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Design Simulation and Analysis of U-Shaped and Rectangular MEMS Based Triple Coupled Cantilevers

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In this paper, we have proposed a new shape Micro-Electromechanical Systems (MEMS) based triple coupled Cantilever sensor, named as U-Shaped Cantilever. We have designed and simulated a U-Shaped MEMS based micro-cantilever made up of P-Silicon (Polycrystalline, Lightly doped) in COMSOL multiphysics. U-Shaped single beam Cantilever is designed with the dimensions of 100μm*20μm*2μm. U-shaped triple coupled Cantilever is designed with the dimensions of 20μm*120μm*2μm, 100μm*20μm*2μm. The simulation results like displacement, Eigen-frequency, surface stress, temperature, measurements of the U-shaped triple coupled cantilever is compared with rectangular triple coupled cantilever.

Keywords: MEMS, Surface Stress, Eigen Frequency, Sensor, Triple Coupled Cantilever

Introduction

Cantilever sensors have a vital role over last decade due to their high sensitivity, throughput and detection of target elements[1]. The main principle of cantilever is that the sensor responds mechanically when there is change in external parameters like temperature, molecule adsorption. Cantilever has its one end fixed and the other end is movable. Generally beams which are made up of silicon were used as sensors. There can be measured by measuring, defection or resonance frequency changes. There are different mode measurements like static mode, dynamic mode, heat mode, photo thermal spectroscopy, detection of changes, and detection of magnetic forces. Mainly focused on static and dynamic modes. In the static mode, during the adsorption of molecule or any target particle on the surface layer, there will be stress on the surface layer. In the dynamic mode, according to the molecule or target particle adsorption or desorption from the surface of the cantilever beam, beam gets oscillated at its resonance frequency and is monitored with the changes in the resonance frequency. The response of MEMS cantilever sensor can be monitored by using different methods like piezoelectric, piezoresistive, optical etc. Cantilever sensors can find its applications in many sensing applications like chemical and biological detections[2,3]due to their high sensitivity, low cost. In this paper a new shape cantilever named as U-shaped cantilever is designed, simulated and analyzed using COMSOL Multiphysics.

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Design of Cantilever

Procedure

- Selecting Physics: In this step, required physics is selected i.e., solid mechanics, thermal stress etc.
- Defining geometry: In this step, dimensions and required shape is defined to make cantilevers i.e., rectangular, square etc., with required dimensions in micrometers.
- Defining materials: In this step, material is defined to make a cantilevers i.e., silicon(c), sio_2, P-silicon, n-silicon etc., with their different properties like young's modulus (E), Poisson's ratio(nu), density (n_d) etc.,
- Setting up physics: In this step, required physics is selected i.e., Fixed Constraint, Body load, Point load etc.
- Meshing: In order to achieve the results accurately we need to use an element mesh with respect to the dimensions of the elements i.e., Fine, Finer, Coarse, Coarser etc.
- Simulation: In this step is done Simulation according to the desired specifications.
- Analysis of results: In this step results are analyzed through graphs like point graph, line graph etc.

Simulation of MEMS Based Cantilevers

Here, the analysis is performed for rectangular triple coupled cantilever, U-Shaped triple coupled MEMS cantilevers. The simulations are carried out materials (si(c), p-si (polycrystalline)) having the young's modulus of 170e9 [Pa], 160e9 [Pa], Poisson's ratio of 0.28, 0.22 and density of 2329[kg/m^3] 2320[kg/m^3] for si(c), p-si respectively.

Rectangular triple coupled Cantilever

This Cantilever is performed with the geometric parameters as 20μm*120μm*2μm and 100μm *20μm*2μm and the displacement of MEMS cantilever is simulated by using COMSOL Multiphysics with material silicon(c) and p-Silicon when load is applied on all the beams of rectangular triple coupled cantilever the displacements values are calculated with the materials Silicon(c) and p-Silicon[4,5]. When point load is applied on all the beams of rectangular triple coupled cantilever the displacements values are calculated and are mentioned in the Table 1 with the materials Silicon(c) and p-Silicon.

Proposed

U-Shaped triple coupled Cantilever

This U-Shaped MEMS based cantilever is performed with the geometric parameters as 20μm*120μm*2μm and 100μm*20μm*2μmand the displacement of MEMS cantilever is simulated by using COMSOL Multiphysics with material silicon(c) and p-Silicon when no load which is shown in figure 3.When load is applied on all the beams of rectangular triple coupled cantilever the displacements values are mentioned in the Table 2 with the materials Silicon(c) and p-Silicon[6,7].When point load is applied on all the beams of rectangular triple coupled cantilever the displacements values are mentioned in with the materials Silicon(c) and p-Silicon.

Thermal Stress, Temperature Stress

When there is a change of temperature as it can be uniform or non-uniform on the material, the material inhibits over contraction or expansion is call Thermal Stress and the change in temperature called Temperature Stress. When certain temperature is applied on the surface of the rectangular and U-Shaped triple coupled cantilever beam the thermal stress and temperature stress is mentioned in the Table 3.

Results and Discussion

The coupled cantilevers are more sensitive and localized when compared with single cantilevers in micro structure. The main advantage of coupling is to increase the potential throughout of the system[8-11]. These coupled cantilevers provide higher sensitivity when compared with traditional cantilevers[12]. The phenomena of coupled cantilevers is expressed in most of the articles, especially the triple coupled cantilevers by Hossien Pakdast and Marco Lazzarino;

Table 1 — Displacement for Rectangular triple coupled Cantilever when Body, Point load is applied

	Rectangular triple coupled Cantilever					
S. No	Load type	Silicon(c)	P-silicon	Load type	Silicon(c)	P-Silicon
	Body Load(N/ m^3)	Displacement(μm)	Displacement(μm)	Point load(N)	Displacement(μm)	Displacement(μm)
1	10	$3.8235 * 10^{-9}$	$4.3444* 10^{-9}$	10	$2.2732 * 10^{6}$	$2.3587 * 10^{6}$
2	20	$7.647 * 10^{-9}$	$8.6887 * 10^{-9}$	20	$4.5465 * 10^{6}$	$4.7173 * 10^{6}$
3	30	$11.471 * 10^{-9}$	$13.033 * 10^{-9}$	30	$6.8197 * 10^{6}$	$7.076 * 10^{6}$
4	40	$15.294 * 10^{-9}$	$17.377 * 10^{-9}$	40	$9.0929 * 10^{6}$	$9.4347 * 10^{6}$
5	50	$19.118 * 10^{-9}$	$21.722 * 10^{-9}$	50	$11.366 * 10^{6}$	$11.793 * 10^{6}$

Table 2 — Displacement for U-shaped triple coupled Cantilever when Body, Point load is applied

	U-Shaped triple coupled Cantilever					
S. No	Load type	Silicon(c)	P-silicon	Load type	Silicon(c)	P-Silicon
	Body Load (N/ m^3)	Displacement (μm)	Displacement (μm)	Point load(N)	Displacement (μm)	Displacement (μm)
1	10	$4.3444 * 10^{-9}$	$4.6507 * 10^{-9}$	10	$2.3587 * 10^{6}$	$2.5189 * 10^{6}$
2	20	$8.6887 * 10^{-9}$	$9.3014 * 10^{-9}$	20	$4.7173 * 10^{6}$	$5.0378 * 10^{6}$
3	30	$13.033 * 10^{-9}$	$13.952 * 10^{-9}$	30	$7.076 * 10^{6}$	$7.5566 * 10^{6}$
4	40	$17.377 * 10^{-9}$	$18.603 * 10^{-9}$	40	$9.4347 * 10^{6}$	$10.076 * 10^{6}$
5	50	$21.722 * 10^{-9}$	$23.253 * 10^{-9}$	50	$11.793 * 10^{6}$	$12.564 * 10^{6}$

Table 3 — stress and temperature stress of Rectangular & U-Shaped triple coupled cantilevers

S. No	Temperature [deg c]	Rectangular		U-Shaped	
		Thermal Stress [N/m^2]	Temperature Stress[K]	Thermal Stress [N/m^2]	Temperature Stress[K]
1	10	$1.4587* 10^7$	283.15	$1.537* 10^7$	283.15
2	20	$1.367* 10^{-8}$	293.15	$1.432 *10^{-8}$	293.15
3	30	$1.4586* 10^7$	303.15	$1.537* 10^7$	303.15
4	40	$2.9172* 10^7$	313.15	$3.0741*10^7$	313.15
5	50	$4.3758* 10^7$	323.15	$4.6111*10^7$	323.15

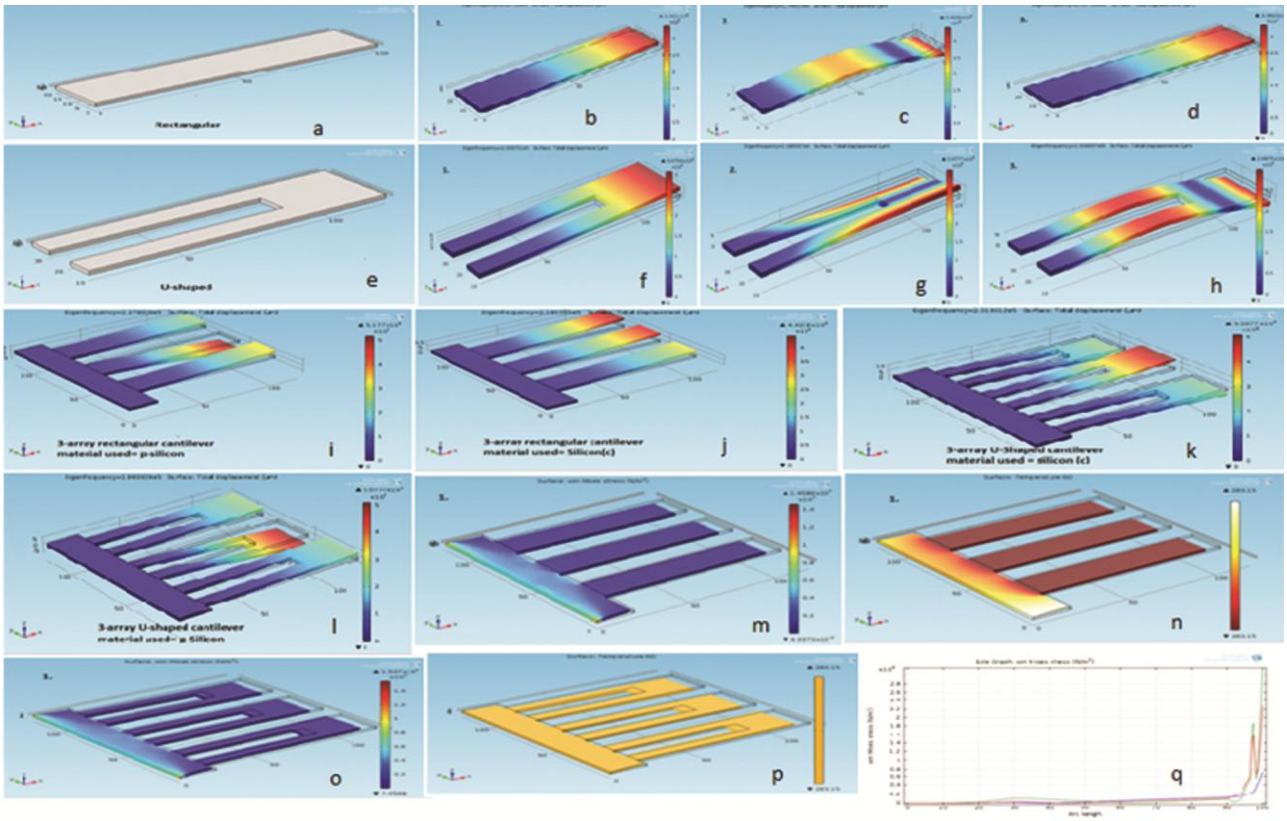

Fig.1 —a) Rectangular cantilever b) eigen mode1 c) eigen mode d) eigen mode e) Simulated Coupled Cantilever f) eigen mode g) eigen mode h) eigen modei) , j) Triple Couple Cantilever modes k) ,l) Rectangular triple coupled m) n) Thermal, Temperature stress, o) U-Shaped Single beam and triple coupled

explained the mass detection and localization of TCC with change in overhang and cantilever dimensions are validated with Eigen frequency response[13]. In this work we concentrated on structural variations of triple couple cantilever, one is rectangular and another is U shaped. The Eigen frequency analysis for with load and without load is simulated using FEM tool. The thermal variation analysis is also simulated for TCC, it is observed that eigen frequency and displacement of rectangular and U- shaped cantilever are better for Bio-Sensing when compared with conventional TCC. For Bio-sensing application higher frequencies are preferred where TCC are considered as a choice. The rectangular are having higher Eigen frequency modes when compared with U shaped cantilever and displacement of the U shaped is more in load condition describing the higher sensitivity. With corresponds to this thermal analysis is also calibrated along with the stress analysis for both U and Rectangular shaped TCC cantilevers. In overall the U shaped cantilever is having higher sensitivity for load condition when compared with Rectangular TCC.

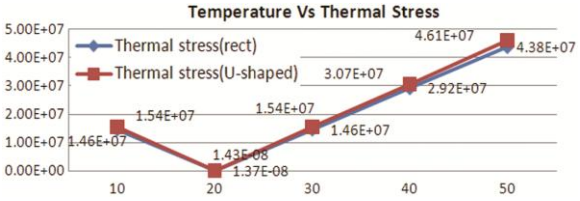

Fig. 2 — Triple coupled U-shaped, Rectangular cantilever Temperature vs Thermal

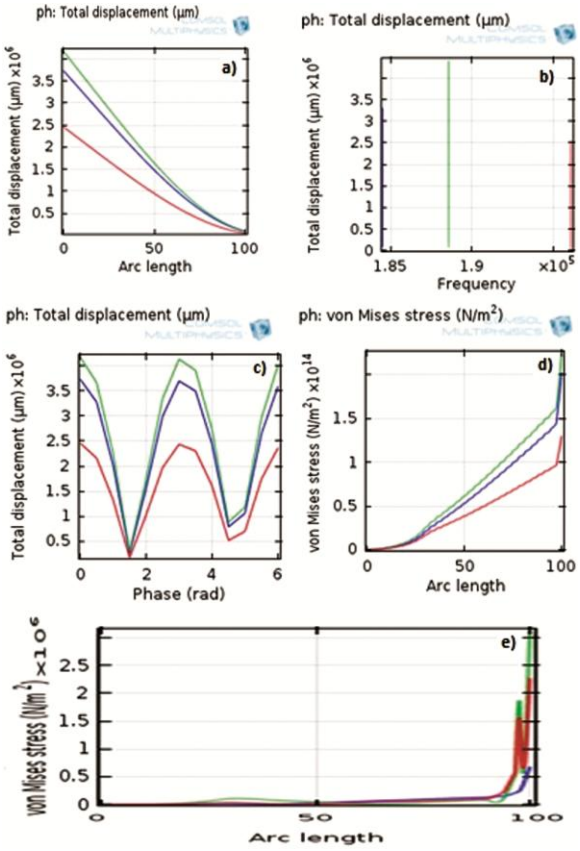

Fig. 3 — a) Displacement Vs arc length b) Displacement Vs frequency c) Displacement Vs phase, d) Thermal stress Vs arc length (Eigen frequencies),e) Thermal stress Vs arc length(Non Eigen Frequency)

Conclusion

The MEMS cantilever sensors are used in various applications. Here, the U-shaped MEMS cantilever with the dimensions of 100µm*20µ*2µm produces the total displacement of $3.4777*10^6$ µm is high when compared to Rectangular MEMS cantilever where it's displacement is of $3.4258 * 10^6$ µm. The simulation is performed using COMSOL Multiphysics and the variation of rectangular, U-shaped MEMS cantilever is studied by considering the piezo resistive, Semi-Conductor materials. Thermal stress also measured for U-shaped triple coupled MEMS cantilever. Related graphs are taken which are shown in figures 1, 2 and 3. Further for different materials like metals, polymers etc., analysis were to be measured and compared.

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