Resistance change for different piezoresistive cantilever geometries

Ankit Sagar, Chetan Kamble, M.S. Panse

V.J.T.I. Mumbai, ankitsagar124@gmail.com

Abstract— Cantilever beams are one of the basic microelectromechanical systems (MEMS) structures. They are used for sensing and actuation purposes. Piezoresistive readout is one of the most promising methods to find out the mechanical displacements of these cantilever beams. In this paper the resistance change of various cantilever geometries is found out. By using simulations done by COMSOL multiphysics the mechanical displacement of these cantilever beams is found out and a virtual instrumentation program is used to process the COMSOL data. The fractional change in resistance is found out by Stoney's equation and the real change in resistance has been found out by using VLSI equations..

Keywords— Cantilever beam, MEMS, piezoresitive readout, Stoney's equation.

INTRODUCTION

MEMS are gaining wide spread acknowledgement in the field of VLSI as sensors and actuators. Cantilever beams are being used in a variety of applications like sensing of gases, explosives, fluids and various physical parameters such as stress, temperature, pressure etc. In Piezoresistive readout method a piezoresistive layer is deposited on the cantilever surface. Due to the adsorption of target molecules on the sensing layer of the cantilever stress is developed at the fixed end of the cantilever and the cantilever bends [1]. This changes the resistance of the piezoresistive layer. In order to measure this small change in resistance a Wheatstone bridge network can be used. Various geometries of cantilever beams have been proposed. In order to find the actual change in resistance of these geometries it is necessary to find out their individual displacements for a given value of stress.

CANTILEVER GEOMETRIES

Cantilever geometries are shown from figure 1 to 5. These geometries were subjected to load varying from 0 to 42 micrograms in COMSOL multiphysics and their displacements were found out. Gravity was applied to all these geometries and very fine meshing was done. The result is shown in figure 6. [2]

Table 1: Geometry parameters of rectangular Cantilever beam

Length of cantilever	200 [um]
Breadth of cantilever	50 [um]
Thickness of cantilever	1 [um]
Length of piezoresistive layer	80 [um]
Breadth of piezoresistive layer	5 [um]
Thickness of piezoresistive layer	0.5 [um]
Length of functionalized layer	50 [um]
Breadth of functionalized layer	50 [um]
Thickness of functionalized layer	1 [um]

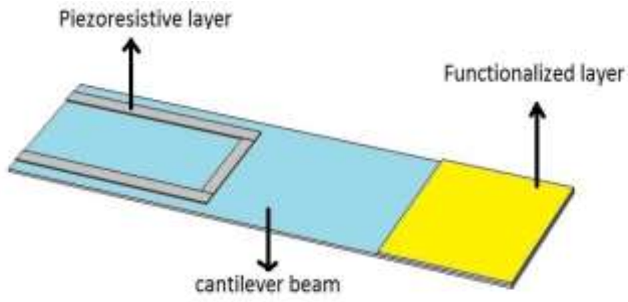

Fig. 1. Rectangular cantilever beam

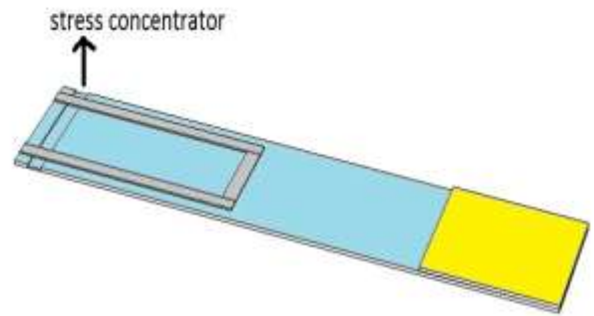

Fig. 2. Rectangular cantilever beam with stress concentrator

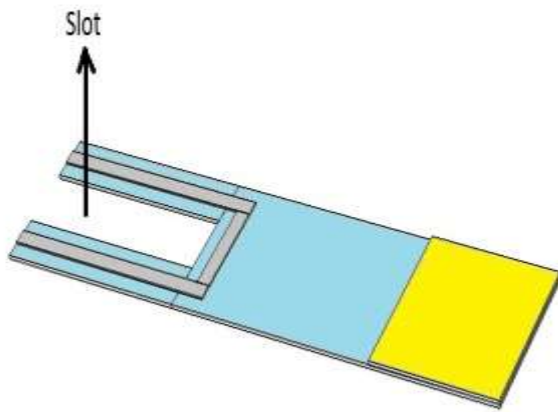

Fig. 3. Rectangular cantilever beam with slot

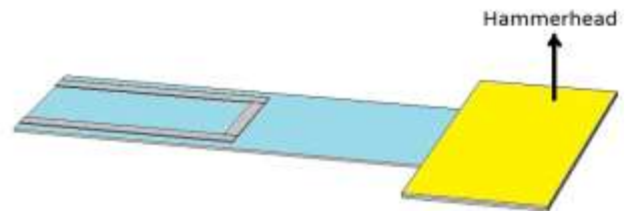

Fig. 4. Rectangular cantilever beam with hammerhead

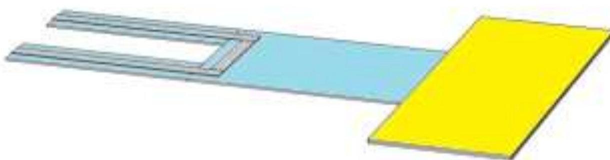

Fig. 5. Rectangular cantilever beam with hammerhead and slot

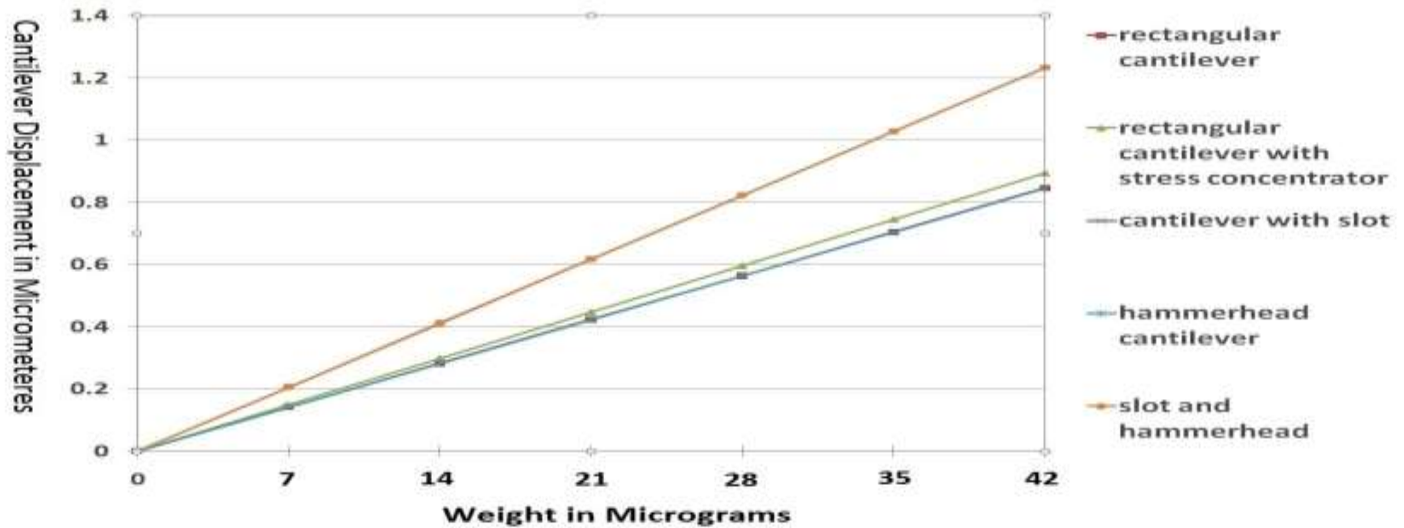

Fig. 6. Weight in micrograms vs. Cantilever deflection

STONEY'S EQUATION:

Deflection is a mechanical parameter which needs to be converted to electrical parameters. In order to this a piezoresistive thin film is deposited on the silicon substrate. As the mass of the target molecules gets added to the functionalized layer the cantilever bends and so does the piezoresistive thin film. This changes the resistance of the thin film.

In order to calculate the change in resistance Stoney's Equation is used. Stoney had derived a relation between adsorption induced stress and the radius of curvature of a thin substrate. It is given as

$1/R = 6*(1-\upsilon)*\sigma / E*t^2$

Where

R is the radius of curvature

υ is the poison's ratio

σ is the differential stress i.e. stress between the top and bottom surface of the thin film

E is the young's modulus

And t is the thickness of the film.

From geometry the radius of curvature is related to the displacement of the free end of the cantilever and to its length as $1/R=2*\delta/L^2$ where δ is the displacement and L is the length of the cantilever. The resulting fractional change is given by piezoresistive relation $\Delta R/R=\beta*3*E*t*\pi_l* \delta/2*L^2$. Where πl is called the longitudinal coefficient and for the <110> crystallographic axis of silicon its value is $71.8*10^{-11}$. The co-efficient β is called as correction factor and its value is between 0 and 1. The above given equation can be modified to

$\Delta R/R= \delta *E*T* \pi_l* \beta/L^2$. [3]

DATA PROCESSING

The above equations were used to find the change in fractional resistance of the piezoresistive layer. In order to process the data quickly and efficiently LABVIEW is used. The displacement data of the various cantilever designs is exported from COMSOL into text or spreadsheet application. LABVIEW can import data from this text or spreadsheet file for further processing. The front panel and block diagram of the designed software is shown in figure. The final results are displayed on the front panel. The front panel and block diagram are shown in figures 7 and 8 respectively. The results are shown separately in figure 9.

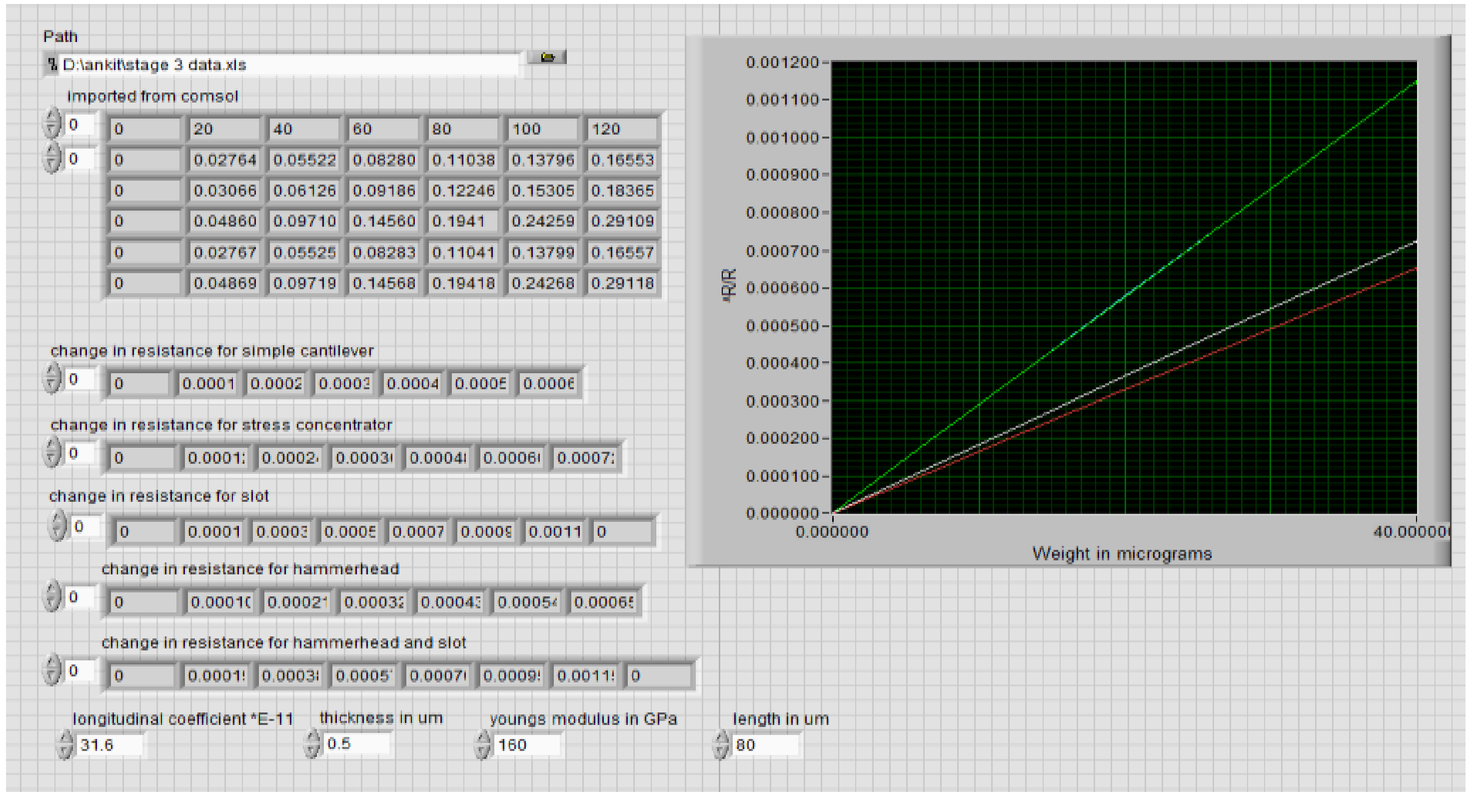

Fig. 7. Front panel

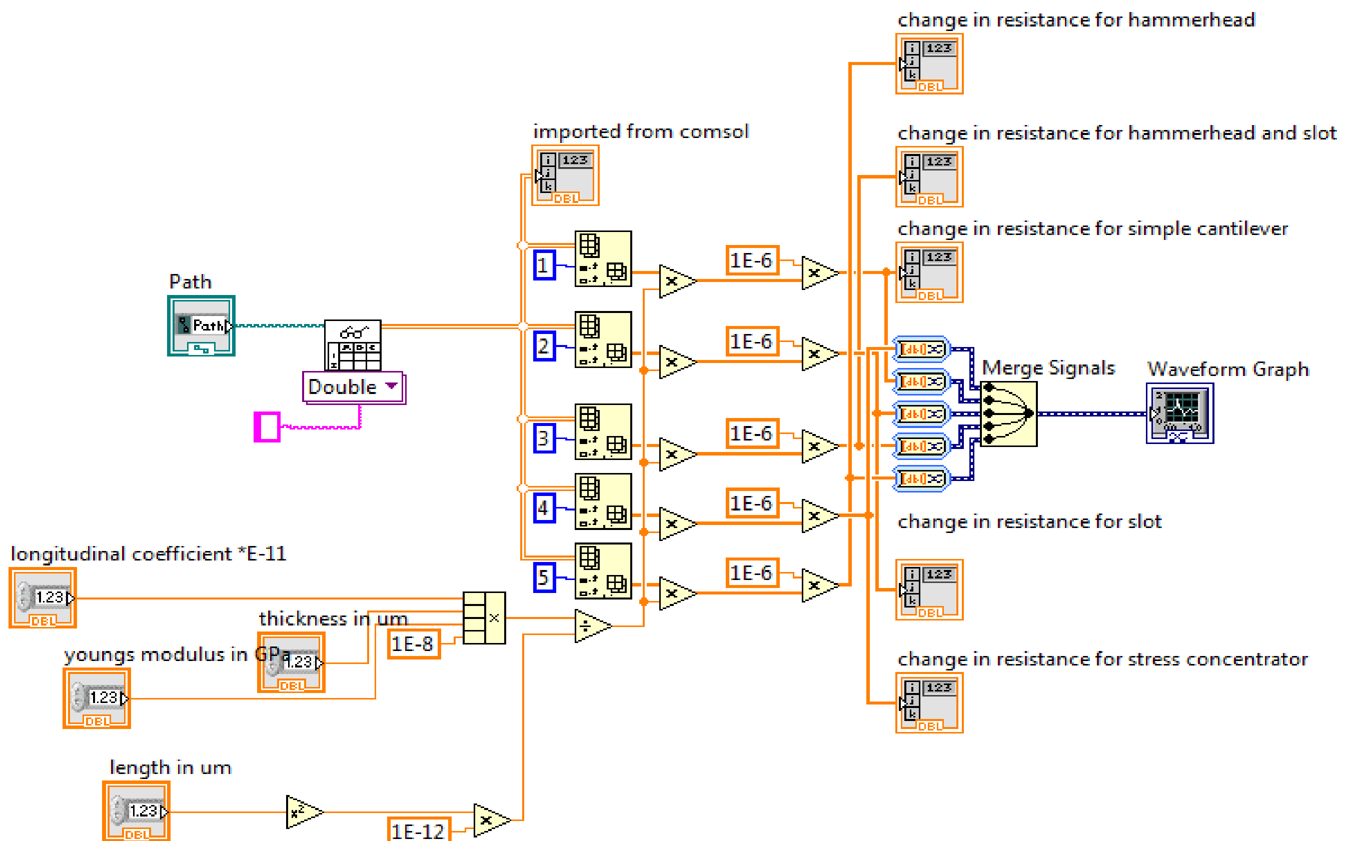

Fig. 8. Block Diagram

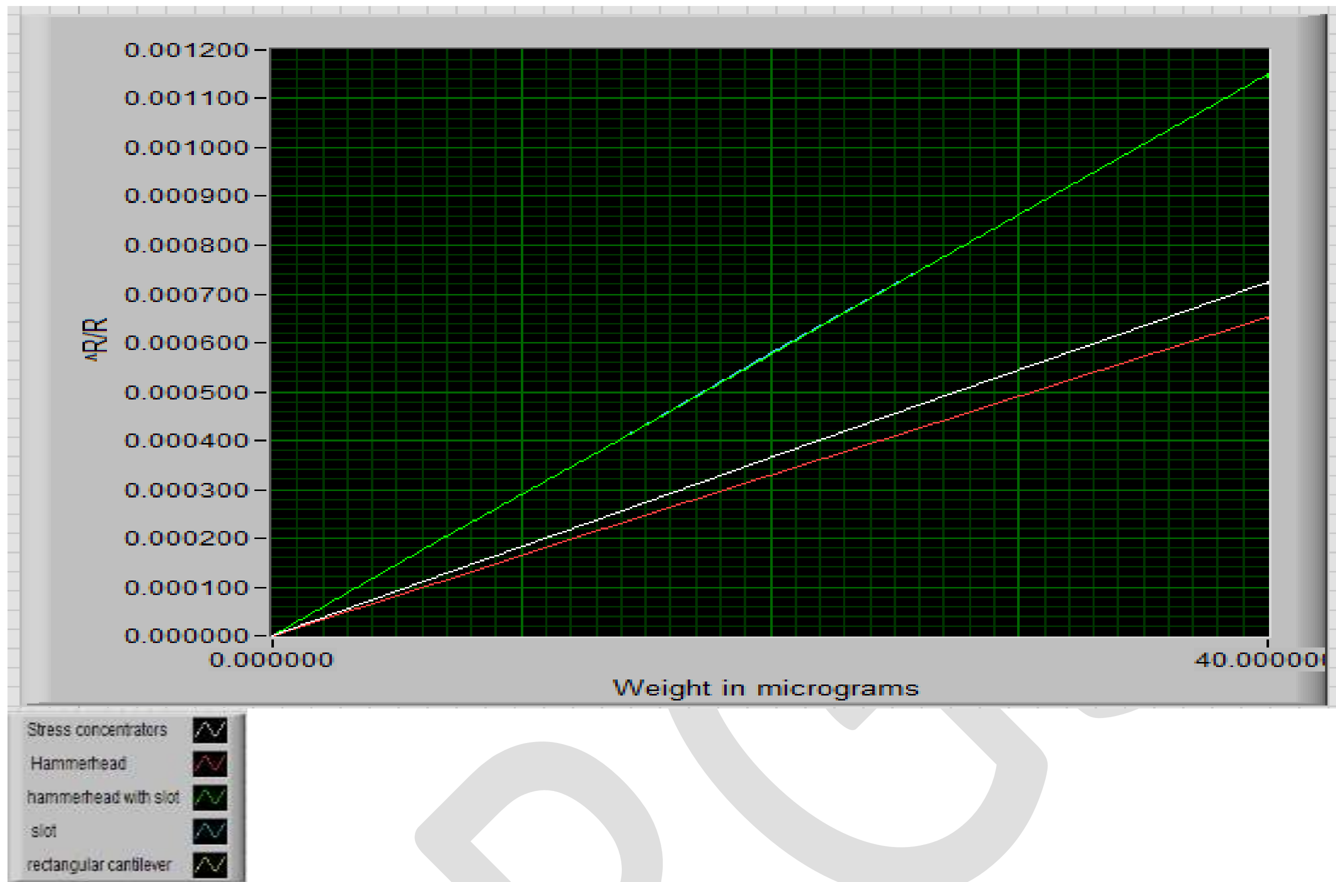

Fig. 9. Fractional change in resistance vs. weight in micrograms

REAL RESISTANCE CHANGE

In order to calculate the real change in resistance it is necessary to calculate the original value of the piezoresistive layer without stress. For this the basic formula of resistivity (ρ) and resistance (R) is used which is given as R= ρ*L/A

In order to calculate resistivity we first need to calculate the conductivity and take its reciprocal. The conductivity of a semiconductor is given as

$\sigma = qn\mu_n + qp\mu_p$

Where σ is the conductivity

q is the charge on electron

μ_n is electron mobility

μ_p is the hole mobility

n is the electron concentration and

p is the hole concentration.

The above formula gets modified when doping is used. For n type of silicon as a piezoresistor hence the formula gets modified to

$\sigma = qn\mu_n$

The typical values of the various quantities is as follows

μ= 1360 cm^2/v-sec

$q = 1.6*10E^{-19}$

$n = 10^{-14}$ [4].

On putting this values in the above equation we get σ= 2.176 hence the value of resistivity becomes 0.45 Ωm. The length of the Piezoresistor is 200 micrometer, its breadth is 5 micrometer and thickness is 0.5 micrometer. On putting the above values in equation 1 we get the actual resistance as 32.76 MΩ.

From the above graph we can find any weight added and multiply it with the y axis value to get real change in resistance. For example the value of change in real resistance is 9828 Ω for weight added as 10 microgram. This change is 0.03% of the original resistance.

CONCLUSION

Hammerhead cantilever with slot provided the most change in the resistance of the piezoresistive layer. Hence it the most sensitive geometry from the above discussed geometries. The change in resistance is linear with respect to the deflection or the weight added to the cantilever beam. The actual change in resistance gives a very good estimate of the voltage changes across the Wheatstone bridge and it will be useful in actual hardware development.

REFERENCES:

[1] Sandeep kumar Vashisth, "A review of microcantilever for sensing applications", Journal of nanotechnology, Vol.3, Pages 1-18, June 2007.

[2] Ankit Sagar, Chetan Kamble, M.S. Panse, "Comparision of cantilver shapes for maximizing sensitivity", International Journal of Computer and electronics research (IJCER), FEB 2016, Volume 5. issue No. 1 Pages 5-8.

[3] Marc J. Madou ,"Fundamentals of Microfabrication: The Science of Miniaturization", 2002, second edition, pages 311-313.

[4] John P. Uyemura, "Introduction to VLSI Circuits and Systems", First edition, 2012 reprint, pages 78-81

[5] J. Amirola, A. Rodriguez, L. Castafier, M. C. Horrilto, F. J. GutiGrrez "Micromachined Silicon microstructures for gas sensors" IEEE Electron Devices, 2005 Spanish Conference, Feb. 2005, Pages:569 – 572.

[6] Bharat Bhushan "Springer Handbook of Nanotechnology", 3rd edition, 2010, pages: 436-438.

[7] Chetan Kamble, Dr.MS Panse, "Simulation of Acetone Vapour Sensing using Microcantilever" 3rd International Conference on Nanotechnology for Biological and Biomedical Applications (Nano-Bio-Med), IIT Bombay, 1-4 Dec 2015, (un*published*)

[8] Chetan Kamble, Dr.MS Panse, "Design of Acetone Vapour Sensor using Microcantilever" Sixth International Congress on Computational Mechanics and Simulation (ICCMS), IITB Mumbai, 27 june-1 july 2016.