

Sensitivity enhancement and comparison of MEMS/NEMS cantilevers

¹Anuj Kumar Goel, ²B.Hari krishna, ³S.Poongodi

^{1,2,3}Professor, C.M.R.Engineering College, Hyderabad,India.

<https://doi.org/10.26782/jmcms.2019.02.00029>

Abstract:

MEMS, macroscopic devices posses characteristic length of less than $1\mu\text{m}$ and integrate mechanical and electronic components on a single chip. Sensitivity is the major concern in existing MEMS/NEMS devices which are mostly made of elastic cantilever beam. In this work porous MEMS cantilevers are designed using Silicon dioxide, Polysilicon, Silicon nitride & Aluminium. The designed cantilevers are in the micrometer range with optimized dimension as $l=120$, $w=10$ and $t=1.5$ (all are in micrometers). Sensitivity is measured on Silicon dioxide based cantiliver with different type of hole on fixed end as rectangle, circle and ellipse. The ellipse hole gives better result (maximum resultant stress 1767.5 N/m^2) in terms of sensitivity of the device. Futher elliptical hole parameters (position, number and dimension) are varied in order to achieve maximum stress and in response maximum deflection of microcantilevers. The optimized design achieved is implemented with two more materials viz. polysilicon and silicon nitride for comparison.

Keywords: MEMS, Microcantilevers, COMSOL Multiphysics.

I. Introduction

MEMS, which integrate moving microdevices, radiating energy microdevices, microscale driving/sensing circuitry and controlling/ processing integrated circuits, are widely used [VI,VII]. MEMS cantilevers are main microstructures used for sensors and actuators. These are used in physical, chemical and biological sensing [XI]. The microcantilever resonance responses such as resonance frequency, deflection [VIII], amplitude, and Q-factor[III] undergo variation due to external stimuli. The resonance response change is because of mass loading, surface stress, or damping[II-X-IX]. Researchers used different shapes to design MEMS cantilevers to enhance output sensitivity[V].

II. Previous Workdone

Initial MEMS cantilever is designed with 120μm of length, 20μm in width and 2μm of thickness. After the load application and simulation output stress is measured then different physical parameters such as length and thickness are varied and respective results are compared to obtain optimum beam size. Material properties also change the device performance that's why different materials(Silicon dioxide, silicon nitride, polysilicon and aluminium) are used for cantilever formation. Respective results are compared and found that Silicon dioxide gives the maximum stress on fixed end. For further cantilever's design same optimum dimensions and silicon dioxide as material is used. All these approaches for design of cantilevers prove the Stoney's formula[IV].

$$z = \frac{3\sigma(1-\nu)}{E} \left(\frac{L}{d}\right)^2$$

Next section III demonstrate the comparative analysis of different porous cantilevers. Section IV uses different approaches to increase sensitivity of the device with elliptical hole formation on fixed end of beam. Section V is the conclusion of the research paper.

III. Design of Porous MEMS cantilevrns

Sensitivity enhancement is performed with formation of Porous MEMS cantilevers. From the given formula it is clear that stress of cantilevers is increased with reducing the effective surface area of the device:

$$\sigma = \frac{F}{A}$$

With formation of holes on surface of MEMS cantilevers, effective surface area of Microcantilever is reduced and in response stress is increased [I].

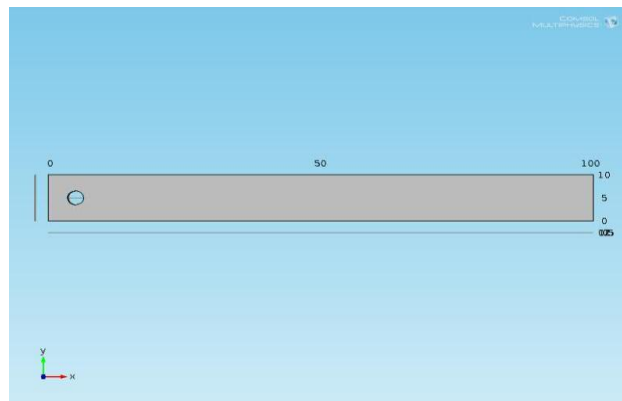


Fig.1: Designed MEMS cantilever with circular hole.

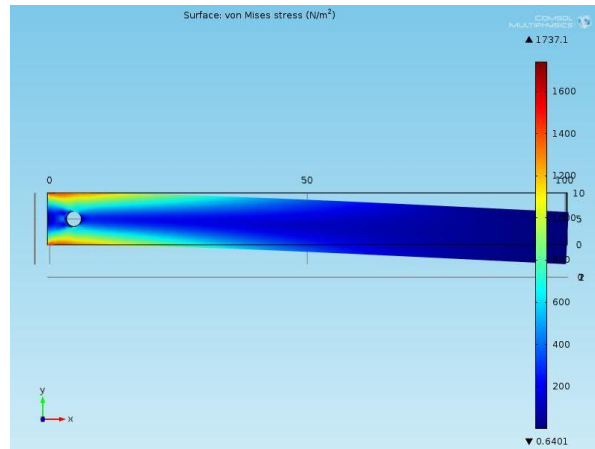


Fig.2: Simulated model on COMSOL Multiphysics.

Table 1: Resultant stress change

Sr. No.	Dimension of Microcantilever (in micrometers)	Shape of Hole	Resultant Stress
1.	120 X10 X 1.5	Simple cantilever	1596
2.		Rectanglar hole	1741.1
3.		Circlar hole	1737.2
4.		Elliptical hole	1767.5

In the observations we observed that maximum stress is obtained with elliptical hole formation with 10.74 % increase in stress with respect to cantilever without any hole formation.

IV. Sensitivity enhancement approaches

a) Change in location of Elliptical hole

As from previous point it is clear that sensitivity enhancement is achieved with elliptical hole formation and designed shape have size of 3*1*2 (micrometers). Now the location of designed hole is changed in X-axis. With this change corresponding change in stress is achieved. Simulated results are

analyzed and compared which shows that maximum stress (1907 N/m^2) and sensitivity is obtained when hole is placed 10 micrometer from fixed end.

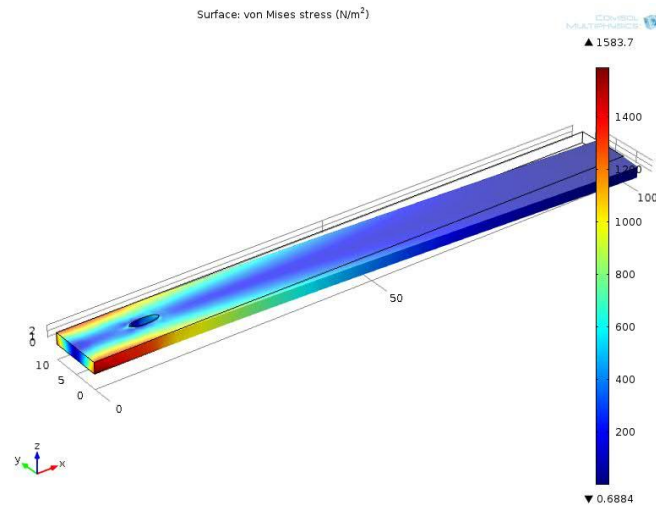


Fig.3: Simulated result with elliptical hole formation

Table 2: Resultant Stress with change in location of Elliptical hole

Sr. No.	Positioning of Elliptical hole from fixed end	Resultant Stress
1.	5 μm	1734.7
3.	10 μm	1907
4.	50 μm	1581
5.	98 μm	1573.5

b) Sensitivity enhancement with increase in number of Elliptical holes

Further stress is increased by formation of increased number of elliptical holes on the MEMS cantilevers. Location of cantilevers is changed in different combinations and all results are compared. Optimum positioning of the cantilevers is found which is shown in tabular form.

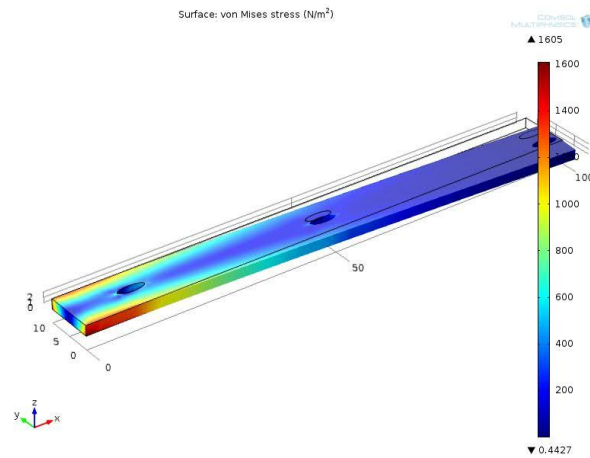


Fig.4: MEMS crocantilever with three elliptical holes

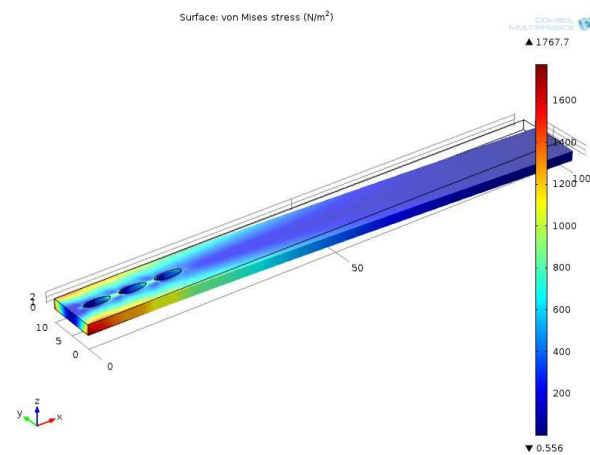


Fig.5: MEMS crocantilever with three elliptical holes on same end.

Table 3: change in stress with formation of mre number of holes

Sr. No.	Elliptical hole locations from fixed end (in micrometers)	Stress achieved
1.	a1=5, a2=10, a3=15.	1767.7
2.	a1=10, a2=50, a3=98.	1605

c) Variation in size of Elliptical holes

Sensitivity enhancement is the main concern of research so next methodology is used to further increase the sensitivity of cantilevers. The dimension of elliptical holes are changed i.e. effective surface area is reduced while the cantilever's physical dimensions remain the same as in initial case.

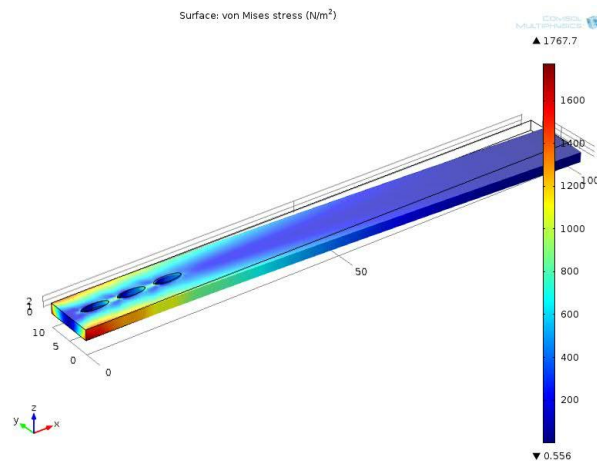


Fig.6: Resultant beam with variation in dimension of Elliptical holes

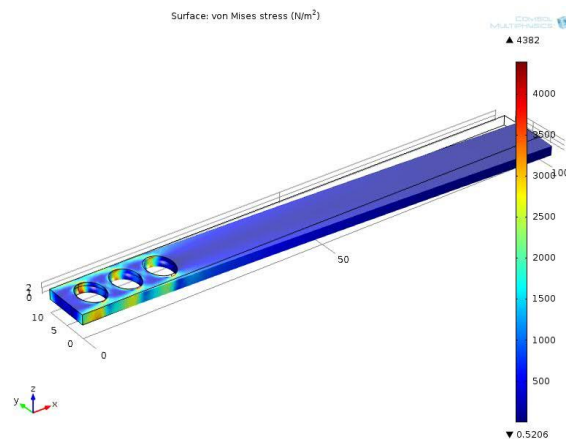


Fig.7: Resultant beam with further change in dimension of Elliptical holes

Table 4: resultant stress change with respective variation in dimensions of Elliptical holes.

Sr. No.	Position of three Elliptical holes	Elliptical hole dimension (in micrometers)	Resultant Stress
1.	a1=5 μ m,	3*1*2	1768
2.	a2=10 μ m,	3*2*2	1850
3.	a3=15 μ m.	3*3*2	2173
4.		3*4*2	4383

V. Conclusion

Different MEMS cantilevers are designed and simulated with observation that formation of elliptical holes enhances the resultant stress and achieved higher deflection. Single elliptical hole placed at 10 μ m from fixed end gives higher stress. Sensitivity of device is further enhanced by creation of more number of holes on cantilever's surface. Higher resultant stress is achieved with formation of three elliptical holes starting from 5 μ m from the fixed end. After that effective surface area of cantilevers is further reduced by increasing the size of MEMS cantilevers and higher resultant stress and increased deflection is achieved with formation of holes with dimension a=3, b=4, c=2 (all in micrometers).

References

- I. Ansari, M.Z., Cho, C., Kim, J., Bang, B. Comparison between deflection and vibration characteristics of rectangular and trapezoidal profile microcantilevers. *Sensors* **2009**, 9, 2706–2718.
- II. Anuj Kumar Goel. Analytical modeling and simulation of microcantilever based MEMS devices. *Wulfenia*, 2017, vol. 24, No.1, pp.79-91.
- III. Anuj Kumar Goel, Kuldip Kumar, Dushyant Gupta. Design and Simulation of Microcantilevers for Sensing applications. *International Journal of applied engineering research*, 2016, Vol. 11 No. 1 pp 501-503.

- IV. Chivukula V, Wang M, Ji HF, Khaliq A, Fang J & Varahramyan K. Simulation of SiO based piezoresistive microcantilevers. *Sensors and Actuators A*, 2006; vol. 125: pp. 526- 533.
- V. Fernando, S., Austin, M., Chaffey, J. Improved cantilever profiles for sensor elements. *J. Phys. D: Appl. Phys.* **2007**, *40*, 7652–7655.
- VI. Madhu Santosh Ku Mutyala, Deepika Bandhanadham, Liu Pan, Vijaya Rohini Pendyala, Hai-Feng Ji. Mechanical and electronic approaches to improve the sensitivity of microcantilever sensors. *Acta Mechanica Sinica*, 2009, Vol. 25. No. 1. pp 1-12.
- VII. Mansour Abtahi, Gholamreza Vossoughi, Ali Meghdari. Full Operational Range Dynamic Modeling of Microcantilever Beams. *Journal of Microelectromechanical systems*, 2013, Vol. 22. No. 5.
- VIII. Mansour Abtahi, Gholamreza Vossoughi, Ali Meghdari. Full Operational Range Dynamic Modeling of Microcantilever Beams. *Journal of Microelectromechanical systems*, 2013, Vol. 22. No. 5.
- IX. Naeli, K., Brand, O. Cantilever sensor with stress-concentrating piezoresistor design, *Sensors*, 2005 IEEE, pp. 592–595.
- X. Rasmussen PA, Hansen O & Boisen A. Cantilever surface stress sensors with single crystalline silicon piezoresistors. *Applied physics letter*, 2005; Vol. 86.
- XI. Shahriar Kouravand. Design and modeling of some sensing and actuating mechanisms for MEMS applications, *Applied Mathematical Modelling*. Elsevier, 2011, Vol. 35. pp 5173–5181.