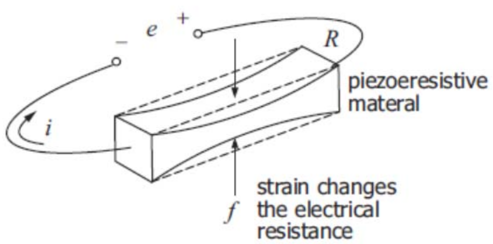
Piezoresistive sensors

- ❑ Perform a basic **bridge analysis**, specifically,
  - ❑ find output voltage as a function of input voltage and the various resistances, and
  - ❑ find the relationship between output voltage and changes in resistance.
- ❑ Find changes in resistance of a **piezoresistive material** undergoing deformation due to
  - ❑ **changes in geometry** and/or
  - ❑ changes in **resistivity**
- ❑ Calculate the **gage factor** for a piezoresitor using **piezoresistance coefficients** and/or **elastoresistance** coefficients where appropriate
- ❑ Use the idea of gage factor to explain how the placement and locations of piezoresitors can affect a device's **sensitivity**
- ❑ Explain the difference between **longitudinal**, **transverse**, **center**, and **boundary** stress/strain.
- ❑ For a given piezoresistive sensor, use the above concepts and objectives to find
  - ❑ the sensor's **bridge equation**,
  - ❑ values of $\Delta R/R$ for each resistor,
  - ❑ value of $\Delta e_o/e_i$, and
  - ❑ the transducer's sensitivity

Piezoresistance

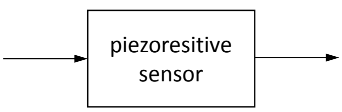


Electrical resistance changes with mechanical deformation (strain)

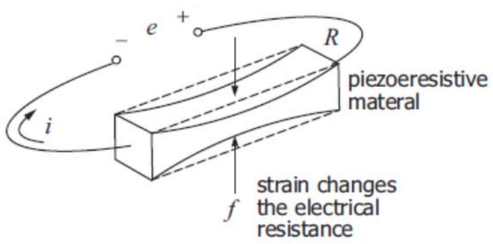
stretching

bending

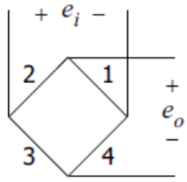
twisting

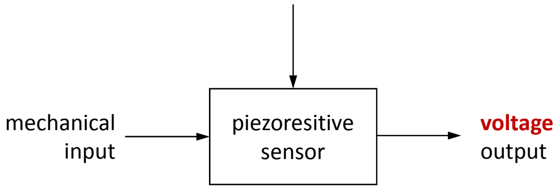


Piezoresistance



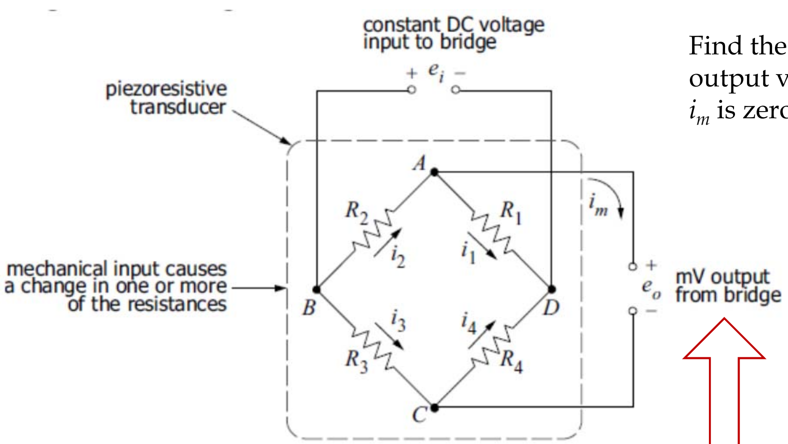
Electrical resistance changes with mechanical deformation (strain)





Wheatstone bridge analysis

Te toca a ti



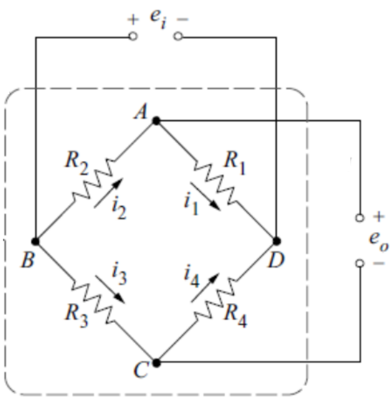
Find the relationship between the input and output voltages for the bridge shown. Assume i_m is zero.

Find the relationship between R_1, R_2, R_3, and R_4 for $e_o = 0$.

Wheatstone bridge analysis

Te toca a ti

Bridge balancing



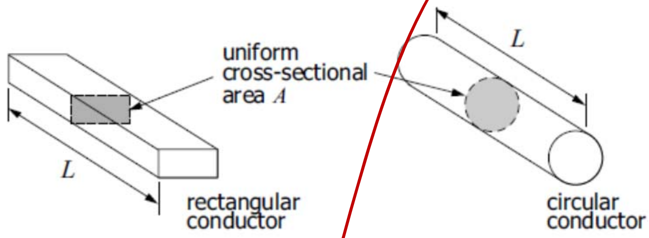
Full bridge:

Half bridge:

What is the relation between a *change* in resistance ΔR and the output voltage e_o?

Gage factors and the piezoresistive effect

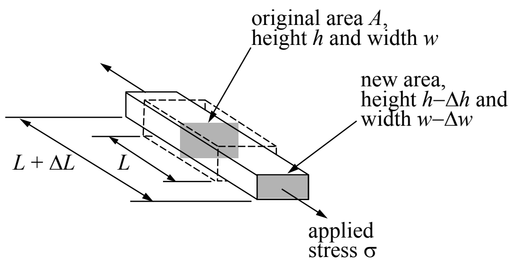
What is the relation between deformation and resistance?



Metals	Semiconductors
Changes in ________ dominate	Changes in ________ dominate

Gage factors for strain gages

Piezoresistors made of metals are usually used in **strain gages** responding to uniaxial strain.



Te toca a ti

Find the **gage factor** for a strain gage subject to uniaxial strain applied to an isotropic material. (Hint: you can neglect products of length changes; i.e., $\Delta h \Delta w \approx 0$.)

Gage factors for semiconductors

Recall that in semiconductors changes in *resistivity* dominate resistance changes upon deformation.

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta A}{A}$$

Stress formulation:

π_L and π_T and are the ______________________________

- L –
- T –

Strain formulation:

γ_L and γ_T and are the ______________________________

Gage factors for semiconductors

Te toca a ti

Find the **gage factor** for a typical *semiconductor device*. Use the elastoresistance coefficients in your formulation. (Hints: Recall that in semiconductors changes in *resistivity* dominate resistance changes upon deformation. How will you model the stress/strain?)

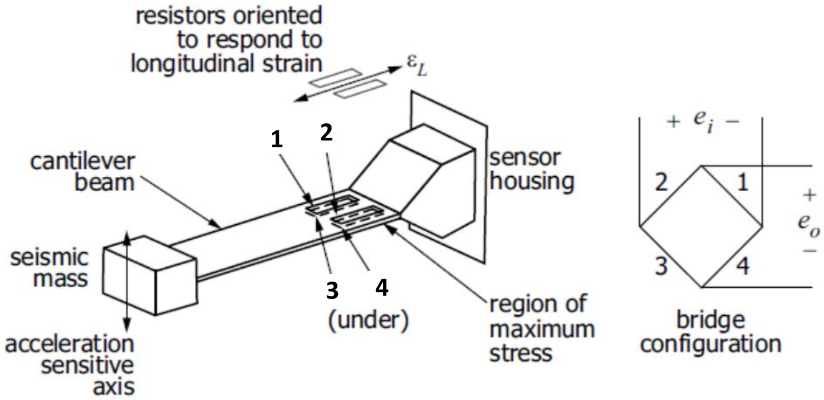
Gage factor as figure of merit

Gage factor is a **figure of merit** that

- helps us decide ____
- helps us decide ____

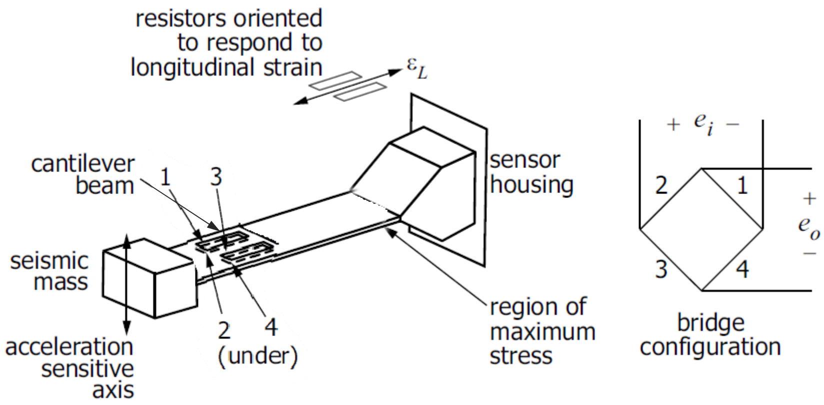
Material	Gage factor, F
Metals	
Cermets (Ceramic-metal mixtures)	
Silicon and germanium	

Physical placement and orientation of piezoresistors



$$\frac{\Delta e_o}{e_i} =$$

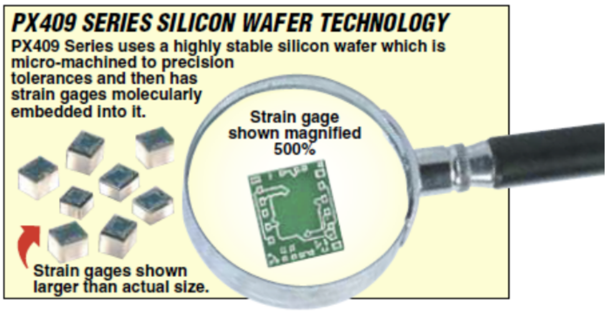
Physical placement and orientation of piezoresistors

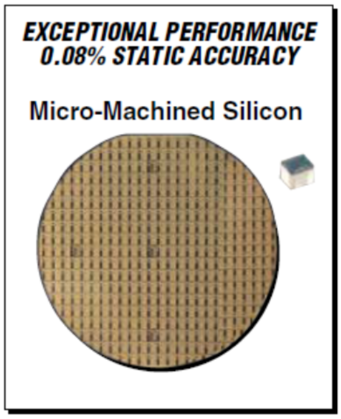


$$\frac{\Delta e_o}{e_i} = \frac{F}{4}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

Device case study: Omega PX409 pressure transducer

Device case study: Omega PX409 pressure transducer





Some definitions

PX429-015GV, shown actual size.

mV/V Specifications

Output: mV/V, 100 mV @ 10 Vdc (Ratiometric 5 to 10 Vdc)
Supply Voltage: 10 Vdc (5 mA @ 10 Vdc)

Input/Output Resistance: 5000 Ω ±20% typical

Accuracy (Combined Linearity, Hysteresis and Repeatability): ±0.08% BSL maximum

Zero Balance: ±0.5% FS typical 1% max (1% typical, 2% maximum for 2.5 psi and below)

Span Setting: ±0.5% FS typical 1% maximum (1% typical, 2% maximum for 2.5 psi and below) Calibrated in vertical direction with fitting down

Operating Temperature Range: -45 to 121°C (-49 to 250°F)

Compensated Temperature:
- **Ranges >5 psi:** -29 to 85°C (-20 to 185°F)
- **Ranges ≤ 5 psi:** -17 to 85°C (0 to 185°F)

Thermal Effects Zero (Over Compensated Range):
- **Ranges >5 psi:** ±0.5% span
- **Ranges ≤5 psi:** ±1.0% span

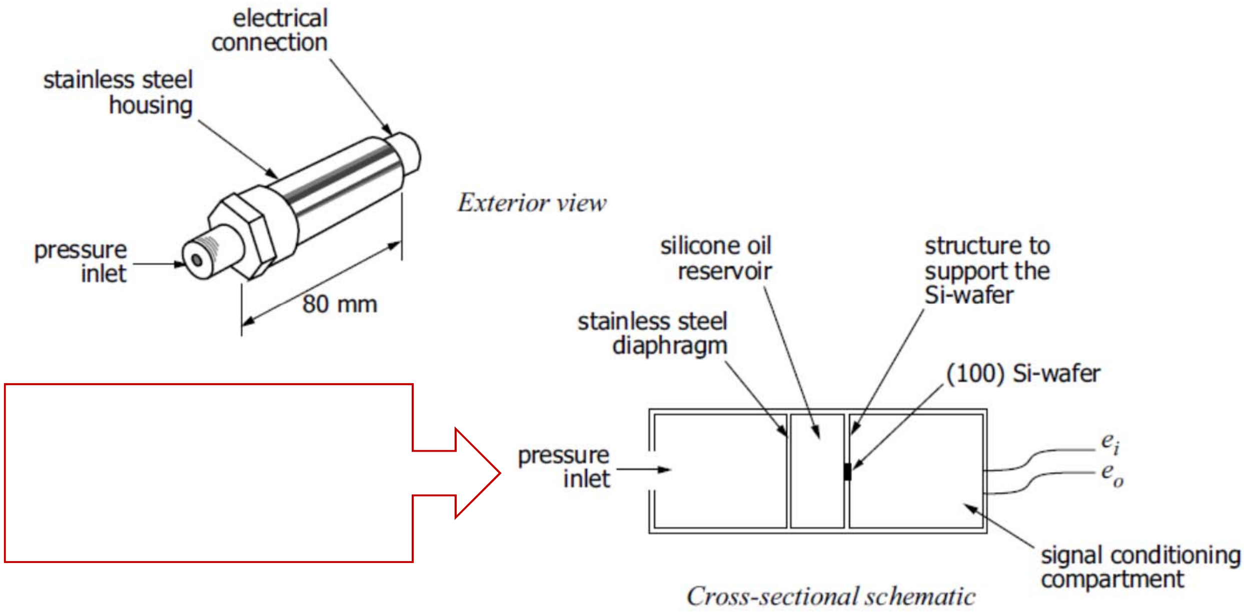
Thermal Effects Span (Over Compensated Range):
- **Ranges >5 psi:** ±0.5% span
- **Ranges ≤5 psi:** ±1.0% span

To Order

RANGE psi	RANGE bar	2 m (6') CABLE TERMINATION	MINI-DIN TERMINATION	TWIST-LOCK TERMINATION
mV/V OUTPUT, GAGE PRESSURE RANGES				
10 in-H_2O	25 mb	PX409-10WGV	PX419-10WGV	PX429-10WGV
1	69 mb	PX409-001GV	PX419-001GV	PX429-001GV
2.5	172 mb	PX409-2.5GV	PX419-2.5GV	PX429-2.5GV
5	345 mb	PX409-005GV	PX419-005GV	PX429-005GV
15	1.0	PX409-015GV	PX419-015GV	PX429-015GV
30	2.1	PX409-030GV	PX419-030GV	PX429-030GV
50	3.4	PX409-050GV	PX419-050GV	PX429-050GV
100	6.9	PX409-100GV	PX419-100GV	PX429-100GV
150	10.3	PX409-150GV	PX419-150GV	PX429-150GV
250	17.2	PX409-250GV	PX419-250GV	PX429-250GV
500	34.5	PX409-500GV	PX419-500GV	PX429-500GV
750	51.7	PX409-750GV	PX419-750GV	PX429-750GV
1000	69	PX409-1.0KGV	PX419-1.0KGV	PX429-1.0KGV
1500	103	PX409-1.5KGV	PX419-1.5KGV	PX429-1.5KGV
2500	172	PX409-2.5KGV	PX419-2.5KGV	PX429-2.5KGV
3500	241	PX409-3.5KGV	PX419-3.5KGV	PX429-3.5KGV
5000	345	PX409-5.0KGV	PX419-5.0KGV	PX429-5.0KGV
mV OUTPUT, ABSOLUTE PRESSURE RANGES				
5	345 mb	PX409-005AV	PX419-005AV	PX429-005AV
15	1.0	PX409-015AV	PX419-015AV	PX429-015AV
30	2.1	PX409-030AV	PX419-030AV	PX429-030AV
50	3.4	PX409-050AV	PX419-050AV	PX429-050AV
100	6.9	PX409-100AV	PX419-100AV	PX429-100AV
150	10.3	PX409-150AV	PX419-150AV	PX429-150AV
250	17.2	PX409-250AV	PX419-250AV	PX429-250AV
500	34.5	PX409-500AV	PX419-500AV	PX429-500AV
750	51.7	PX409-750AV	PX419-750AV	PX429-750AV
1000	69	PX409-1.0KAV	PX419-1.0KAV	PX429-1.0KAV

*Ordering Examples: **PX409-1.0KGV**, mV output, 1000 psi gage pressure range, 2 m (6') cable termination. **PX429-015AV**, mV output, 15 psi absolute pressure, twist lock termination, **PT06F10-6S**, mating twist lock connector (sold separately), and **DP25B-S**, 4-digit meter, system with meter.*
(See page B-25h for information on meters).

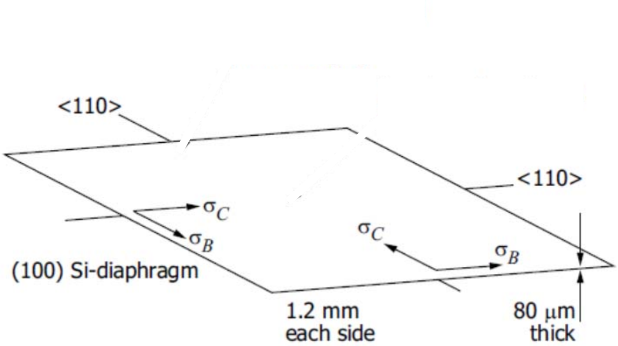
Schematics of the sensor



Designing for a given sensitivity

We would like to design a pressure sensor with a 0–1 MPa (145 psi) **span**, 0–100 mV **full scale output**, a 10 VDC **excitation**, and p-Si piezoresistors.

What is the **sensitivity**?



How do we *design* the senor to achieve this **sensitivity**?

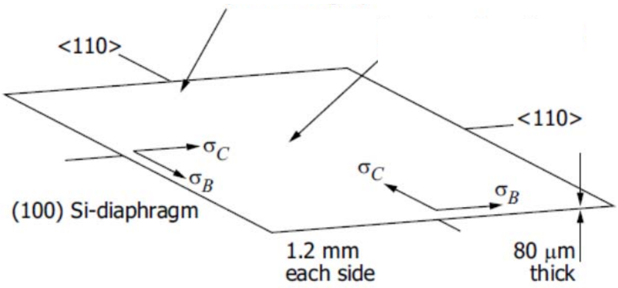
Location of piezoresistors

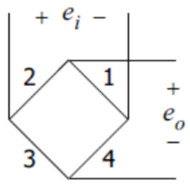
Where should we place the piezoresistors on the diaphragm?

σ_C –
σ_B –

Typical values at max deflection:

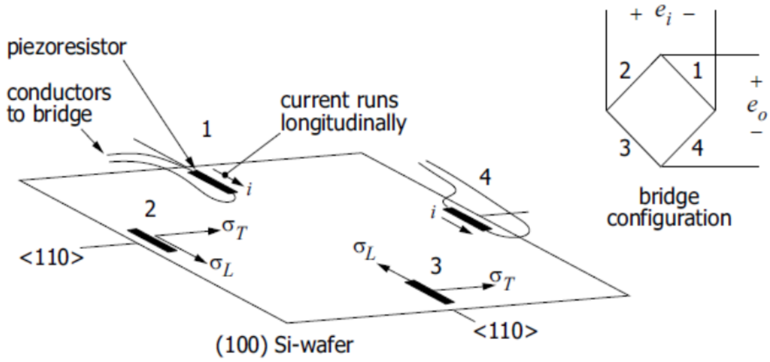
σ_C = , σ_B =
ε_C = , ε_B =





Designing for a given sensitivity

Next, let’s find the change in output voltage corresponding to resistors in these locations.

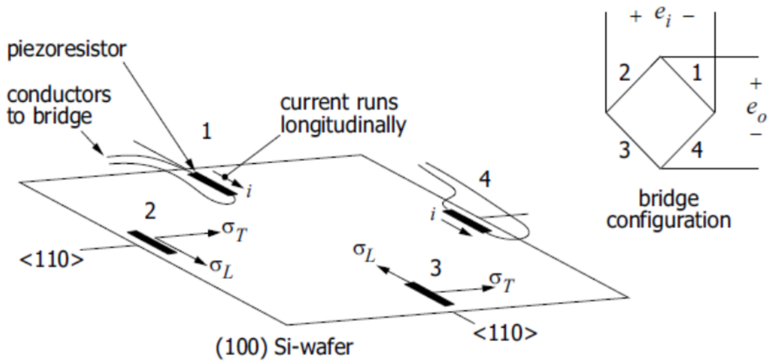


Typical values of stress, strain, and elastoresistance coefficients:

σ_C = 45.0 MPa, σ_B = 22.5 MPa $\quad$ γ_L = 120 <110>
$\varepsilon_C = 152 \times 10^{-6}$, $\varepsilon_B = -17 \times 10^{-6}$ $\quad$ γ_T = -54 <110>

Designing for a given sensitivity

Te toca a ti

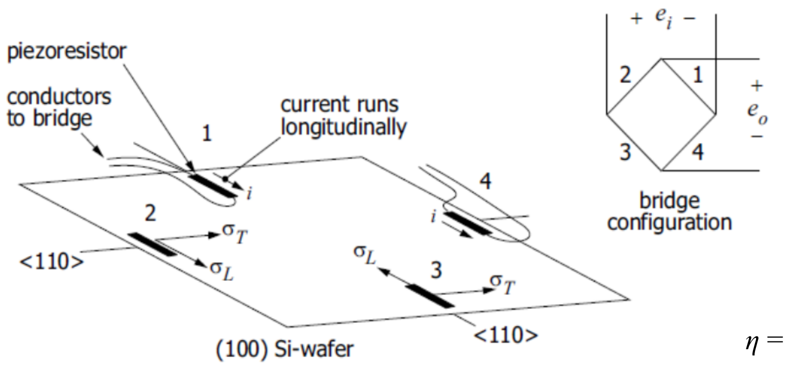


Find the values of $\Delta R_2/R$ and $\Delta R_4/R$ using the same assumed values of stress, strain, and elastoresistance.

Typical values of stress, strain, and elastoresistance coefficients:

σ_C = 45.0 MPa, σ_B = 22.5 MPa $\qquad \gamma_L$ = 120 <110>
$\varepsilon_C = 152 \times 10^{-6}$, $\varepsilon_B = -17 \times 10^{-6}$ $\qquad \gamma_T$ = -54 <110>

Designing for a given sensitivity



Requirements:

-
-
-
-

$\eta =$

$=$

$=$

$$\frac{\Delta e_o}{e_i} =$$

$=$

$=$

$\Delta e_o =$

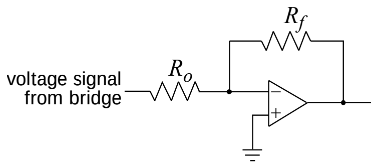
Attenuation of output

$K_{IA} =$

The **gain** is

$K =$

$=$



$K =$

Te toca a ti

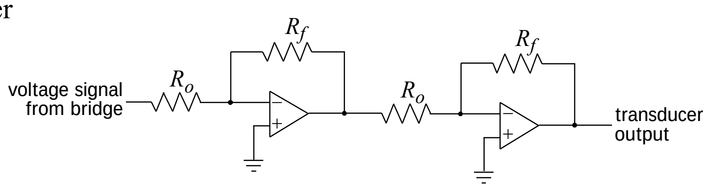
Select two resistors (es decir, R_f y R_0) from the available resistors below to achieve $K = (R_f/R_0)^2 = 0.682$.

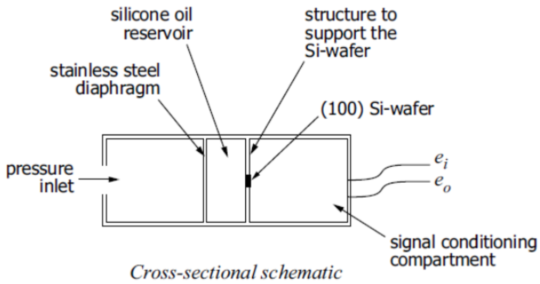
Readily-obtained resistors for use in an op-amp circuit (Ohms)

1	8.2	22	56	150	390
1.5	9.1	24	62	160	430
2.7	10	27	68	180	470
4.3	11	30	75	200	510
4.7	12	33	82	220	560
5.1	13	36	91	240	620
5.6	15	39	100	270	680
6.2	16	43	110	300	750
6.8	18	47	120	330	820
7.5	20	51	130	360	910

Attenuation of output

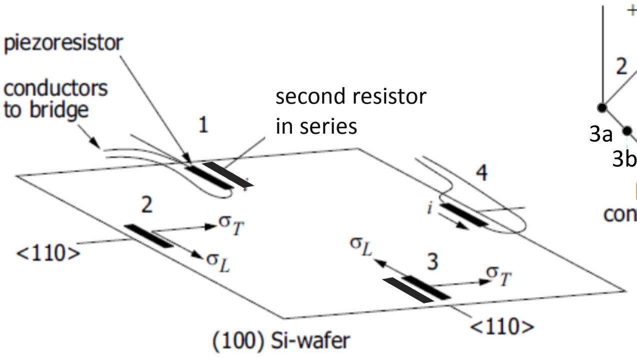
The amplifier goes into the signal conditioning compartment of the transducer

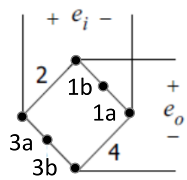




Cross-sectional schematic

Te toca a ti





bridge configuration

A configuration of p-Si resistors on a square diaphragm is suggested in which *two* resistors in series are used to sense the maximum stress, σ_C, as shown in the figure. Find

a. the new bridge equation (i.e., e_o in terms of e_i and the various resistances),
b. $\Delta R/R$ for each resistor,
c. $\Delta e_o/e_i$, and
d. the transducer sensitivity (with no amplifier circuit)

Assume the same dimensions, sensor requirements, materials, and stress/strain values as in the case study.