Exercise 1: Pressure Sensor

This problem set is intended to be a walk through the design and operation of a silicon pressure sensor. The pressure sensor is made of highly boron doped resistors standing on a silicon oxide film to eliminate the p-n junctions and therefore increase the operating temperature range of silicon based pressure sensors as shown in Figure 1.

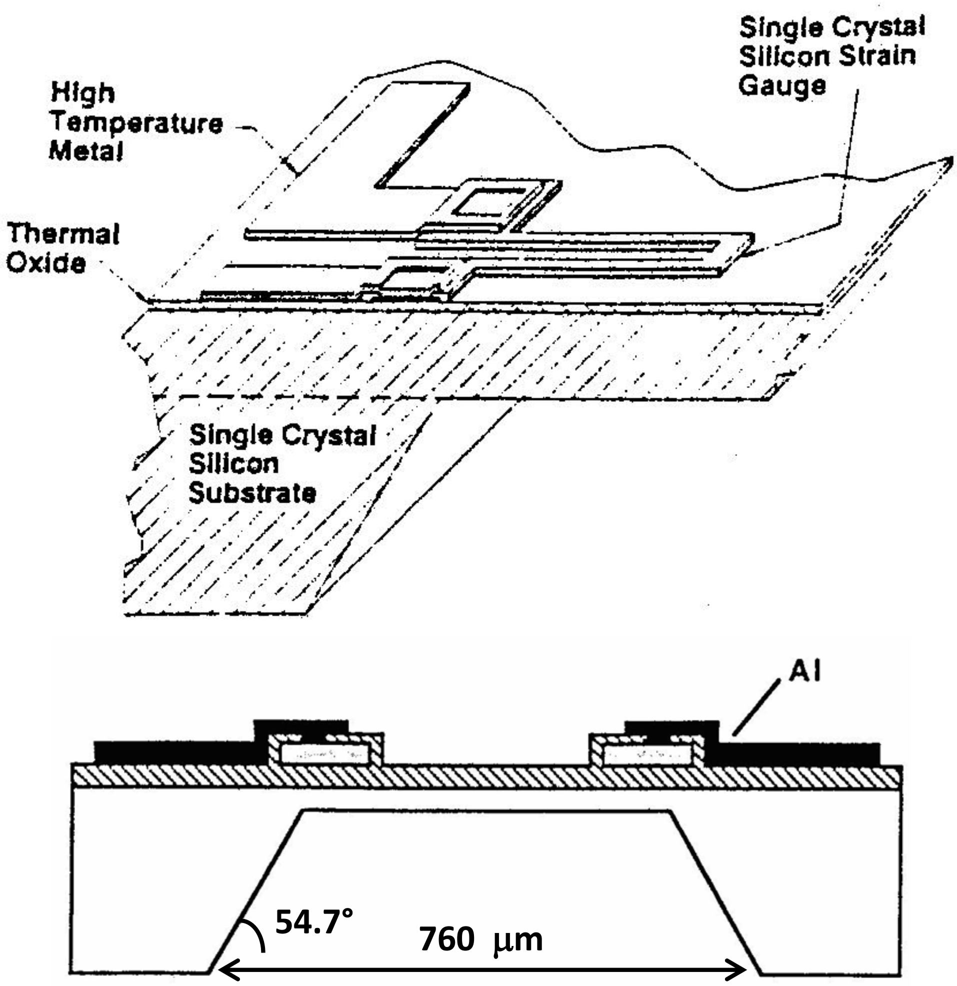


Figure 1: Cutaway view and cross-section of single-crystal silicon resistors standing on a silicon membrane passivated with a silicon oxide film.

Some characteristics:

- Wafer thickness of 275 µm.
- The silicon membrane has a thickness of 20 µm.
- The piezoresistors thickness is 1.0 µm.

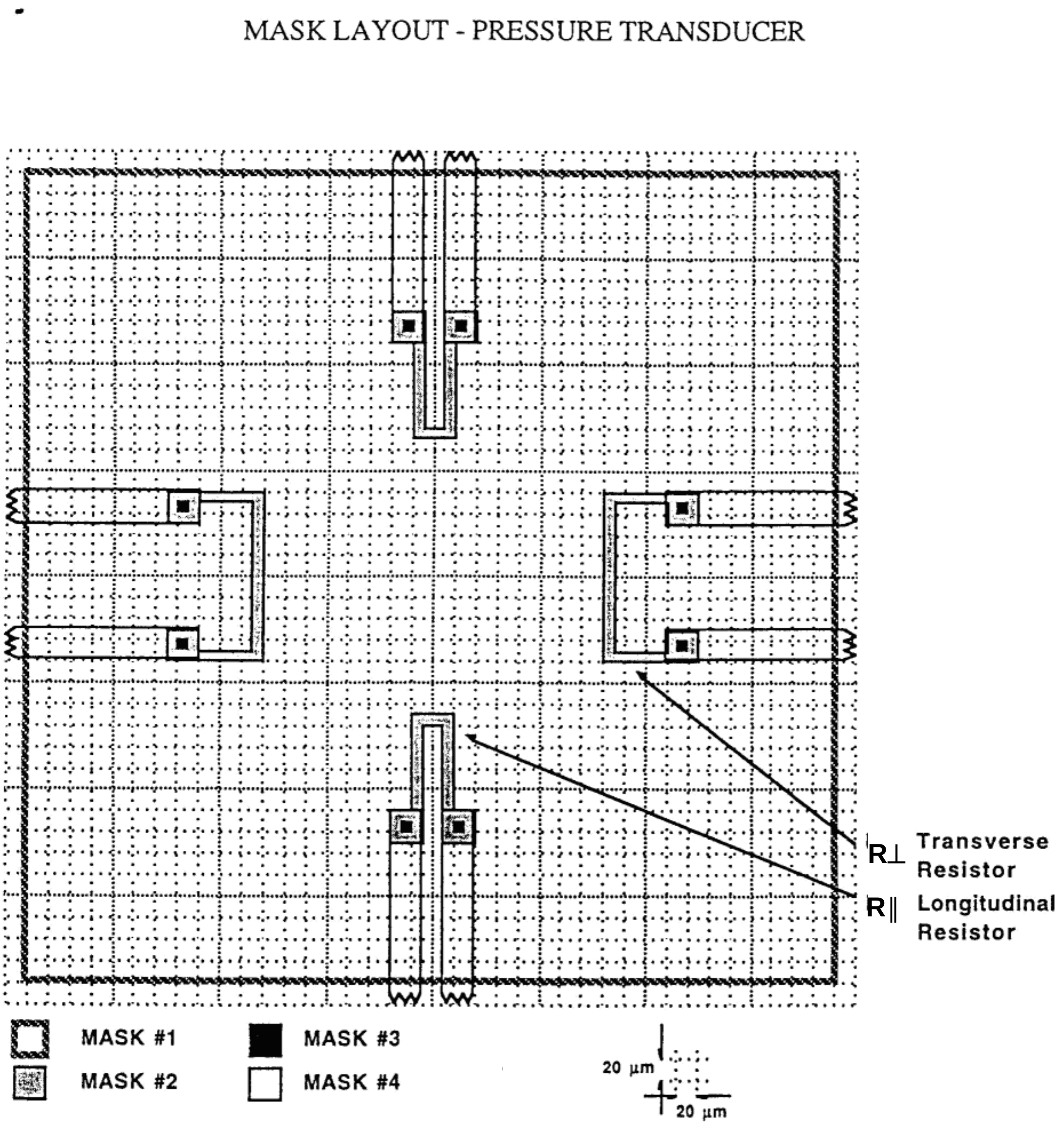


Figure 2: Layout of the pressure sensor using a 4 masks fabrication process.

a) What is the criteria to define the location of the piezoresistors on the silicon membrane ?

b) Why are the piezoresistors positioned in two different orientations, $R_{\perp}$ and $R_{\parallel}$.

c) On Figure 2 draw the edges of the silicon membrane.

d) Complete the section below on the characteristics of the pressure sensor fabricated using the mask layout presented in Figure 2. (thickness of piezoresistors: 1 μm, ρ Si = 0.001 Ω-cm).

Membrane thickness: _______ Membrane edge length: ________

Sheet resistance of the silicon used for the Si piezoresistors: ________

Values of the two transversal and longitudinal piezoresistors:

$R_{\perp}$ = __________ $R_{\parallel}$ =__________

e) Using this pressure transducer, we will determine the expected resistor change due to an applied pressure. Some expressions are given to you below to solve the following questions.

For silicon: $\frac{E}{1-\nu^2} = 200$ GPa,

For a square diaphragm, the deformation at the centre is:

$$w = 1.638 \times 10^{-3}\ \frac{12(1-\nu^2)}{E} \bullet \frac{l^4}{h^3} P$$

$$\sigma_{\perp} = \frac{0.294 \times l^2 \times P}{h^2} \qquad \sigma_{\parallel} = \frac{0.115 \times l^2 \times P}{h^2}$$

$$\frac{\Delta R_{\parallel}}{R_{\parallel}} = \pi_{\parallel}\sigma_{\parallel} + \pi_{\perp}\sigma_{\perp} \approx {}^{1}\!/_{2}\, \pi_{44}\, (\sigma_{\parallel} - \sigma_{\perp})$$

$$\frac{\Delta R_{\perp}}{R_{\perp}} = \pi_{\parallel}\sigma_{\perp} + \pi_{\perp}\sigma_{\parallel} \approx {}^{1}\!/_{2}\, \pi_{44}\, (\sigma_{\perp} - \sigma_{\parallel})$$

Assuming an applied pressure of 2.5 MPa and ½(π_{44}) = 36x10^{-11} Pa^{-1}:

i) What is the deflection in the middle of the diaphragm?

ii) Determine the longitudinal and the transverse stress at the centre of the diaphragm edge where the piezoresistors are located.

iii) What is the fractional change in resistance for a 2.5 MPa load for resistors placed in parallel and perpendicular to the diaphragm edge?

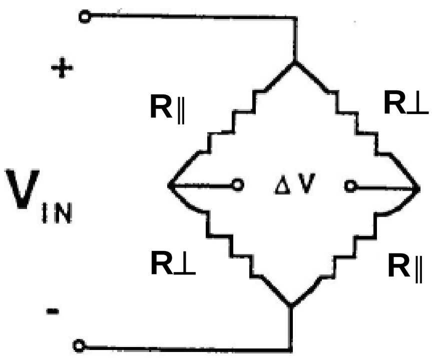
f) Assume that the resistors are configured as a full Wheatstone bridge (see drawing below).

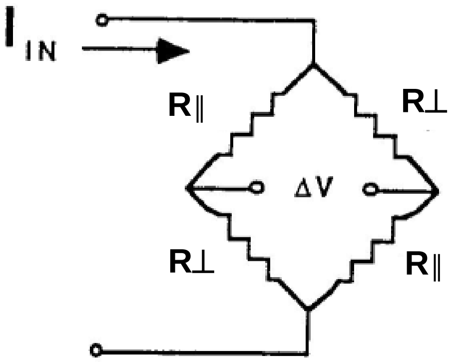
i) Determine an expression for the differential output voltage from this circuit for a change in pressure, **P,** as a function of RII and R⊥.. Derive the expression for both constant voltage drive and constant current drive, as shown below.

ii) Is either mode, constant current / constant voltage, preferred?

iii) Using the resistance values from the previous questions, what is the output voltage for a 2.5 MPa load? Assume that $\mathbf{V_{IN}}$ and $\mathbf{I_{IN}}$ are chosen such that the static power dissipation is less than 10 mW.

iii) Estimate the minimum detectable pressure if the dominant noise source is thermal noise in the resistors. Assume a bandwidth of 10 kHz.





g) Estimate the effect of the following variables on the sensitivity of the sensor.

i) ± 5 μm wafer thickness variation.

ii) ± 1 μm line width variation.

Exercise 2: Accelerometer

a) Using the piezoresistive principle, what would you change to the configuration of the pressure sensor in exercise one to make an piezoresistive accelerometer?

b) And using the same configuration as in a) how would you implement capacitive transduction? And if you would like to perform a differential capacitive measurement?

c) What is currently the mainly used capacitive transducer configuration in MEMS accelerometers?

Exercise 3: Gyroscope

a) Describe the implementation of a MEMS gyroscope using a schematic drawing.

b) Give the name and the expression of the force that will result in a displacement of the structure due to an angular rotation.

c) Which parameters can you play with to increase the sensitivity of the gyroscope response? And how these should be optimised for higher sensitivity.