interfacing standards must be introduced [4][1].

III. STRUCTURAL ANALYSIS OF MEMS DEVICE ON DIFFERENT SUBSTRATE MATERIALS USING ANSYS 18.1

Nowadays, MEMS structures are commonly being stimulated using softwares like Coventorware, Ansys, Intellisuite before their actual fabrication. These softwares help to analyze their structures, mesh them and stimulate so that the structural dimensions can be optimized according to the desired output to save cost and time during MEMs fabrication [1].

These MEMS stimulation softwares are often used to analyze much more than just MEMS structural issues such as modal, harmonic, contact, hysteresis, temperature, sensitivity and piezoelectric analysis. All of the above can be done by computing stress, strain, contactor reaction forces, or parameters depending mainly on dimensions and material properties of the MEMs structures [2].

Although, these software's are highly paid and are not available to all. In this study, we will be focusing mainly on structural properties of the particularly designed MEMS cantilever. Furthermore, we will be giving insight to linear analysis on different material properties, their varying nature and consideration for a good substrate material [4].

Linear analysis on different type of substrate materials has been carried out in this study. Basically, to analyze linear properties of a substrate material following parameters are taken into account:

a. **Density:** Basically, it is the volumetric mass of any substance. With increase or decrease of pressure and temperature, the density of the substance is modified. The effect of pressure or temperature in a solid or liquid can be used to determine the compressibility in the solid or liquid [14]. Thus, it becomes one of the basic parameter to analyze. Its standard SI unit is kilogram per cubic metre (kg/m^3) [1]. Mathematically, it can be derived as mass per unit volume,

$$p = \frac{mass}{volume}$$

b. **Young's modulus:** It is the fundamental property of the material that remains unchanged. It is also pressure and temperature dependent. It describes the stiffness of a material and how much it can be bent or stretched [4]. Mathematically, it can be given as,

$$\Upsilon = \frac{stress}{strain}$$

c. **Poisson's Ratio:** It is the measure of properties in which a material tends to expand in the direction perpendicularly to the direction of compression [2][1]. If a material is assumed to be compressed or stretched along axial direction, we can say-

$$\text{Poisson's ratio, } \nu = \frac{transverse\ strain}{axial\ strain}$$

IV. ANSYS 18.1

Micro electromechanical systems (MEMS) are the devices that can sense, actuate and control at micro-scale to achieve an impact at macro-scale.[1][4] They are complex devices whereas the never ending requirement to build on a more efficient but smaller scale has always been a challenge for design engineers [3]. Thus, simulation of MEMS devices can involve numerical analysis in diverging areas of physics like solid mechanics, heat transfer, fluid dynamics, electromagnetic, etc [3].

ANSYS being general purpose software is based on the finite element analysis (FEA). It allows complete 3D simulations without compromising the geometrical details. Ansys is one of the simulation providers in the industry of high technology field for MEMS based sensors and actuators. ANSYS facilitates static, modal, harmonic, transient analysis. ANSYS parameter design language (APDL) provides an easy way to realize a weak coupling [3].

The breadth and depth of ANSYS analysis can simulate vast areas of sensors and actuators, from RF sensors relying on electromagnetic fields to gyroscopes relying on mechanical motion [3]. The devices like piezoelectric sensors that have both electromagnetic and mechanical features can also be simulated by Ansys [4][1]. Furthermore, multi-physics simulations with high-fidelity analysis of design and performance can be accomplished.

V. MEMS CANTILEVERS

Cantilever means a projected beam supported by only one end. The cantilever beam carries a supported load resisted by shear stress. [5] They are the most omnipresent structures in the field of MEMS design and study. Figure 1.1 shows the cantilever design chosen for the further analysis. These cantilevers can be fabricated from different substrate materials like Silicon or other polymers. The behaviour of the cantilever varies differently for different substrate materials. [2]

In this project, three different substrate materials are considered which exhibit different properties and behavior under same ambient conditions. The MEMS cantilevers have variety of applications [4]. These are finding applications trending in biosensors, RF resonators and filters. The major benefit of using MEMS cantilever is their convenience in fabrication for large arrays and cheaper cost.

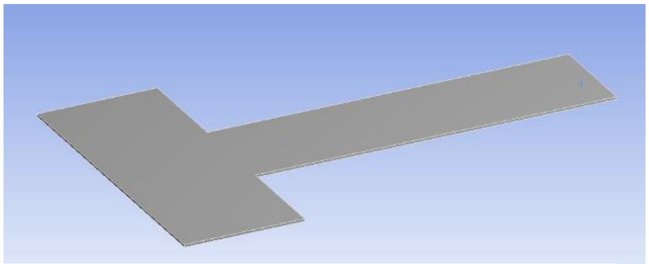

Figure 1.1: Selected Cantilever Design

Cantilever Design

Cantilevers are the basic blocks in many MEMS application. Cantilever designs vary with the device application. In this chapter we will be focussing on the cantilever design as shown in the figure. The basic parameters which define the cantilever performance are its thickness, width, length and young's modulus. It should be noted that young's modulus of the cantilever will depend upon the type of substrate material which will be different for different materials[5][1].

Note that for further observations the following parameters are kept constant for the cantilever design being used:

- Width of the cantilever beam,
- Length of the cantilever beam,
- Thickness of the cantilever beam.

VI. STRUCTURAL ANALYSIS WITH DIFFERENT MATERIALS & EXPERIMENTAL RESULTS

Deformation in any solid occurs due to the change in material properties on an external applied force. One of the objectives of this project is to study the elastic properties of different substrate materials and determine the best suited material for the design of MEMS devices. Therefore, the elastic properties of the below mentioned materials are analysed in order to essence the stiffness of a material for restricting its deterioration.

In this paper, three distinct substrate materials are examined linearly with varying behaviour under equivalent ambient conditions. The elastic properties of these materials have been statistically analysed in the study below.

The three substrate materials considered are-

- Quartz
- Silicon
- PET

Main purpose behind examining these different materials is to select out the best considerate material for MEMS device fabrication. Aim is to pick out the one that shows high sensitivity at minimum applied force. It can be stated that following experiment has been performed to determine a substrate material that senses and actuates upon least stimuli applied.

Figure 1.2 shows the geometry and the direction of the external force applied to the cantilever in this project. The applied force has been varied to 0.2N, 0.5N, 0.8N and 1.0N respectively to determine the optimum results. The next section elaborates the observations in detail.

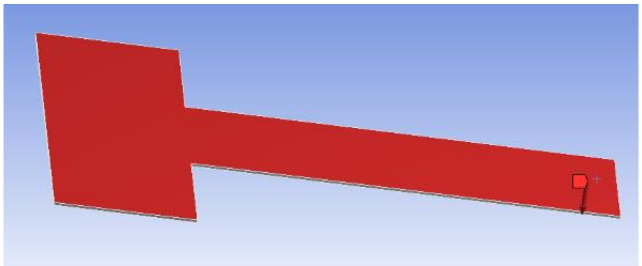

Figure 1.2: Geometry and direction of the force applied.

Quartz

Quartz is a single crystal material with low impurity concentration. It is an extremely versatile material that is currently being used with its vast range of applications. It has phenomenal thermal properties, great optical transmission with excellent electrical and corrosion performance. It also exhibits extensive thermal shock resistance, optically transmits from ultra violet to infra red, distinctive chemical resistance and good electric insulator [3].

Properties of Quartz: Quartz properties are of typical values as shown in the table 1.1.

S.No	Property	Value	Units
1.	Density	2210	Kg/m^3
2.	Young's Modulus	70	GPa
3.	Poisson's Ratio	0.17	Unitless

Table 1.1: Properties of Quartz

Silicon (Bulk Material)

Formation of a stable oxide is one of the important features of Silicon for MEMS fabrication. Silicon is one of very few materials that can be cost effectively manufactured as a single crystal substrate. It is excellently suitable for mechanical, electrical, optical as well as thermal integration. It's crystalline properties allows a uniform distribution of mechanical properties across the wafer surface.

Mechanically, Si remains hard and brittle, elastically deform and robust as a material. It also exhibit excellent chemical properties such as being stable and resistant material that does not release toxic substances. Properties of Silicon as a bulk material: Silicon properties are shown in the table 1.2

S.No	Property	Value	Units
1.	Density	2330	Kg/m^3
2.	Young's Modulus	165	GPa
3.	Poisson's Ratio	0.22	Unitless

Table 1.2: Properties of Silicon

Polyethylene Tetraphthalate (PET)

PET is generally polyester also known as thermoplastic polyester. It is hard, stiff, strong and dimensionally stable material. It exhibits good barrier properties and excellent chemical resistance except in case of alkalis. The PET based films are generally thermally stable and oriented bi-axially. PET films like Mylar are used as graphics, film base and recording tapes.

Properties of PET: PET has a wide range of properties as given in the table 1.3. PET being polyester, its properties are not of a typical values rather exist in a specified range.

S.No	Property	Value	Units
1.	Density	1.3-1.4 (=1.39)	Kg/m^3
2.	Young's Modulus	2-2.7 (=2)	GPa
3.	Poisson's Ratio	0.37-0.44 (=0.37)	Unitless

Table 1.3: Properties of PET

On comparing analytical results of Quartz, Silicon and PET following observations are obtained:

A. *Maximum Deformation*

Table 1.4 give details about maximum deformation in Quartz, Silicon and PET cantilevers at respective forces. It can be observed that PET cantilever shows maximum deformation at every individual force. Figure ** is the graph plotted for total deformation in all three types of substrate materials.

Force	Quartz	Si	PET
0.2	0.00086749	0.00036512	0.029677
0.5	0.0021687	0.0009128	0.074191
0.8	0.0034699	0.0014605	0.11871
1.0	0.0043374	0.0018256	0.14838

Table 1.4: Maximum Deformation

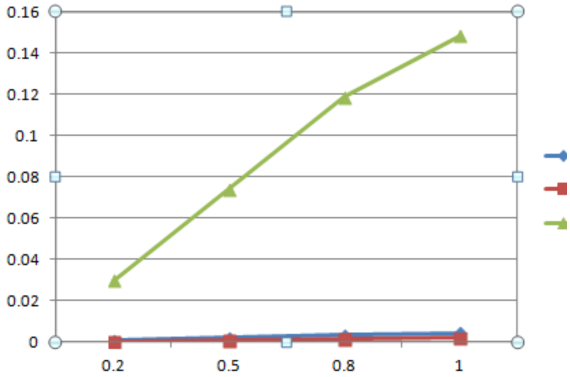

Figure 1.3: Maximum Deformation Plot

B. *Maximum Equivalent Stress*

Table 1.5 give details about maximum equivalent stress in Quartz, Silicon and PET cantilevers at respective forces. In comparison to Quartz and Silicon, PET shows maximum equivalent stress even at smaller amount of force applied.

Force	Quartz	Si	PET
0.2	41033000	39388000	46813000
0.5	102580000	98471000	117030000
0.8	164130000	157550000	187250000
1.0	205160000	196940000	234060000

Table 1.5: Equivalent Stress

Figure 1.4 shows the maximum equivalent stress plot at variant applied force for Quartz, Silicon and PET respectively.

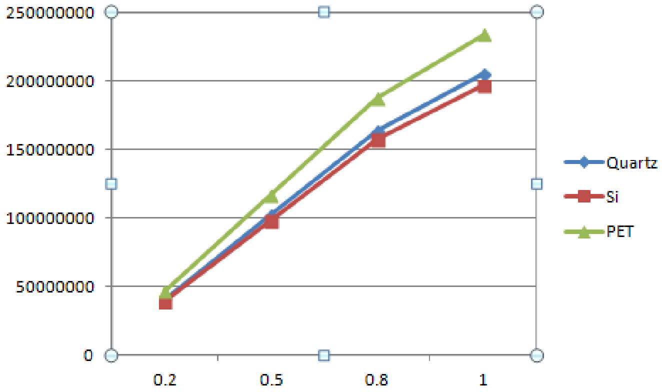

Figure 1.4: Equivalent Stress Plot

C. *Maximum Equivalent Strain*

Table 1.6 give details about maximum equivalent stress in Quartz, Silicon and PET cantilevers at respective forces.

Force	Quartz	Si	PET
0.2	0.000835	0.0003362	0.025093
0.5	0.002088	0.0008405	0.062733
0.8	0.003341	0.0013448	0.10037
1.0	0.004176	0.001681	0.12547

Table 1.6: Equivalent Strain

The figure 1.5 shows a graph plotted among three substrate materials depicting maximum strain exhibited by individual forces on each one of them. The observation represents that PET exhibits maximum strain among the three substrate materials.

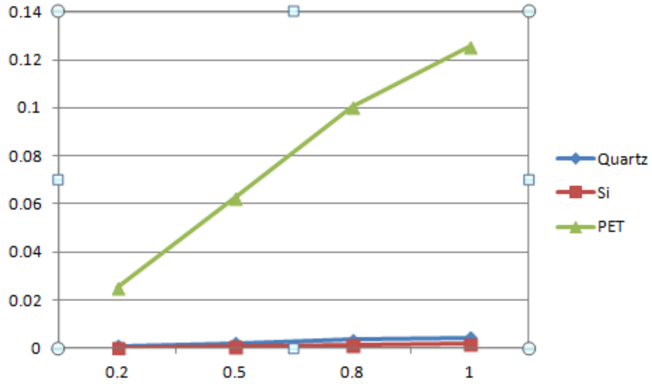

Figure 1.5: Equivalent Strain Plot

Considering above experimental observations, it can be observed that PET produces optimized results as compared to other substrate materials.

PET being polyester exhibits better elastic properties than Quartz and Silicon. On comparing the results obtain from above composition, it can be concluded that PET shows low resistive and high sensitivity to very small stimuli, 0.2N force in this case.

VII. CONCLUSION

A comparative analysis of conventional and various substrate materials is carried out in this paper. The substrate materials are used in micro fabrication of MEMS devices. The proposed study reveals the potential material to replace the limitations of conventionally used materials. Elastic properties of Quartz, Silicon and PET are analyzed in this study to essence the stiffness of a material for restricting its deterioration.

REFERENCES

.

[1]. *Sensors & Transducers Journal, Vol. 91, Issue 4, April 2008, pp. 55-69*

[2]. MEMS: A practical guide of design, Analysis and applications. Edited by *Jan G. , Korvink, Oliver Paul.*

[3]. "ANSYS" http://www.ansys.com

[4]. *Microelectromechanical Systems Journal of*, vol. 23, no. 2, pp. 347-355, 2014

[5]. "Cantilever Beams" Sensors and Actuators A, Vol. 33, pp. 199-206, 1992