Ex: A certain metal strain gauge has a nominal resistance of 1kΩ, and has a GF = 2. If it experiences a 1% axial strain, what does the resistance become?

**Solution**

\[ \varepsilon = \frac{\Delta L}{L} = 0.01 \rightarrow \Delta L = 0.01 \times 1\% \]

\[ GF = \frac{\Delta R}{R} \Rightarrow \Delta R = R \times GF = (1000 \times 0.01)(2) = 20 \Omega \]

\[ R_{new} = R + \Delta R = 1000 + 20 = 1020 \Omega \]

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Single Crystal Si:

- **P-Type**: GF up to +200
- **N-Type**: GF down to -125

**Note**: a negative GF means that resistance decreases with applied strain.

\[ \frac{\Delta P}{P} = PE \] what causes the piezo-resistive effect?

**Answer**: the applied strain affects the majority charge carriers in the semiconductor material.

- **P-Type**: strain \( \uparrow \) mobility of the holes \( \psi : p \uparrow \)
- **N-Type**: strain \( \uparrow \) mobility of the electrons \( \uparrow : p \downarrow \)

**Note**: This effect is highly dependent on crystallographic orientation, doping level and temperature.
\[ \frac{\Delta l}{l} = T_2 \sigma_2 + T_4 \sigma_4 \]

where: 
- \( T_2 \) = longitudinal piezoresistive coefficient
- \( T_4 \) = transverse coefficient
- \( \sigma_2 \) = longitudinal stress
- \( \sigma_4 \) = transverse stress

The longitudinal direction is defined as the direction parallel to the current flow through the piezoresistor.

![Diagram](image)

\( T_2 \) and \( T_4 \) are a function of crystal orientation, doping and temperature.

**Poly Silicon**

A polycrystalline 

\[ \Rightarrow \text{ the piezoresistive effects average over all directions} \]

\[ \therefore \text{GF}_{\text{poly}} < \text{GF}_{\text{single crystal}} \]

\( P \)-Type poly Si: \( \text{GF} \approx +30 \)

\( N \)-Type poly Si: \( \text{GF} \approx -30 \)

Poly Si can be deposited as a thin film (up to a few \( \mu \)m) \([\text{LPCVD}]\) and selectively doped.

\( \therefore \) both \( N \) and \( P \)-type poly Si piezoresistors can be realized
the same device is useful for realizing a Wheatstone bridge sensor.

Where to place a piezoresistor?

Consider this device:

\[
\begin{align*}
p; R &= R_0 + \Delta R \\
n; R &= R_0 - \Delta R \\
\Delta R &= f(\sigma) \\
&= f(\text{displacement})
\end{align*}
\]

Use Wheatstone Bridge Circuit Interface.
Example Microsensor: HMX2000

Hygrometry HM2000 MEMS Humidity Sensor

Glass backing over back side

Polymer coated beams - piezoresistive bridge

Back Side

Front Side

~2mm