COMSOL Simulation of a Dual-axis MEMS Accelerometer with T-shape Beams

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Outline

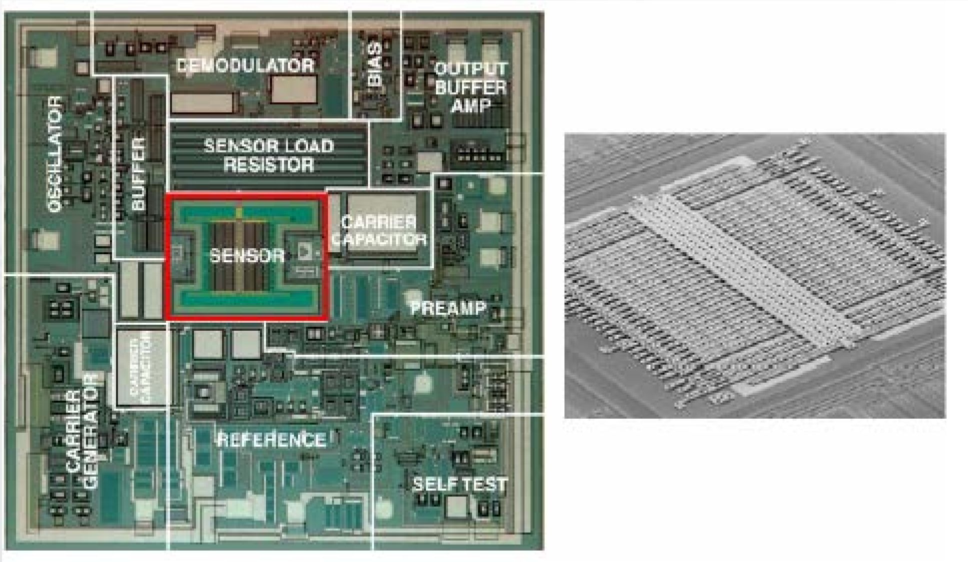
- ✓ Abstract and Introduction
- ✓ Structural Design
- ✓ Theoretical Analysis
- ✓ COMSOL Simulation
- ✓ Results
- ✓ Conclusion and future work

What is MEMS accelerometer

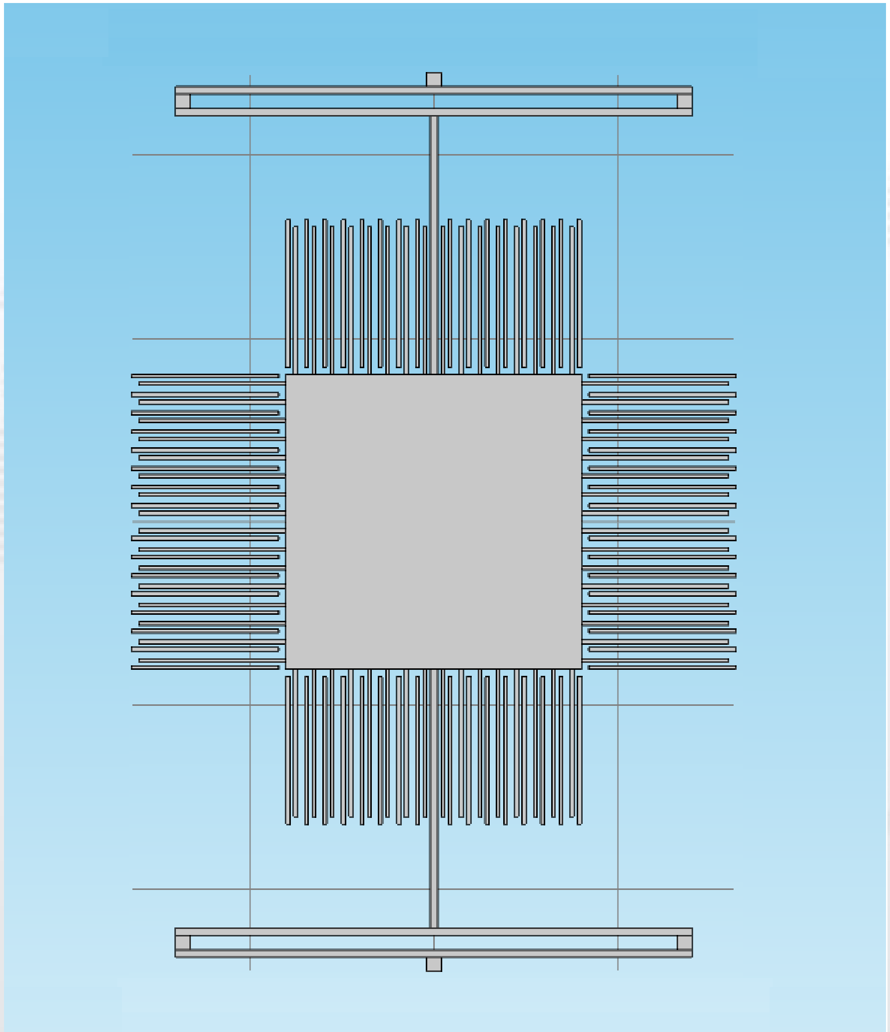
MEMS(Micro Electro Mechanical Systems) technology focuses on the range between micrometers to nanometers.

. MEMS accelerometer is belonged to MEMS inertial sensor.

Inertial navigation requires MEMS acceleration measurement along all three degree-of-freedoms. Most accelerometers are designed to measure acceleration along a single sensitive direction.



Structure of Dual-axis MEMS Accelerometer

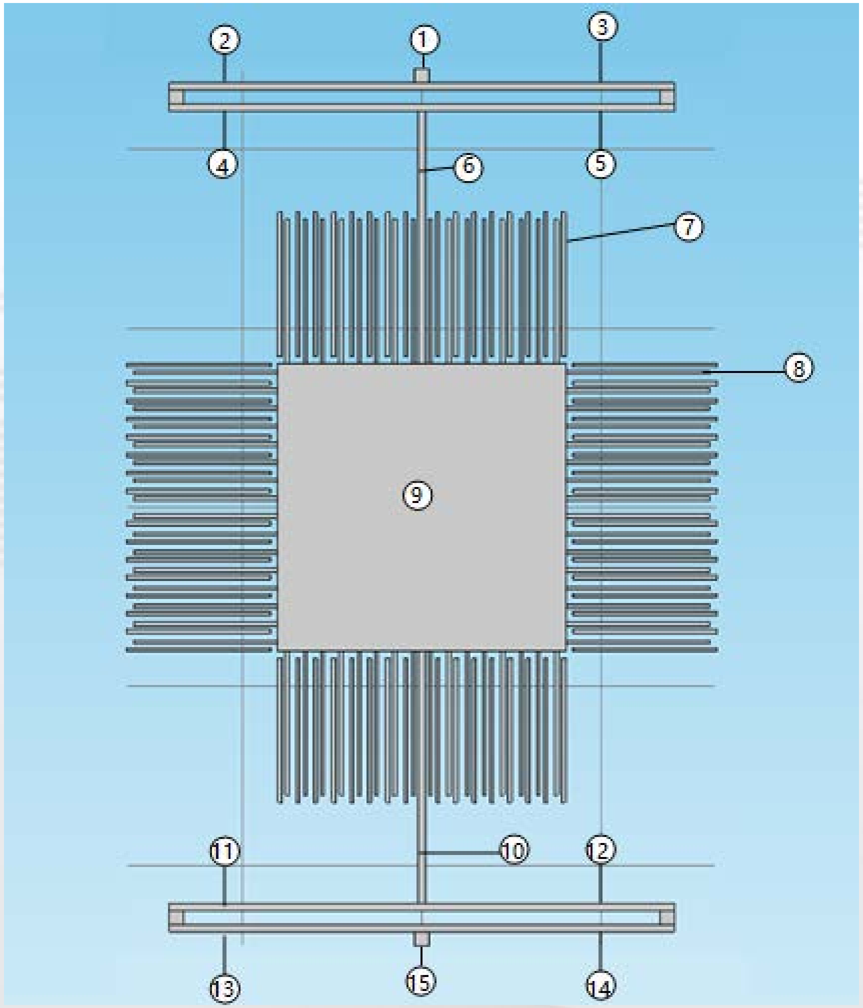


The proposed dual-axis MEMS comb accelerometer has two T-shape beams.

Each T-shape beam consists of one straight beam and 4 folded beams connected between anchors and central mass.

There are eight groups of movable fingers extruding from the top/bottom/left/right of the movable mass.

Structure of Dual-axis MEMS Accelerometer

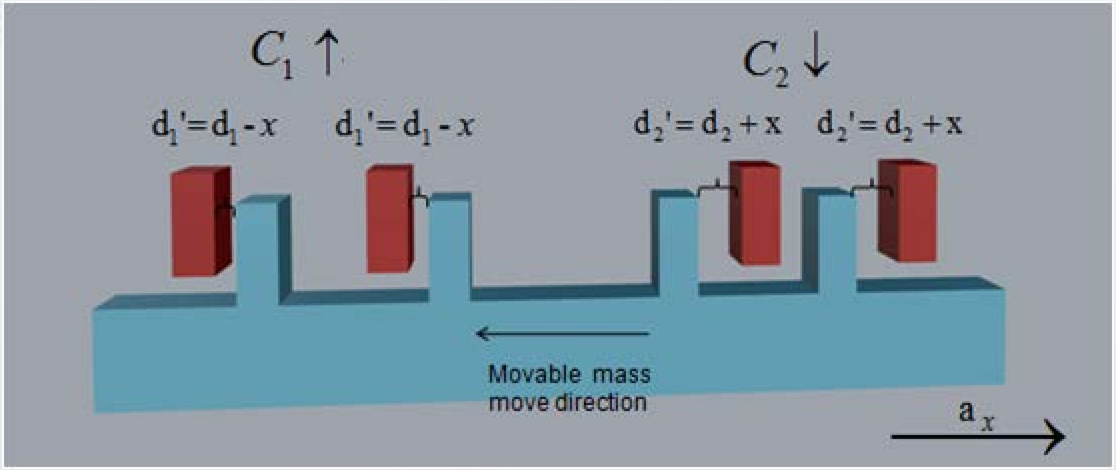


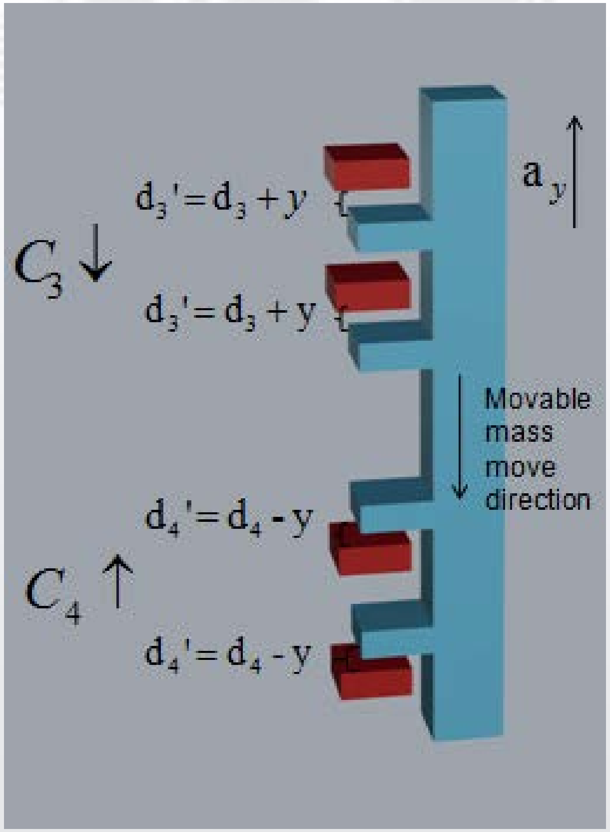
Components	Amount	Length (μm)	Width (μm)	Numbers in figure
Central mass	1	800	800	9
Movable fingers	64 (8×8)	400	10	8
Fixed fingers	64	400	10	7
Folded beam segments	8	700	20	2,3,4,5 11,12,13, 14
Straight beams	2	700	20	6,10
Anchors	2	40	40	1,15

Theoretical Analysis

When there is no inertia force, the displacement of movable fingers to fixed fingers in the right part is equal to the left part which means d1=d2. C1=C2.

When applying inertia force, the horizontal capacitance or vertical capacitance change due to displacement of movable fingers.





Theoretical Analysis

- When there is acceleration along X-axis direction, due to inertial force, the movable fingers move toward left by displacement x, then: d1’=d1-x, d2’=d2+x,the X-capacitance change is

$$\Delta C_x = C_1' - C_2' \approx 2\Delta C_1 = 2\frac{N_x \varepsilon S}{d_0}\cdot\left(\frac{x}{d_0}\right)$$

- Similarly, When acceleration along Y-axis direction,

$$\Delta C_y = C_3' - C_4' \approx 2\Delta C_3 = 2\frac{N_y \varepsilon S}{d_0}\cdot\left(\frac{y}{d_0}\right)$$

- The effective spring constants of the device along X and Y directions can be calculated as

$$K_{xtot} = 2E\cdot w_{bx}{}^{3}\cdot t_{bx}\Big/ L_{bx}{}^{3} \qquad K_{ytot} = 2E\cdot w_{by}{}^{3}\cdot t_{by}\Big/ L_{by}{}^{3}$$

Theoretical Analysis

- The displacement sensitivities along X and Y directions are:

$$S_{dx} = \frac{\rho\left(w_m \cdot L_m \cdot t_m + 64 \cdot w_f \cdot L_f \cdot t_f\right) \cdot g \cdot L_{bx}^{3}}{2E \cdot w_{bx}^{3} \cdot t_{bx}}$$

$$S_{dy} = \frac{\rho\left(w_m \cdot L_m \cdot t_m + 64 \cdot w_f \cdot L_f \cdot t_f\right) \cdot g \cdot L_{by}^{3}}{2E \cdot w_{by}^{3} \cdot t_{by}}$$

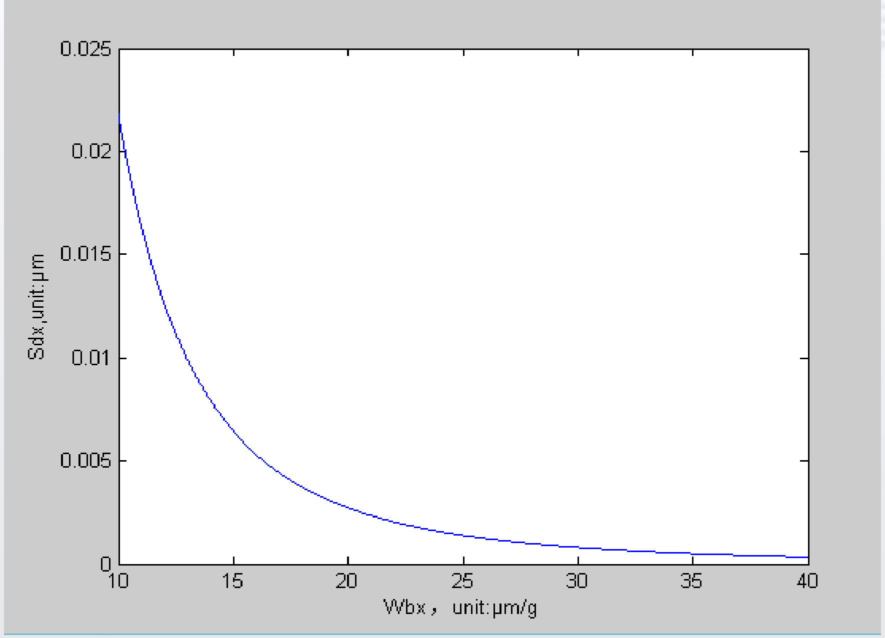


Figure 4. Sensitivity (S_{dx},unit: μm/g) vs width of X-beams(w_{bx}, unit:μm)

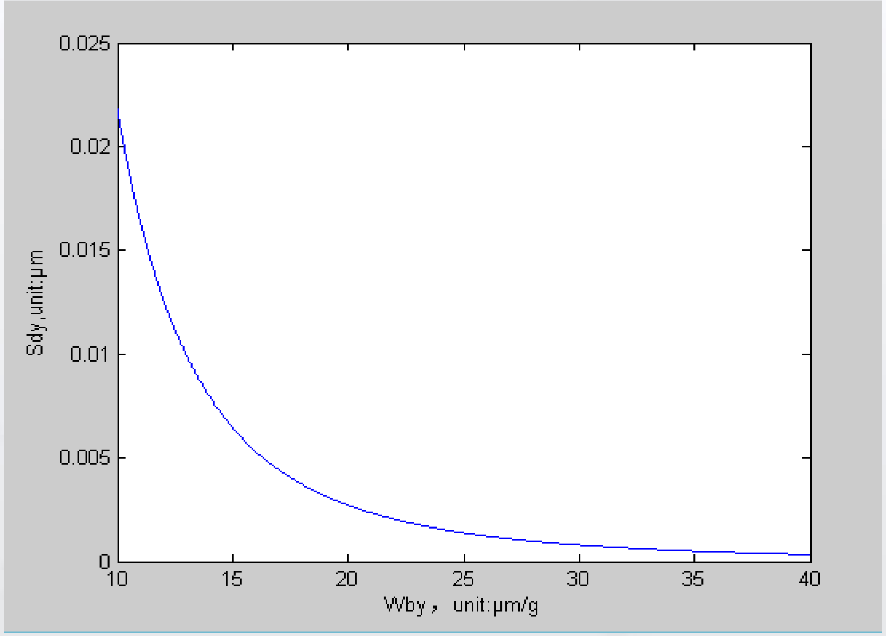
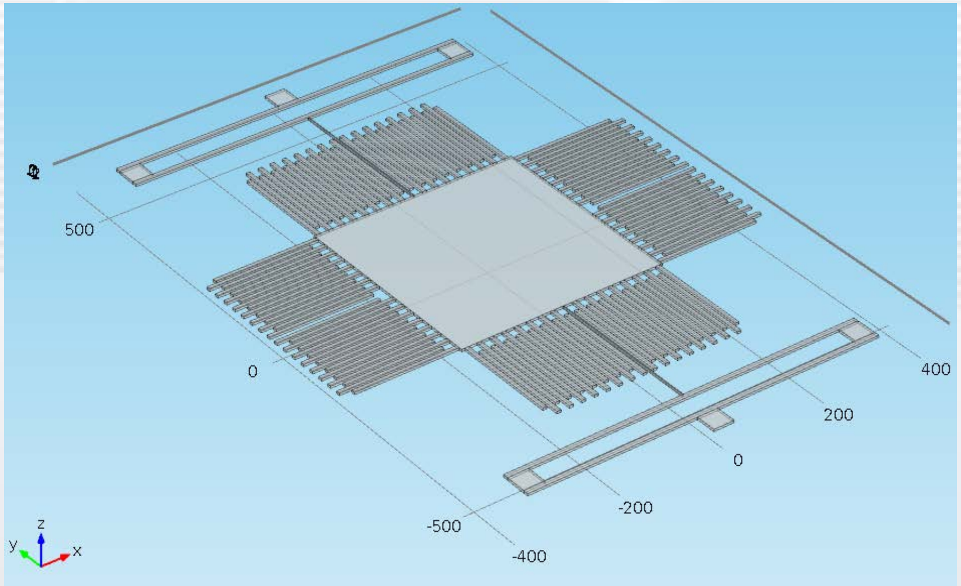


Figure 5. Sensitivity(S_{dy}, unit: μm/g) vs width of Y-beams (w_{by} , unit:μm)

COMSOL Simulation

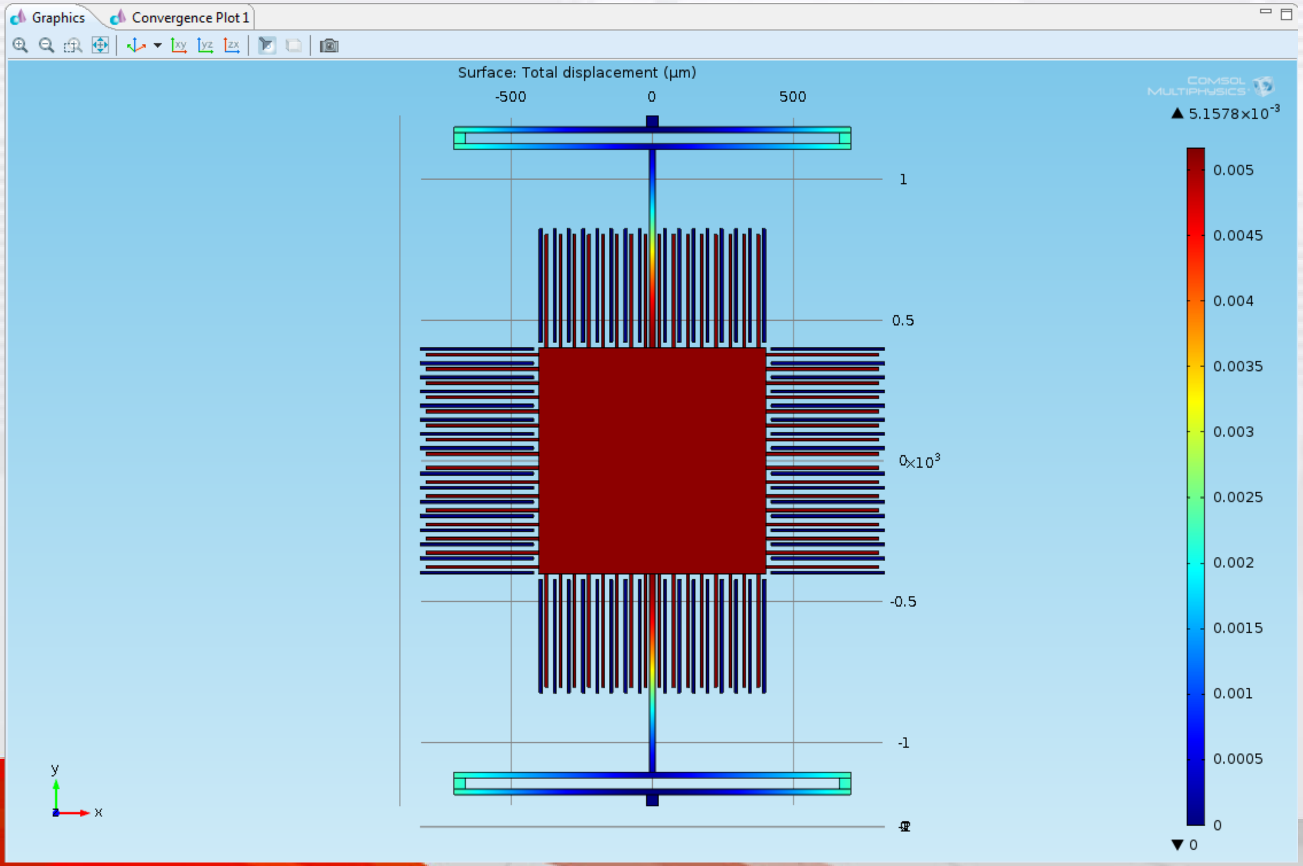
- COMSOL Multiphysics is used to simulate the Displacement sensitivity and Stress of the dual-axis accelerometer along X and Y directions.



The complete device model of the dual-axis MEMS accelerometer is designed in COMSOL. Polysilicon is used as the material of the device.

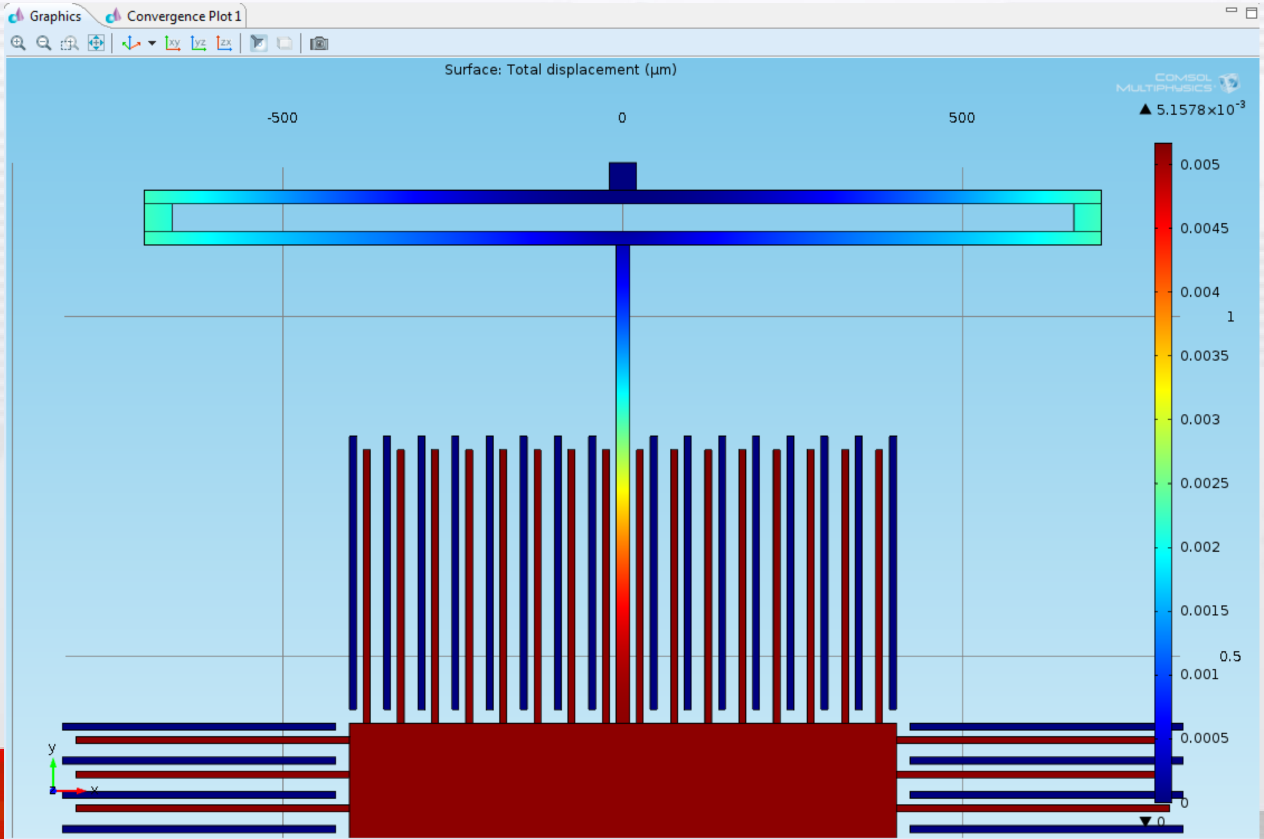
COMSOL Simulation – Sensitivity Simulation

- We apply unit gravity acceleration ($1g=9.8m/s^2$) to simulate the sensitivity along X and Y directions respectively. From the contour plot we can see that the displacement sensitivity of the acceleration along X-direction is S_{dx}=0.0051578µm/g.



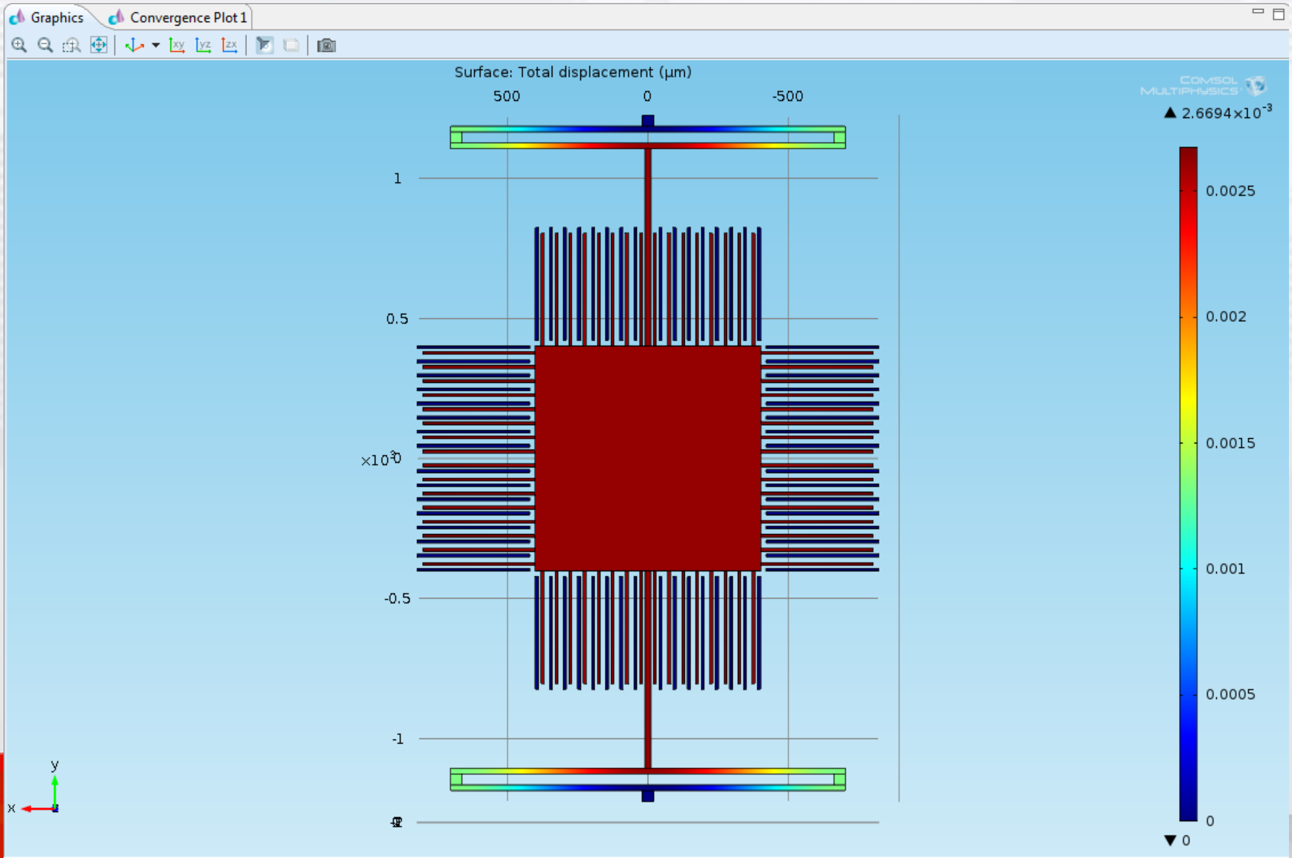
COMSOL Simulation – Sensitivity Simulation

- The detailed bending shape of the straight beam is shown in below. The bending displacement increases along the straight beam, and the maximum displacement is achieved at the end of the straight beam, as well as the movable mass and all movable fingers.



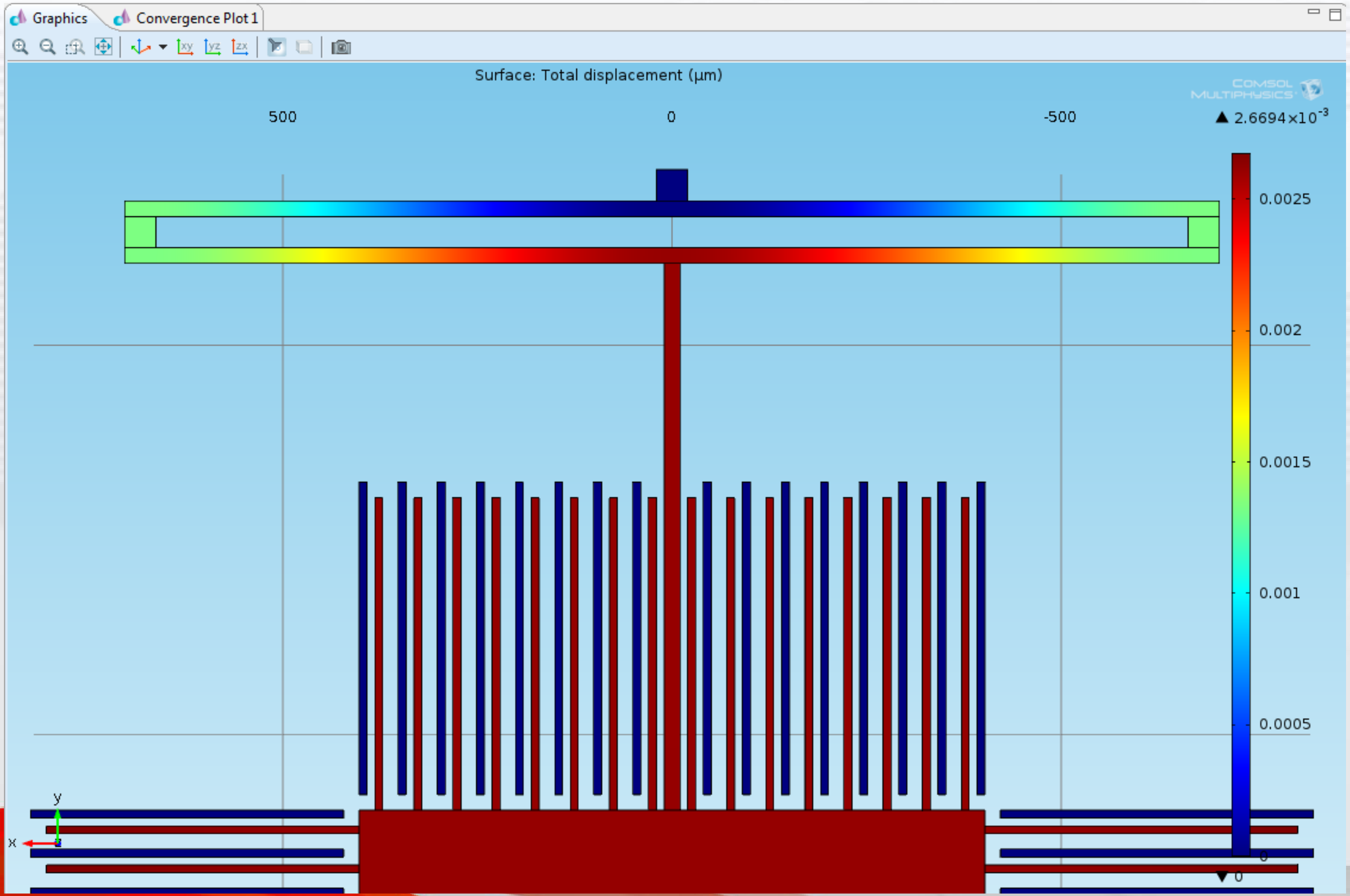
COMSOL Simulation – Sensitivity Simulation

- The COMSOL simulation of displacement sensitivity along Y direction is shown below. The folded beams bend along Y direction due to inertial force. According to the result, the displacement sensitivity along Y direction is S_{dy}=0.0026694µm/g.



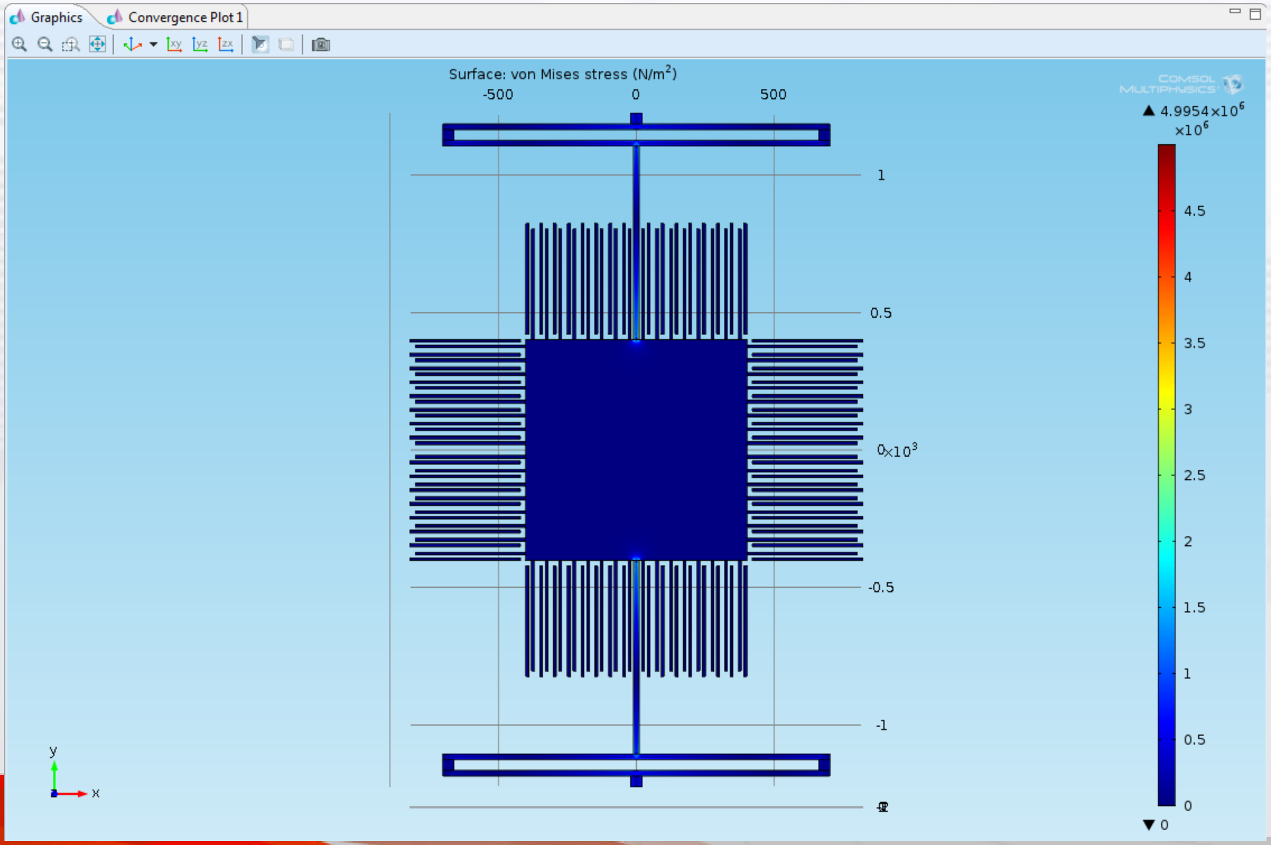
COMSOL Simulation – Sensitivity Simulation

- The detailed bending shape of the folded beam is shown below. We can see that the maximum bending displacement occurs at the end of the folded beams.



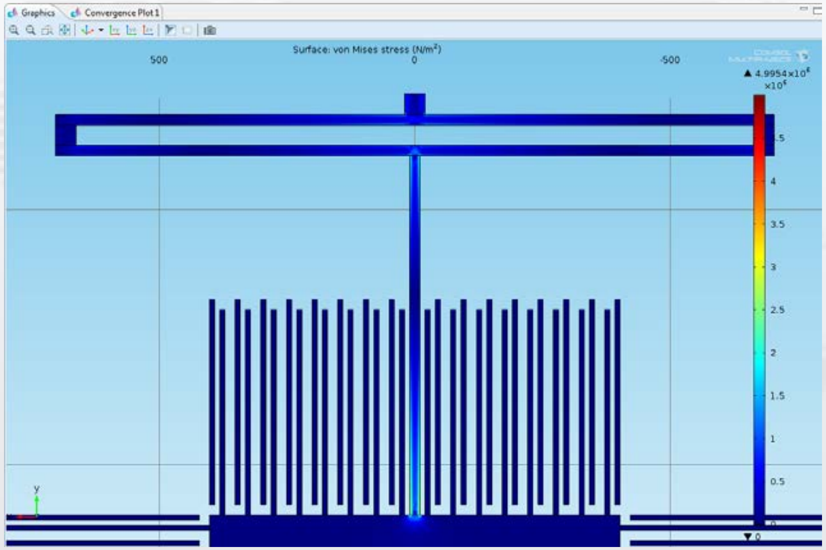
COMSOL Simulation – Stress Simulation

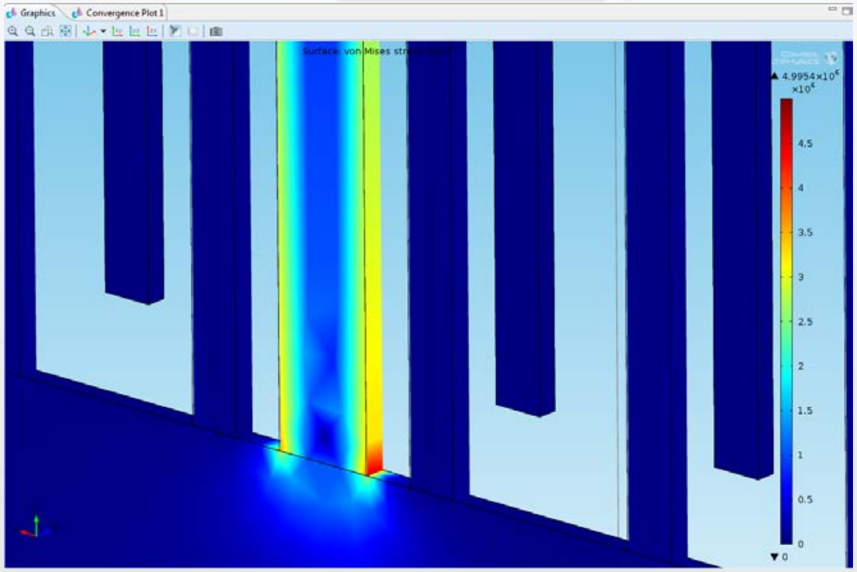
- Stress simulation is performed to find out the stress induced inside the material when the beams bend due to maximum full-scale acceleration input. When acceleration of 50g is applied along X direction, the stress intensity plot of the device is shown below.



COMSOL Simulation – Stress Simulation

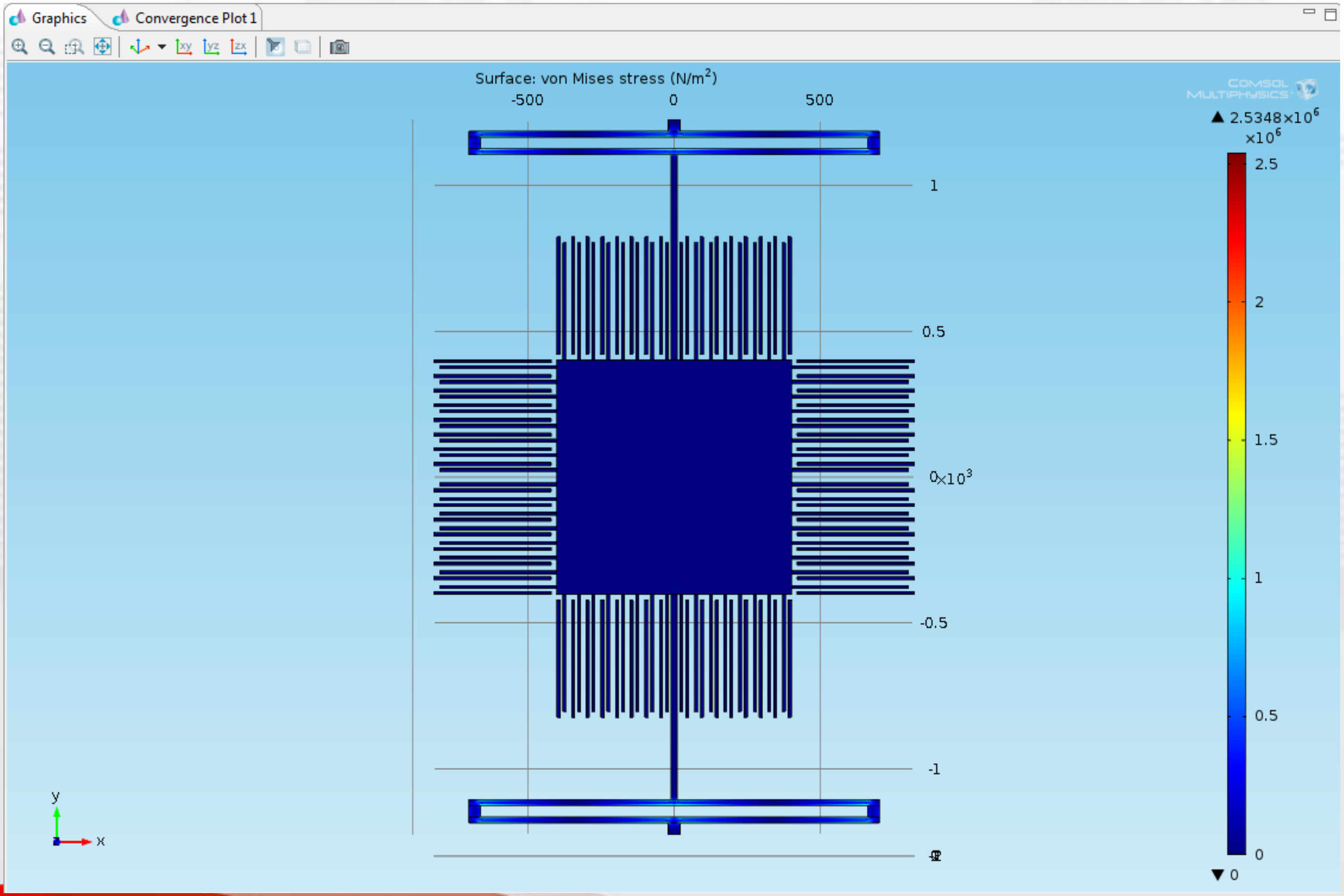
- The stress mainly occurs inside the straight beams, and all the other parts of the device experiences almost zero stress. The stress is induced by the deformation of the straight beams(4.5594×10^6 Pa)





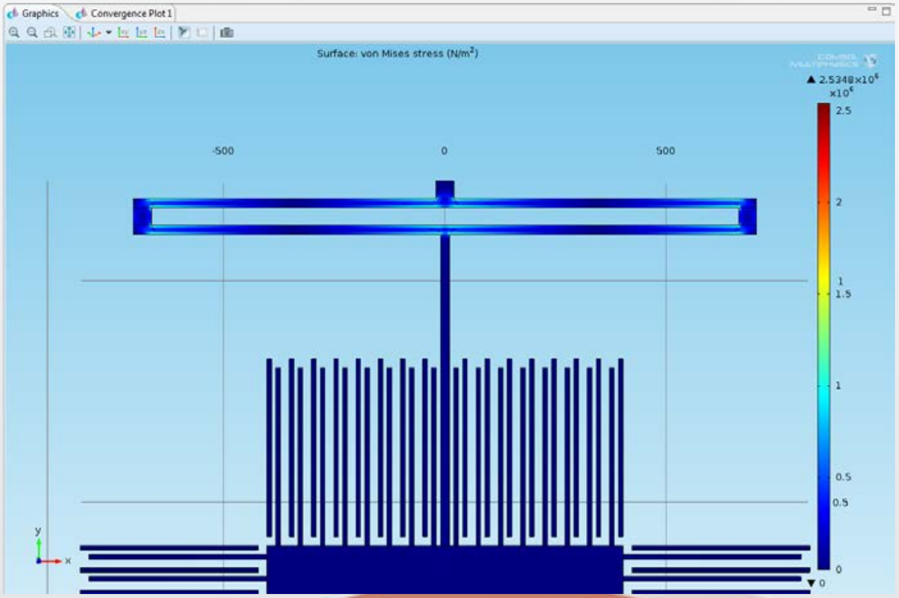
COMSOL Simulation – Stress Simulation

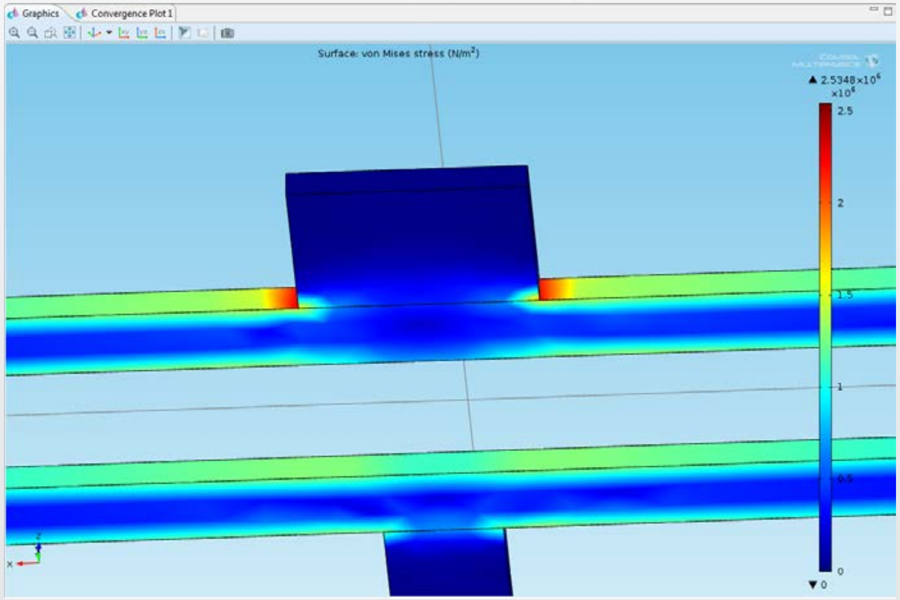
When acceleration of 50g is applied along Y direction, the stress intensity contour plot of the device is shown in below.



COMSOL Simulation – Stress Simulation

- The stress mainly occurs inside straight beams and folded beams (2.5348×10^6Pa)
- The fracture strength of polysilicon is (3.4±0.5) GPa in bending tests.





Conclusion and Future work

- In this paper, a dual-axis MEMS accelerometer with T-shape beams is introduced. T-shape beam structure allows the accelerations along both X-axis and Y-axis to be measured by differential capacitance sensing.

- COMSOL Multiphysics is used to simulate the displacement sensitivities of the accelerometer along X and Y directions. Stress intensity plots were also obtained for 50g acceleration inputs along X and Y directions. Solid Mechanics (solid) physics and Electromechanics (emi) physics are used in device modeling. Compared to the hybrid integration of multiple sensors, dual-axis accelerometer can reduce the fabrication cost and improve efficiency.

- It can be further integrated with a Z-axis accelerometer for complete 3D inertial navigation.

THANKS

Q&A