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Silicon Force Sensor (Load Cell)

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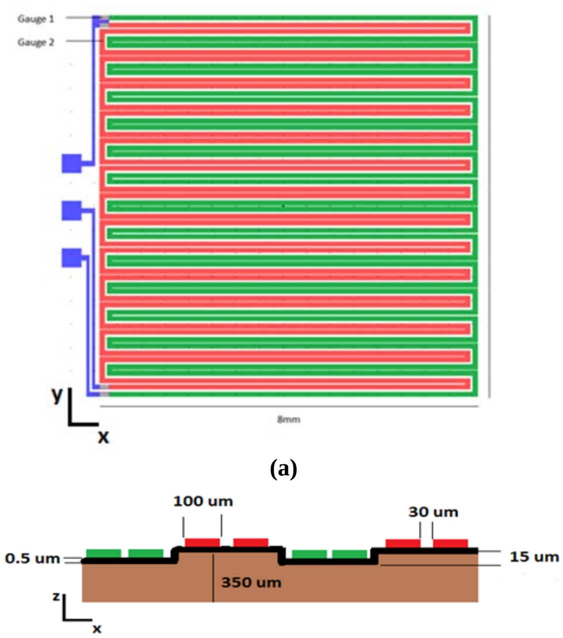
Abstract—*In this paper, a silicon force sensor is presented in which the force is measured by compressing a polysilicon strain gage. This gage is compressed by a plate on which the maximum force of 500 kN is applied. The change in resistance is a measure for the total force. Our design is compensated for the temperature changes and for in plane stretching and bending stresses in the chip. Piezoresistive module of Comsol Multiphysics 4.3 is used for simulation purpose.*

1. INTRODUCTION

The basic structure of silicon force sensor is shown in Fig. 1. Force sensor is placed between two pressing blocks. The force which is to be measured is applied on these blocks. Two polysilicon strain gauges are deposited on the top of 8 mm by 8 mm silicon chip. Gauge 1 is directly loaded. Gauge 2 is situated in 15 µm deep trench and it is not directly loaded.



(b)

Fig. 1.1 (a) Geometric details of load cell (top of load cell), (b) Cross-sectional view

Piezoresistive strain sensors are preferred because of high sensitivity, low noise, better scaling characteristics, wide range of Force measurement etc. also piezoresistive strain sensors need less complicated conditioning circuit.

2. CHARACTERISATION

The relative change of resistance for gage 1 and 2 can be written as

$$\frac{\Delta R_1}{R} = \pi_l(K_1\sigma_z) + \pi_t(K_2\sigma_z + \sigma_z) + \alpha T \qquad (2.1)$$

$$\frac{\Delta R_2}{R} = \pi_l(K_3\sigma_z) + \pi_t(K_4\sigma_z) + \alpha T \qquad (2.2)$$

Here $K_1 = {}^{\sigma_x^1}/_{\sigma_z}$, $K_2 = {}^{\sigma_y^1}/_{\sigma_z}$, $K_3 = {}^{\sigma_x^2}/_{\sigma_z}$ and $K_4 = {}^{\sigma_y^2}/_{\sigma_z}$,

depends on Poison's ratio and geometry. π_l and π_t are piezoresistance coefficients. σ is stress.

By subtracting both (2.1) and (2.2) relative changes of resistance is the result

$$\frac{R_1 - R_2}{R} = \pi_l(K_1 - K_3) + \pi_t(1 + K_2 + K_4)\sigma_z \qquad (2.3)$$

The change in resistance under applied load and corresponding stress along the z-axis is $\sigma_1 = {}^{F}/_{WL}$, Where F is the applied force, W is the width of the Piezoresistor and L is the total length of Piezoresistor.

$$\frac{R_1 - R_2}{R} = K\frac{F}{WL} \qquad (2.4)$$

Where $K = \pi_l(K_1 - K_3) + \pi_t(1 + K_2 + K_4)$.

The value of ΔV_{out} (change in output voltage) can be accurately determined using a voltage divider arrangement (Fig. 2.1). V_s is supply voltage.

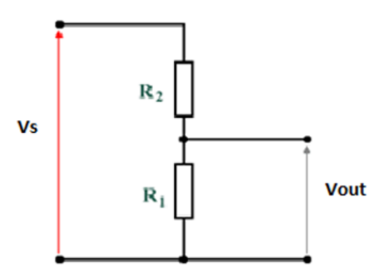


Fig. 2.1 Voltage divider circuit

$$\Delta V_{out} = V_s - \frac{R_2}{R_1+R_2} \quad (2.5)$$

3. MODELLING

Our design is modeled by using Comsol Multiphysics 4.3a. Piezoresistivity, boundary current (pzrb) physics under Structural mechanics module is used to design and simulate model of Load cell.

The geometry is created using block of the required values of width, depth and height. A 2-D work plane is defined on the top of block on which geometry of piezoresistors and connections are defined. Aluminium is used as metal interconnect between piezoresistors. Default values of material properties given in Comsol Multiphysics are used for the purpose of simulation. Next step is to define structural, electrical and piezoresistive properties of our sensor models. For the sensor design 1 fixed constraint is applied on the bottom of block i.e. the lower side of the block is kept fixed and load is applied on the top of the block as boundary load. Gauge 2 is situated under the 15µm deep grooves hence only gauge 1 is loaded. The COMSOL model of force sensor is shown in Fig. 3.1.

Simulation of design is carried out using parametric sweep from 0N to 3kN, in steps of 500N is applied.

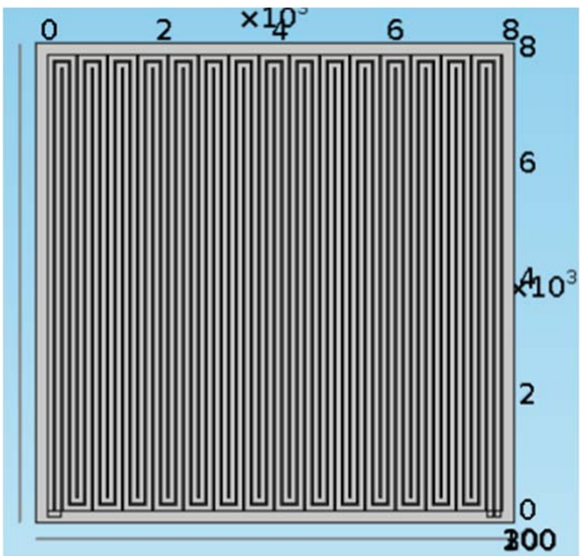
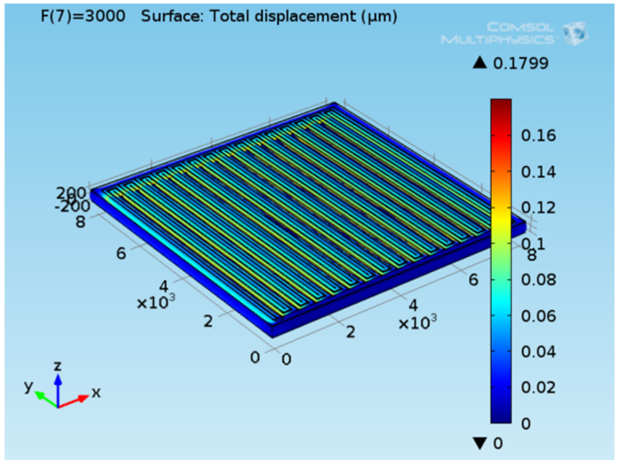


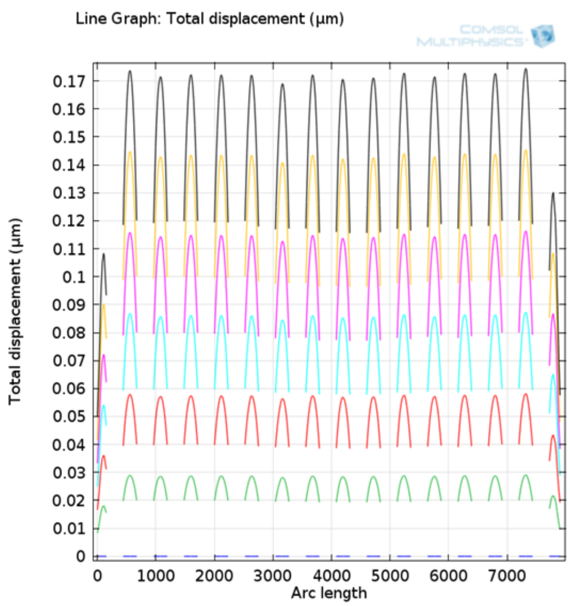
Fig. 3.1: Comsol model of force sensor

4. RESULTS

The displacement profile, stress distribution, potential distribution of the force sensor are shown in Fig. 4.1 and Fig. 4.2 represents its output characteristics.



(a)



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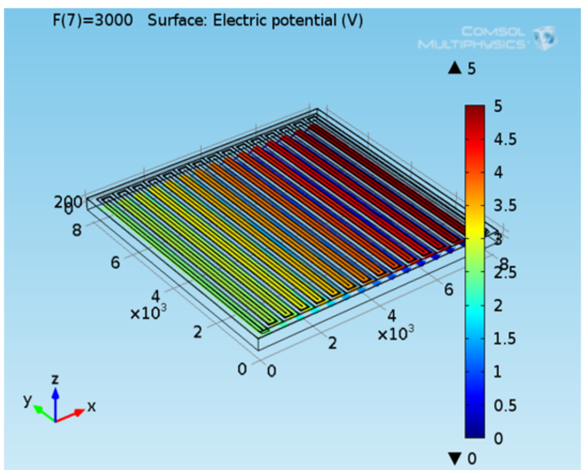

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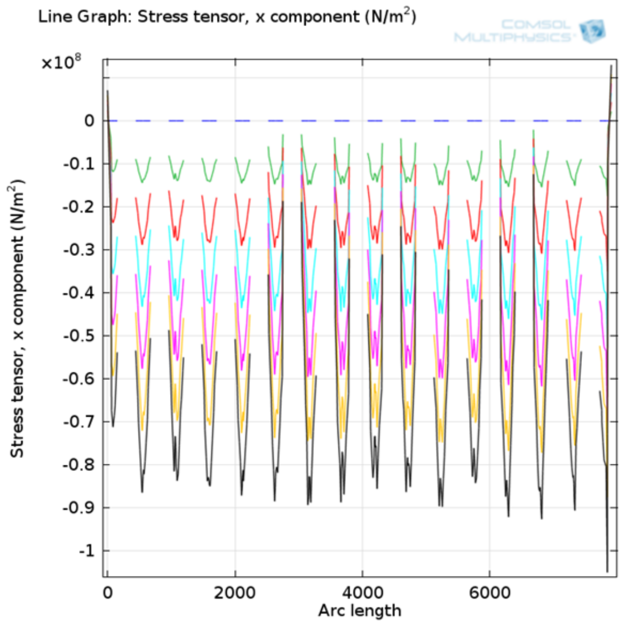

(d)

Fig. 4.1. (a) Displacement profile, (b) Total displacement along the length of sensor under applied loads and (c) Potential distribution for sensor design 1 and (d) Stress along the surface of load cell.

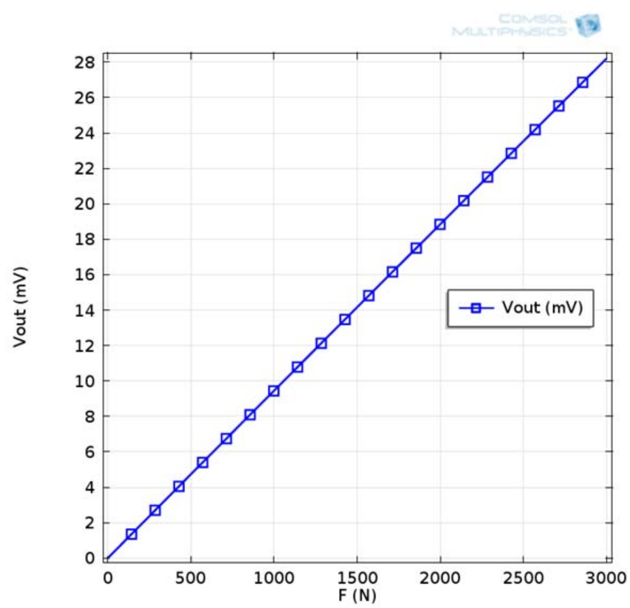

Fig. 4.2. Output characteristics

5. CONCLUSION

Force sensor is simulated for loads up to 3kN and maximum change in output voltage obtained using Potential divider arrangement is ~28 mV at 3kN. The sensitivity comes out to be 1.88 µV/V/N.

The sensitivity of model is further increased by using Wheatstone bridge for determining change in output voltage under applied force.

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