Review of Essential Basics

Electrical

Electrical engineering

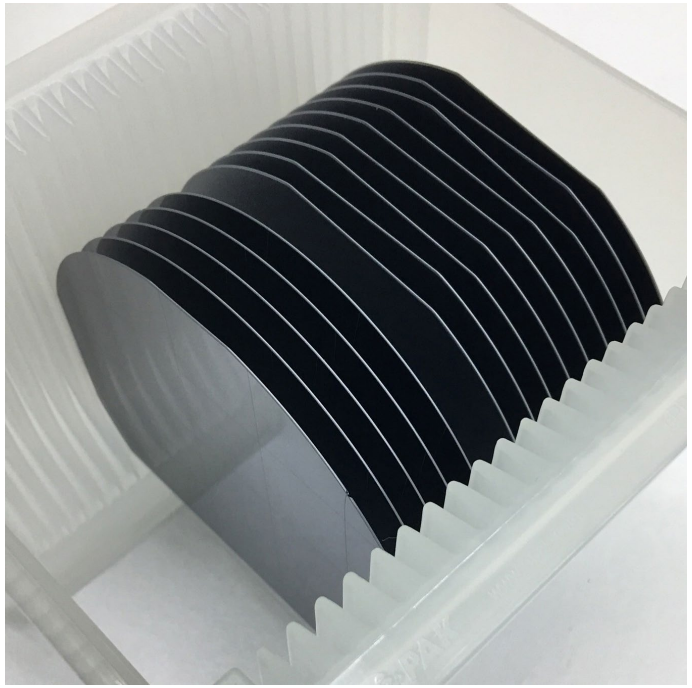
Mechanical engineering

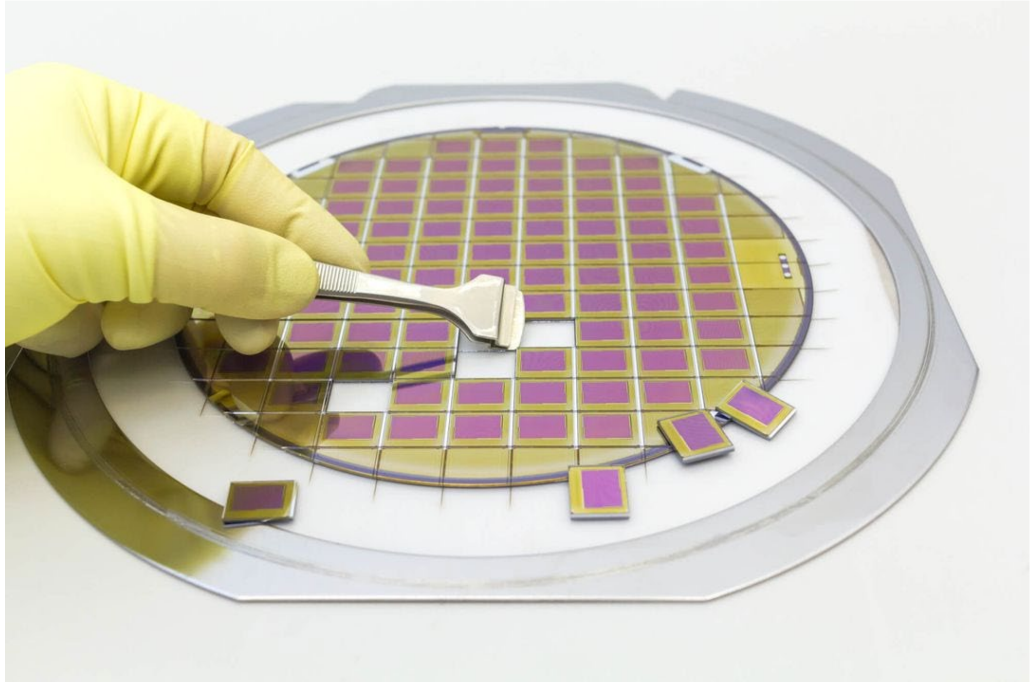
MEMS

Material processing

Microfabrication

Silicon as the substrate



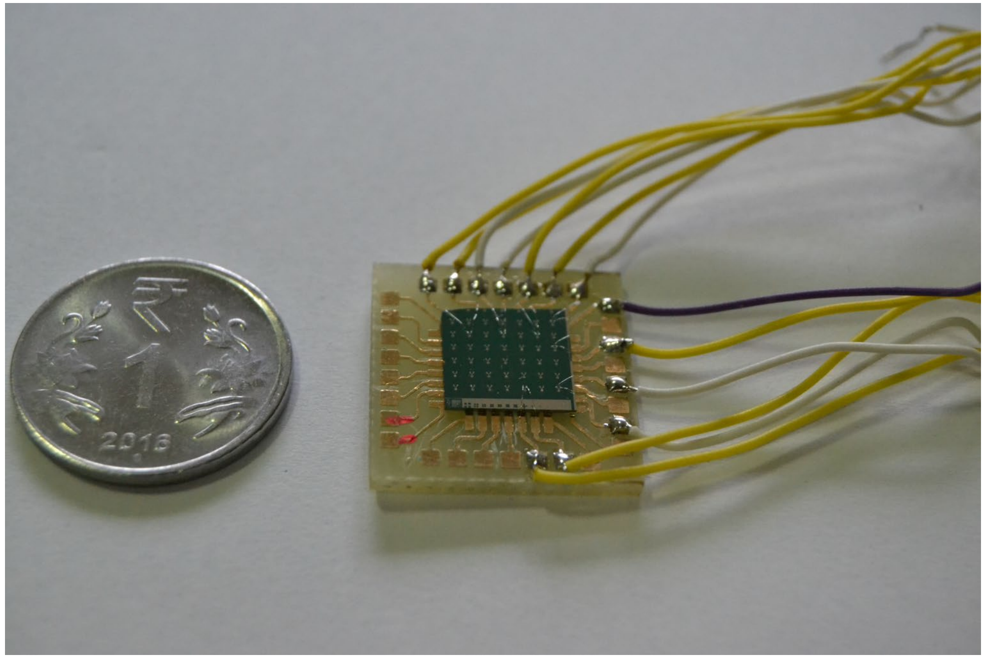


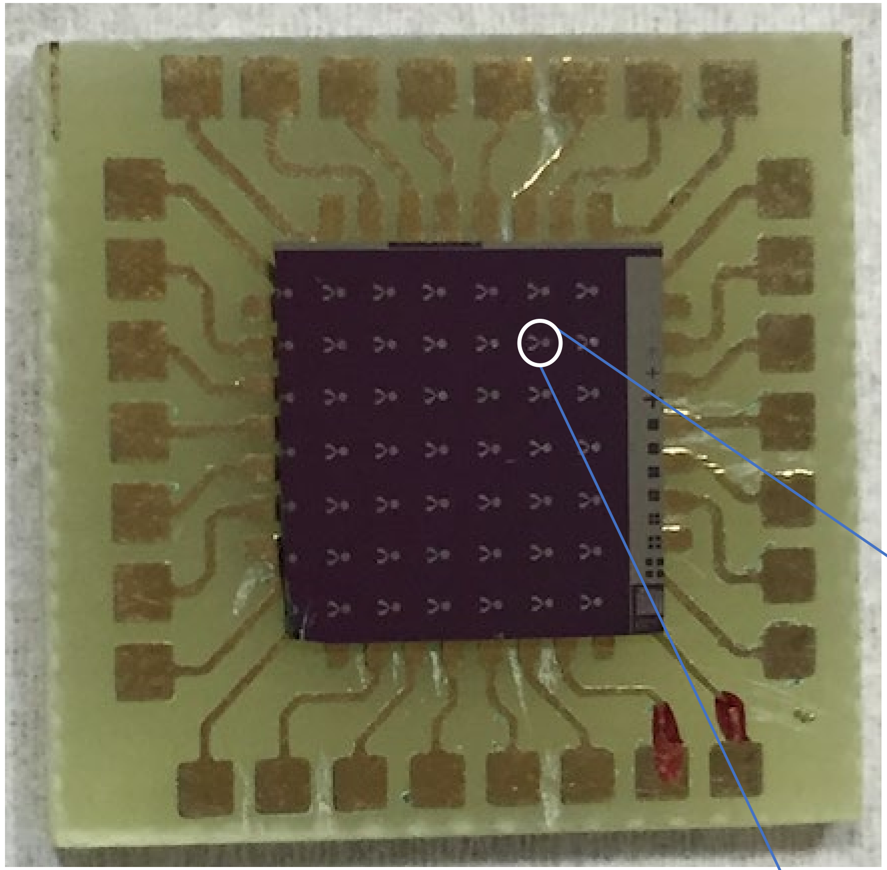
Silicon ingots made by [Czochralski method]

https://www.plutosemi.net/show-14-415-1.html
https://www.vritratech.com/store/product/p-type-silicon-wafer-3-inch/
https://www.waferworld.com/post/top-causes-of-silicon-wafer-breakage

https://www.youtube.com/watch?v=aCOyq4YzBtY
(Sand to Silicon - The Making of a Chip | Intel)

Demo of silicon wafer and microheater array





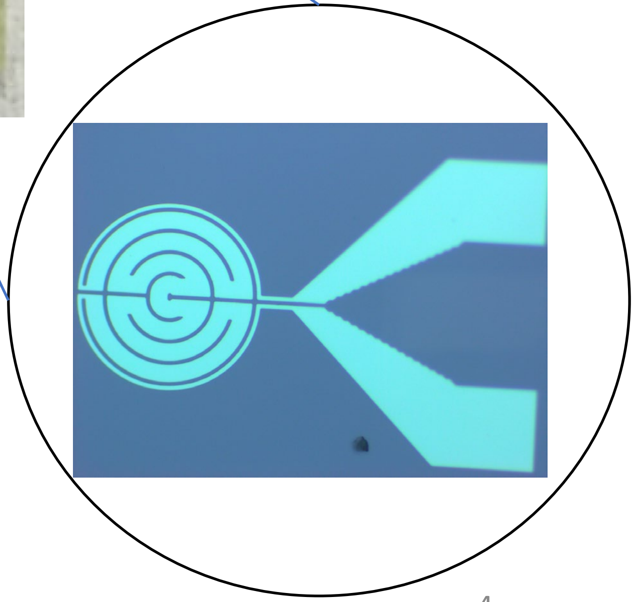


Image © Amruta R Behera

Czochralski process

- Process brief:

https://www.youtube.com/watch?v=skRmyhSOu28

https://www.youtube.com/watch?v=2qLI-NYdLy8

- Actual footage of fabrication:

https://www.youtube.com/watch?v=jh2z-g7GJxE (video at 2000X)

https://www.youtube.com/watch?v=XbBc4ByimY8

- Ingot footage: https://www.youtube.com/watch?v=O2jrjiRe8cE
- Shipping wafers: https://www.youtube.com/watch?v=bB5iWzsztdc
- Attempt by Adani: https://www.pv-magazine.com/2022/12/09/adani-unveils-indias-first-silicon-ingot/

Conductivity of a semiconductor

Semiconductors allow controlling of their conductivity by

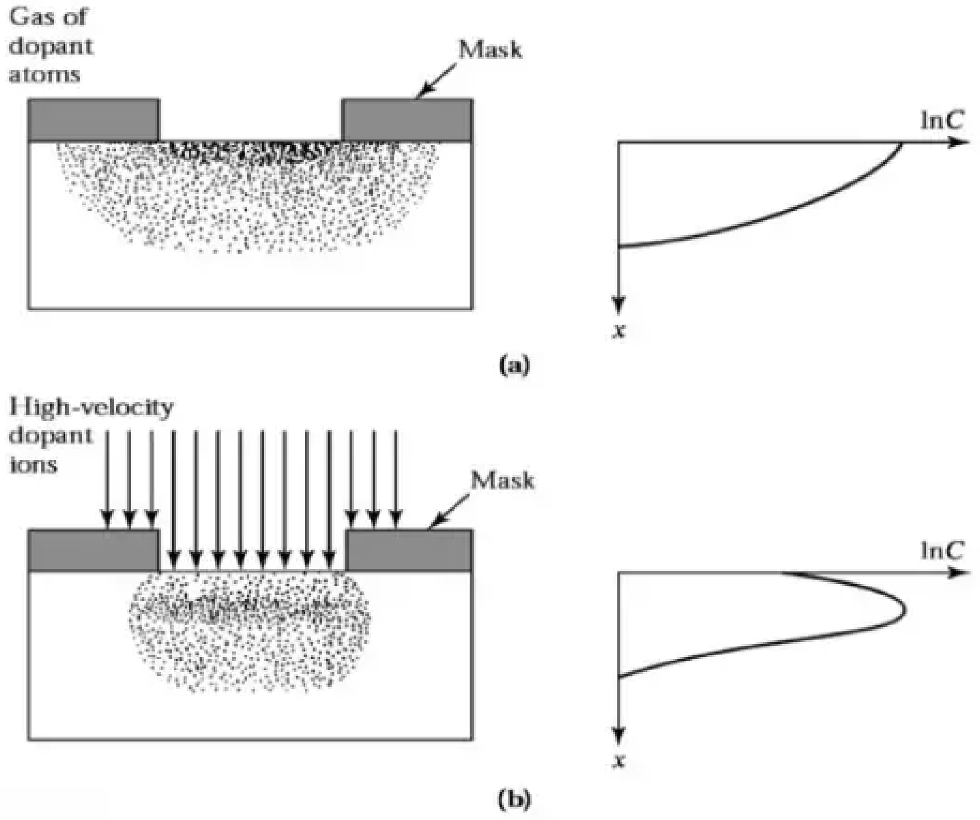
- intentionally introduced impurities
- externally applied electric field
- charge injection
- ambient light
- temperature variations

Bandgap = 1.11eV

https://www.vectorstock.com/royalty-free-vector/periodic-table-element-silicon-icon-vector-11194390

Doping methods

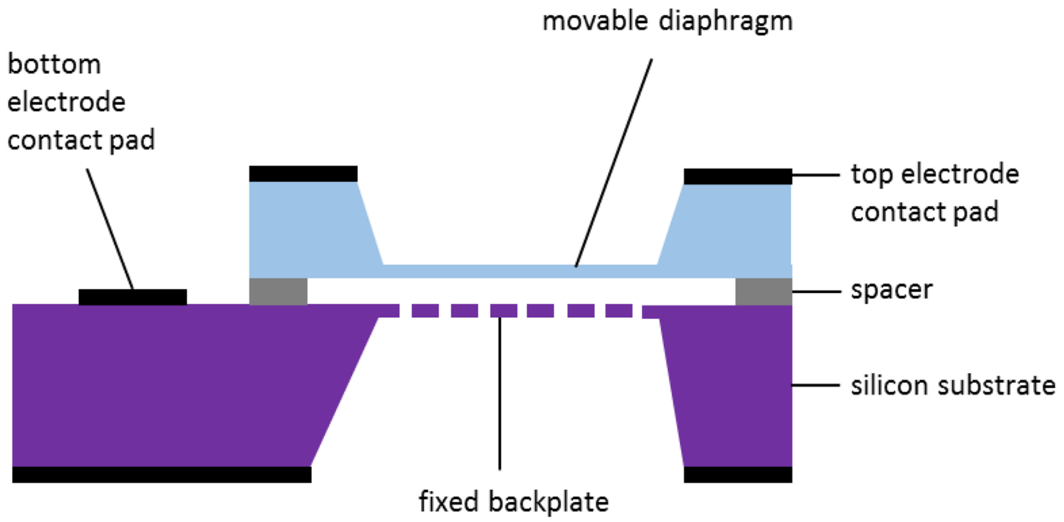
Silicon as a conductor: electrode, heating element



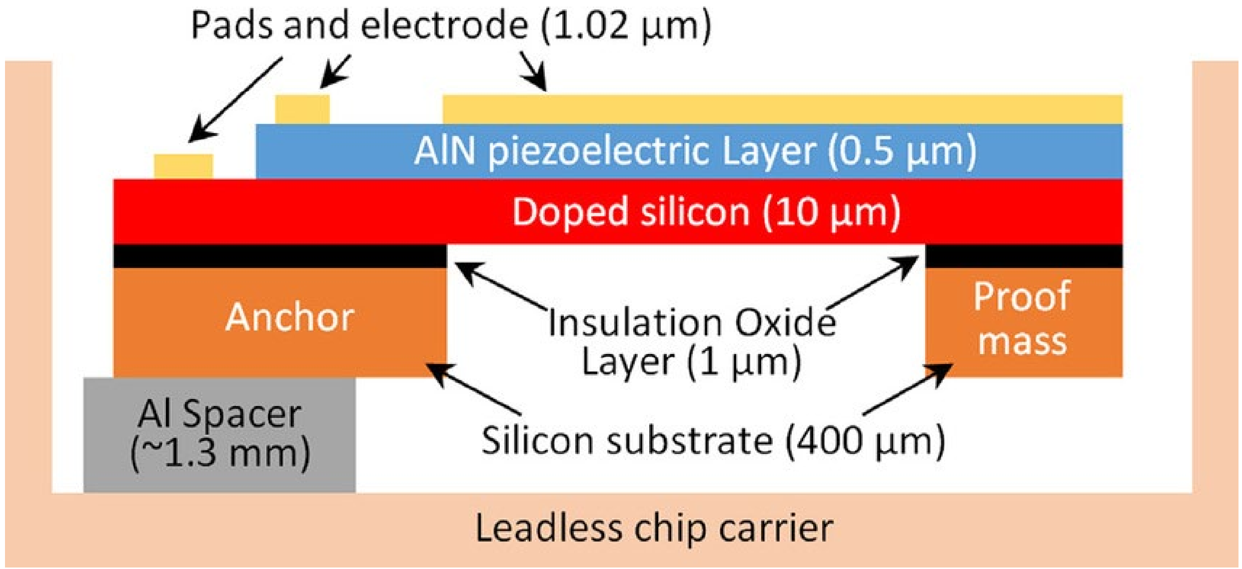
(a) diffusion and (b) ion−implantation techniques

https://siliconvlsi.com/diffusion-and-ion-implantation/

Use of doped Silicon as electrode in MEMS



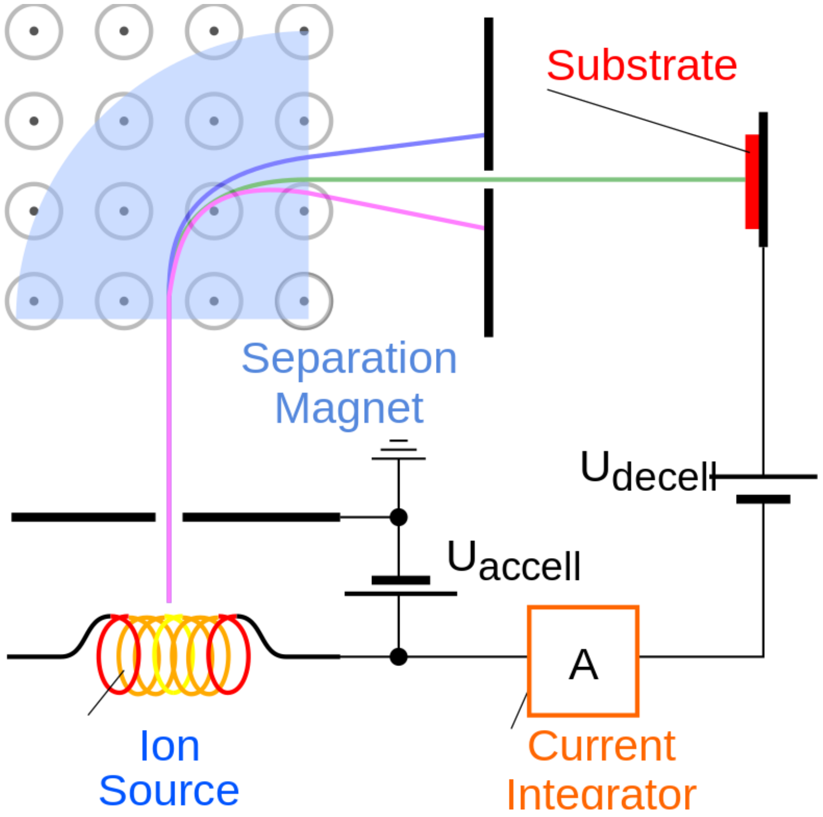
Basic structure of a micro-electro-mechanical system (MEMS) capacitive microphone.



A piezoelectric vibration energy harvester

https://www.mdpi.com/2072-666X/11/5/484
https://www.researchgate.net/figure/MEMS-device-fabrication-process_fig6_318552423

Ion implanter

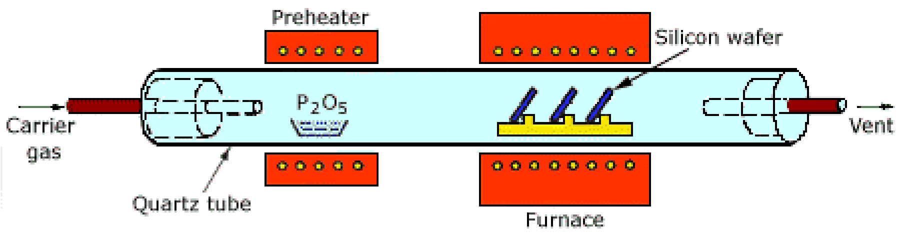


https://en.wikipedia.org/wiki/Ion_implantation#/media/File:Ion_implanter_schematic.svg
https://www.appliedmaterials.com/us/en/semiconductor/products/processes/implant.html
https://www.appliedmaterials.com/us/en/semiconductor/products/processes/implant/vista-3000xp.html

Furnace for diffusion doping

Oxidation furnace – similar furnace used for doping
https://www.youtube.com/watch?v=Hi-1zN1RVqc

Phosphorous diffusion
https://www.youtube.com/watch?v=3MkiUHZsWro



http://web.eng.gla.ac.uk/groups/sim_centre/courses/diffusion/diff_2.html
https://lnf-wiki.eecs.umich.edu/wiki/Tempress_S3T4_-_N-type_in_Situ_Doped_Poly-Si_4%22

Calculation of charge carrier concentration

$$n = p \equiv n_i.$$

$$n_i^2 = 4\left(\frac{4\pi^2 m_n^* m_p^* k^2 T^2}{h^2}\right)^{3/2} e^{\frac{-E_g}{kT}},$$

Commonly accepted values of n_i at $T = 300°$K

Silicon	1.5×10^{10} cm^{-3}
Gallium arsenide	1.8×10^{6} cm^{-3}
Germanium	2.4×10^{13} cm^{-3}

Law of mass action $n_0 p_0 = n_i^2.$

$$p_0 + N_d^+ = n_0 + N_a^-.$$

$$ax^2 + bx + c = 0$$

For b^2 >> c

$$n_0 - \frac{n_i^2}{n_0} = N_d^+ - N_a^-$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$n_0 = N_d^+ - N_a^-.$$

$$p_0 = N_a^- - N_d^+$$

$$\underbrace{n_0^2}_{a=1} - \underbrace{(N_d^+ - N_a^-)}_{b} n_0 - \underbrace{n_i^2}_{c} = 0.$$

$$p_0^2 - (N_a^- - N_d^+) p_0 - n_i^2 = 0.$$

Example 1

Consider a piece of silicon under room temperature and thermal equilibrium. The silicon is doped with boron with a doping concentration of 10^{16} atoms/cm^3. Find the electron and hole concentrations.

Number of electrons in intrinsic silicon $1.5 \times 10^{10}/\text{cm}^3$.

Silicon atom density $5 \times 10^{22}/\text{cm}^3$.

Observations

- The concentration of dopants is much smaller compared to the density of lattice atoms.
- The thermal-equilibrium majority and minority carrier concentrations can differ by many orders of magnitude.

Example 2

Determine the thermal equilibrium electron and hole concentrations for a given doping concentration.
Consider an germanium sample at $T = 300°K$ in which $N_d = 5 \times 10^{13}\ cm^{-3}$ and $N_a = 0$.
Assume that $n_i = 2.4 \times 10^{13}\ cm^{-3}$.