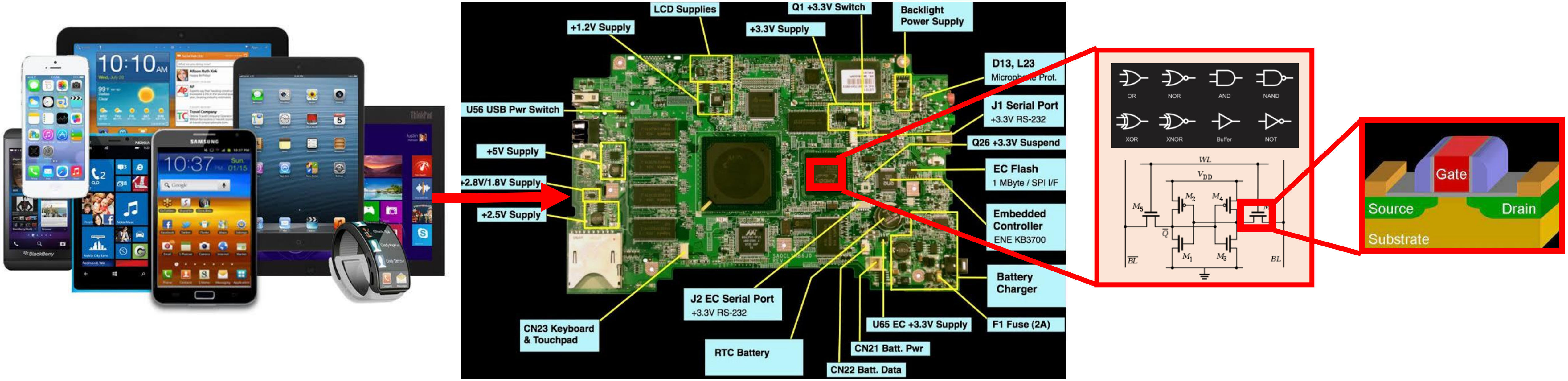

ESC201: Introduction to Electronics

Module 4: Non-Linear Elements

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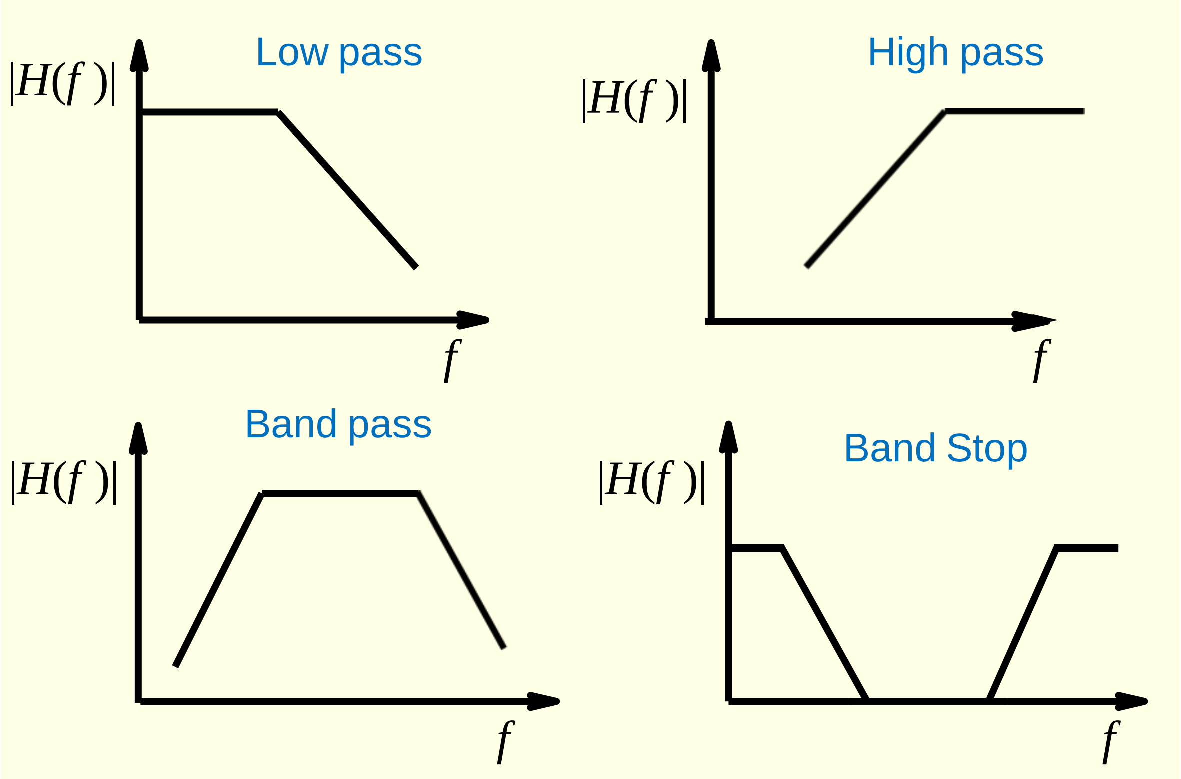
IIT Kanpur

Filters for Electrical Signals

Filter – pass / amplify signal in a band of frequency and reject / attenuate the remaining

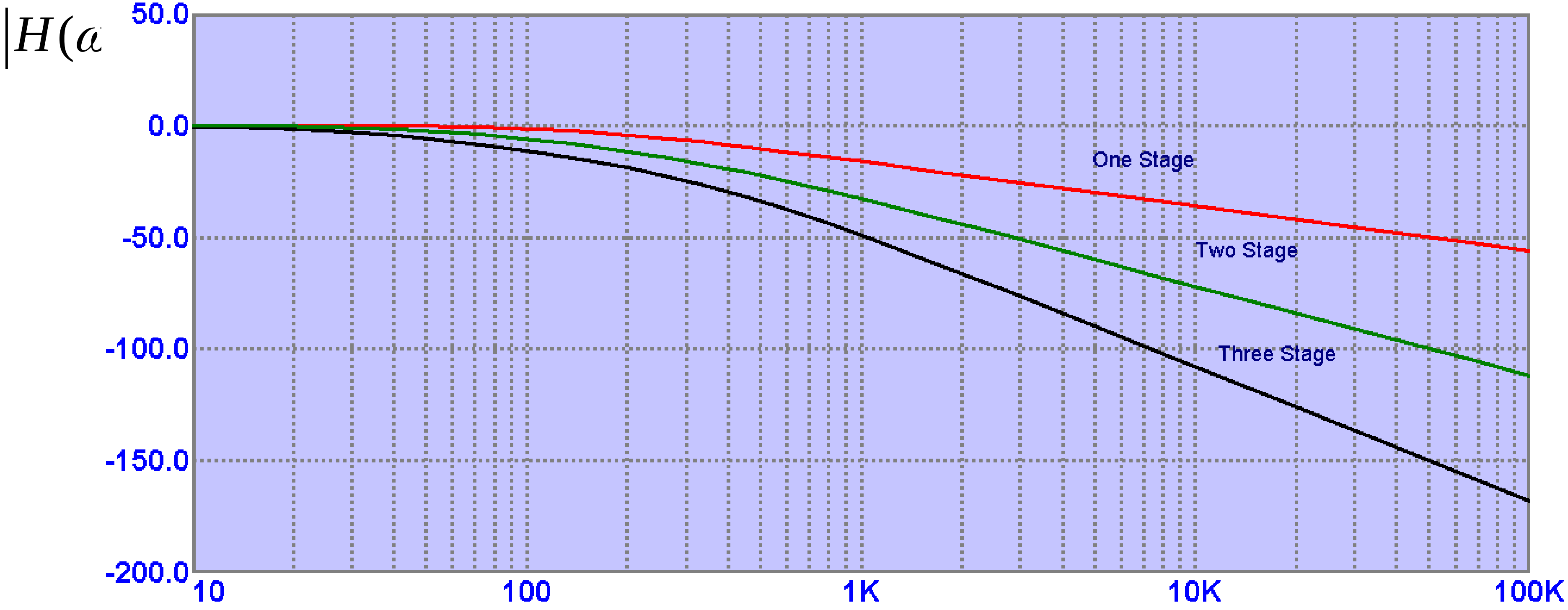


- Many practical applications in electronics and electrical systems
- Tuning radios, cleaning up communication signals, removing higher frequencies from power systems, … + many other areas

FM Radio

Different radio channels are separated by very narrow frequency interval.

For example, one may want to tune to 98.3 MHz signal but reject Vivid Bharti (102.4 MHz) or Red FM (92.5 MHz)



This implies an attenuation of -6000 dB/decade !!

Resonance

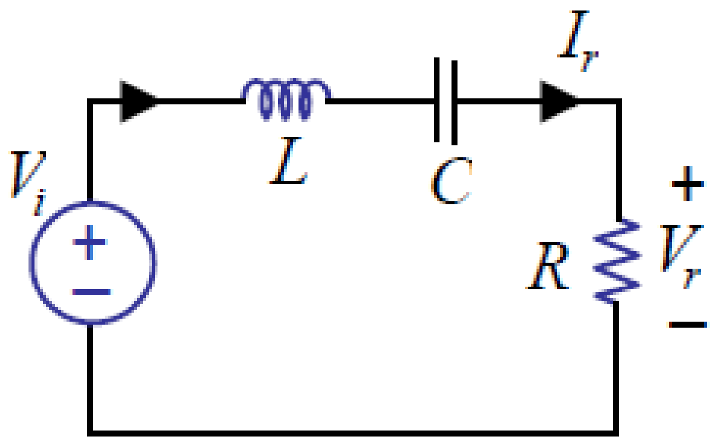
- Every system has its own natural frequency of oscillation.

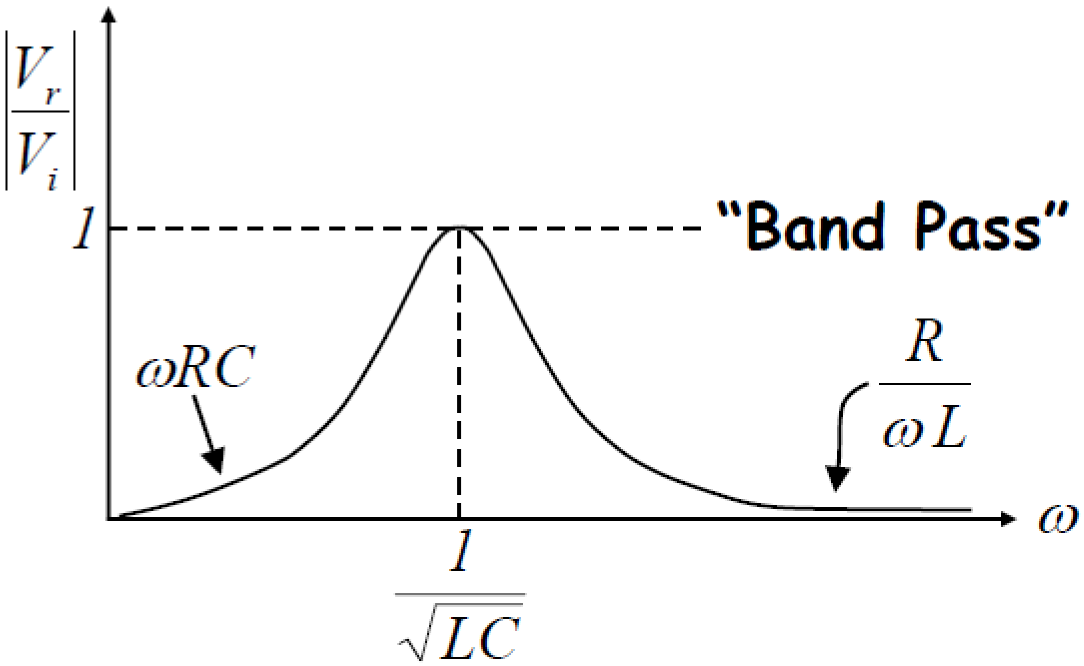
- If you apply an external stimulus at natural frequency: System exhibits an extremely large response

RLC Circuit

$$\frac{V_r}{V_i} = \frac{R}{j\omega L + \frac{1}{j\omega C} + R}$$

$$\left|\frac{V_r}{V_i}\right| = \frac{\omega RC}{\sqrt{\left(1-\omega^2 LC\right)^2 + (\omega RC)^2}}$$





Observe:

$$\text{Low } \omega: \quad \approx \omega RC$$

$$\text{High } \omega: \quad \approx \frac{R}{\omega L}$$

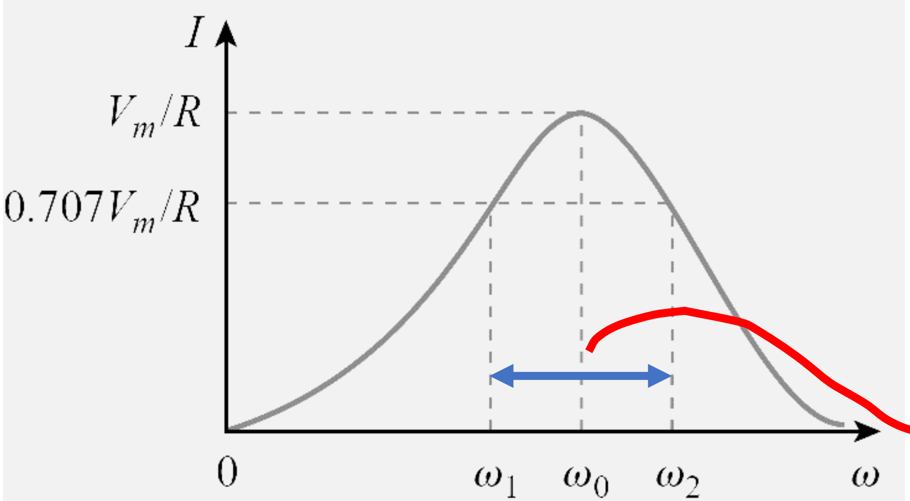
$$\omega\sqrt{LC} = 1: \quad \approx 1$$

Half-power Frequency

$$|I(\omega)| = \frac{V_m}{\sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2}}$$

$$\omega_O = \frac{1}{\sqrt{LC}}$$

ω_1 and ω_2
half-power frequencies



$$\omega_O = \sqrt{\omega_1\omega_2}$$

$$\Delta\omega = \omega_2 - \omega_1 = \frac{R}{L}$$

Bandwidth

$$|I(\omega_1)| = \frac{V_m}{\sqrt{R^2 + (\omega_1 L - \frac{1}{\omega_1 C})^2}} = \frac{V_m}{\sqrt{2}R}$$

$$|I(\omega_2)| = \frac{V_m}{\sqrt{R^2 + (\omega_2 L - \frac{1}{\omega_2 C})^2}} = \frac{V_m}{\sqrt{2}R}$$

$$\omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

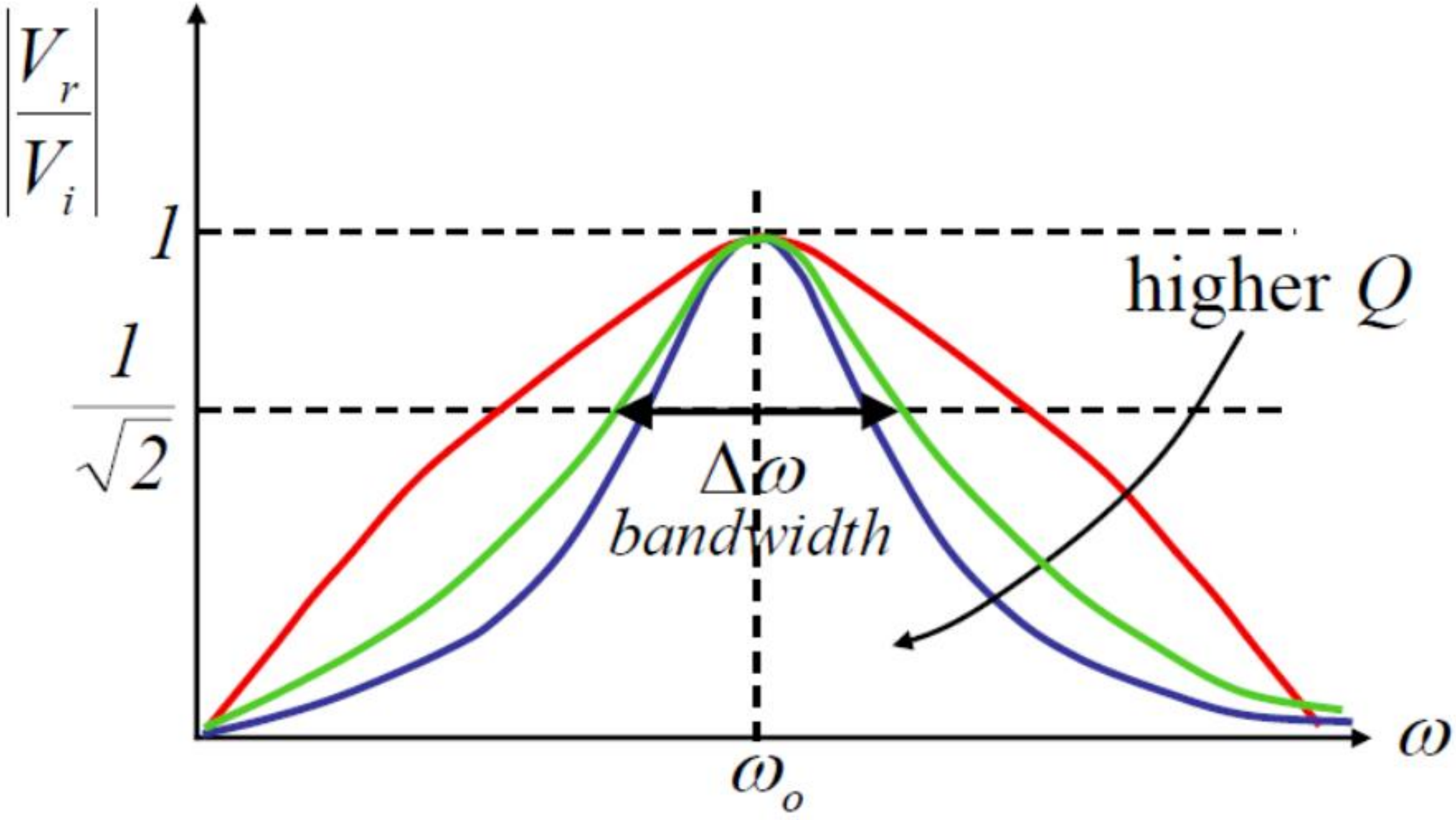
$$\omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

$$Q = \frac{\omega_0}{\Delta\omega}$$

Quality Factor

$$Q = \frac{\sqrt{L}}{\sqrt{C}R}$$

Bandwidth & Quality Factor



$$Q = \frac{\omega_0}{\Delta\omega}$$

Quality Factor

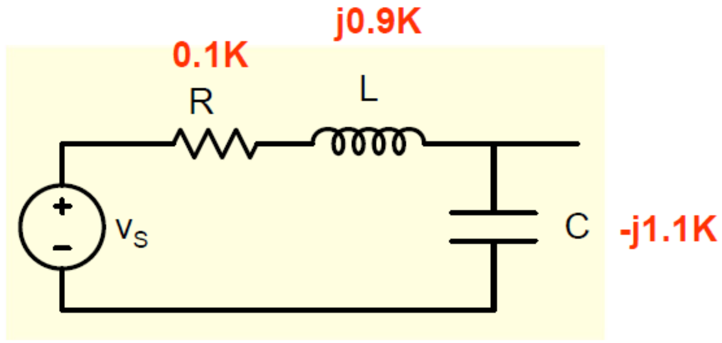
Q represents sharpness of resonance

For high Q circuits:

$$\omega_1 \simeq \omega_0 - \frac{B}{2}, \qquad \omega_2 \simeq \omega_0 + \frac{B}{2}$$

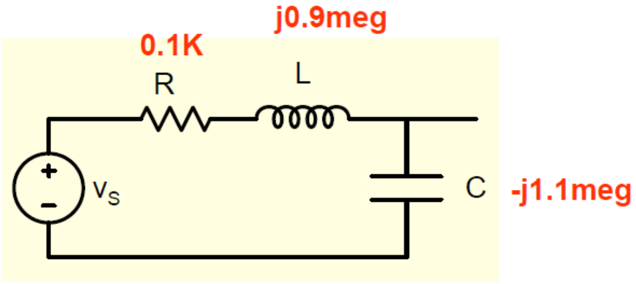
Is resonant filter always effective?

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_o \mathrm{RC}}$$

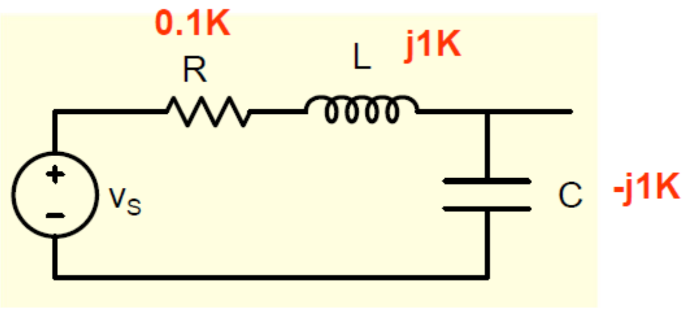


Z=0.1K-j0.1K

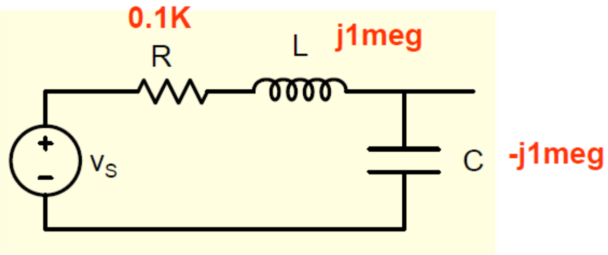
$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_o \mathrm{RC}}$$



Z=0.1K-j0.1meg



Z=0.1K



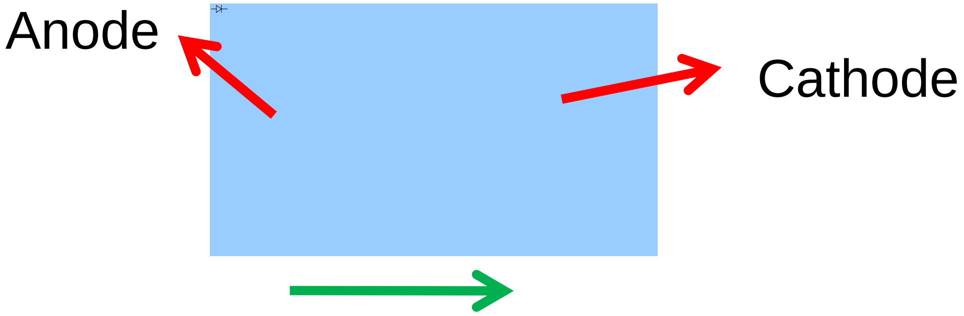
Z=0.1K

very large change in impedance as we approach resonance ! Implying high quality factor

Not very large change in impedance as we approach resonance !

Diodes

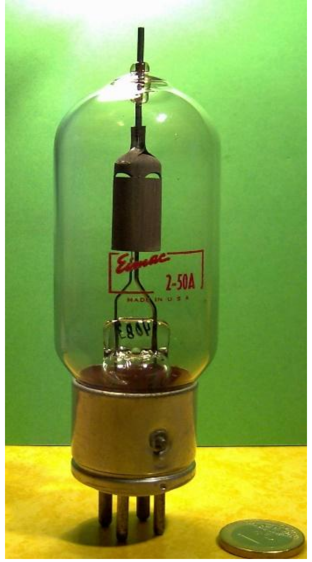
- Diodes allows current in only one direction
  - from anode to cathode terminal



- Non-linear behavior
- Applications:
  - one way valve
  - AC to DC converter
  - Voltage regulator
  - LED
  - logic operations

- Passive device
  - only consumes power

A high power vacuum diode used in radio equipment as a rectifier.



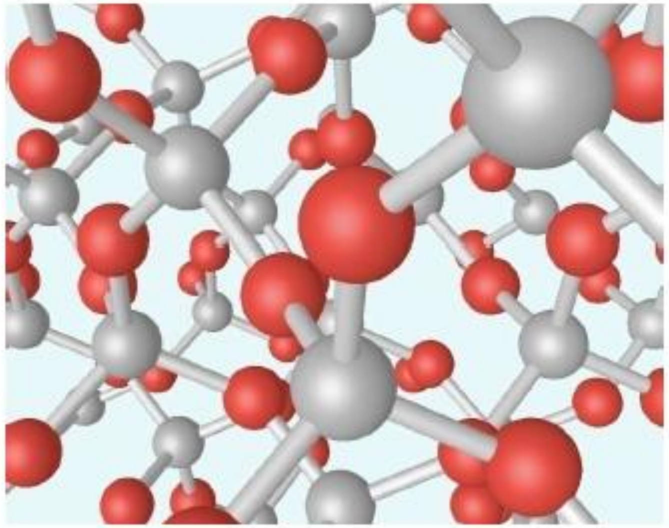
Semiconductor Diode
1N4007 PN Junction Diode

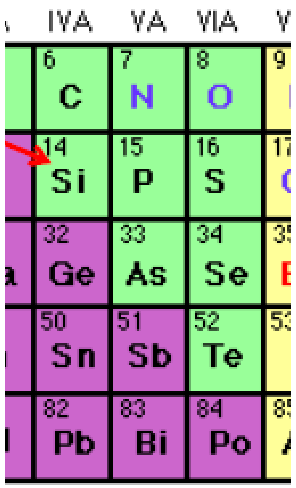
Light Emitting Diode

Semico

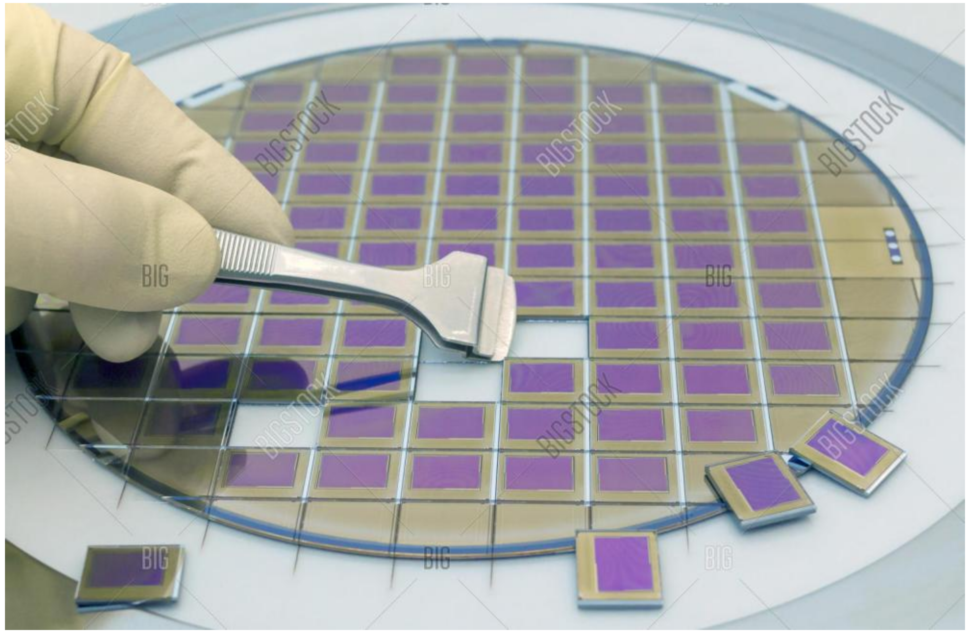
Quartz

SiO_2





➢ Fabrication of Silicon wafers: Czochralski Process



- For any given perimeter, which geometrical shape has the highest area?
- Circle

- Round: Uniformity for Post-processing of wafers.
- Square cake gets burnt in the corner: High gradient at the corners

- Tools for processing are extremely costly: made for circular wafers

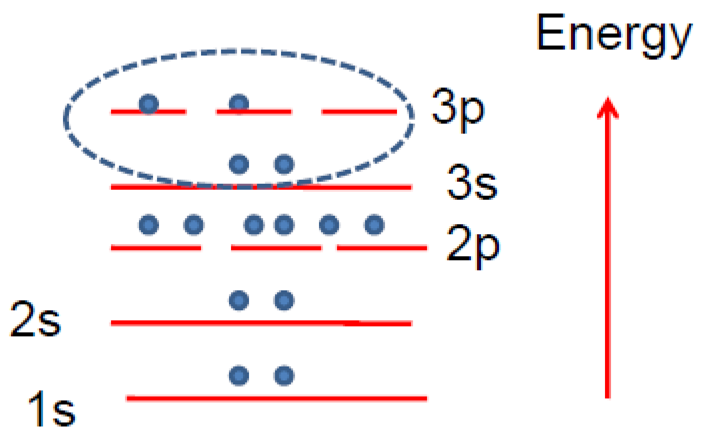
Q2. A tool is capable of processing circular wafer of 12” diameter. Now, if we use a square wafer, how much do we gain/lose in terms of area?

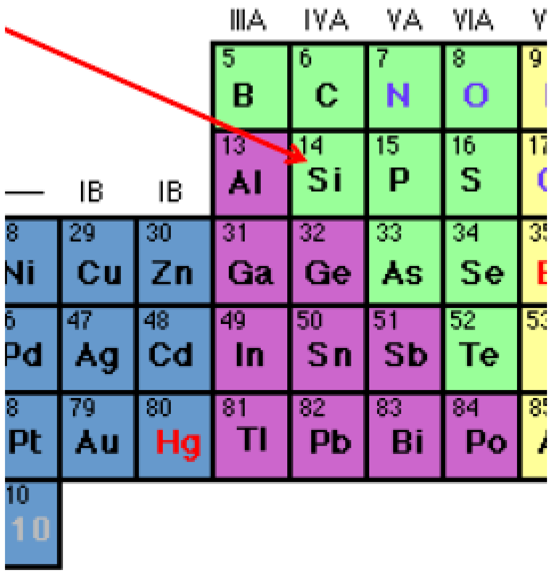
- Diameter of wafer = 12” = diagonal length of the square
- Size of the edges = ?
- Area of the circular wafer = ?
- Area of square wafer = ?
- How much is the area reduction in %?

- If replace square wafers in place of circular ones with existing tools: Area reduction (Not Obvious)

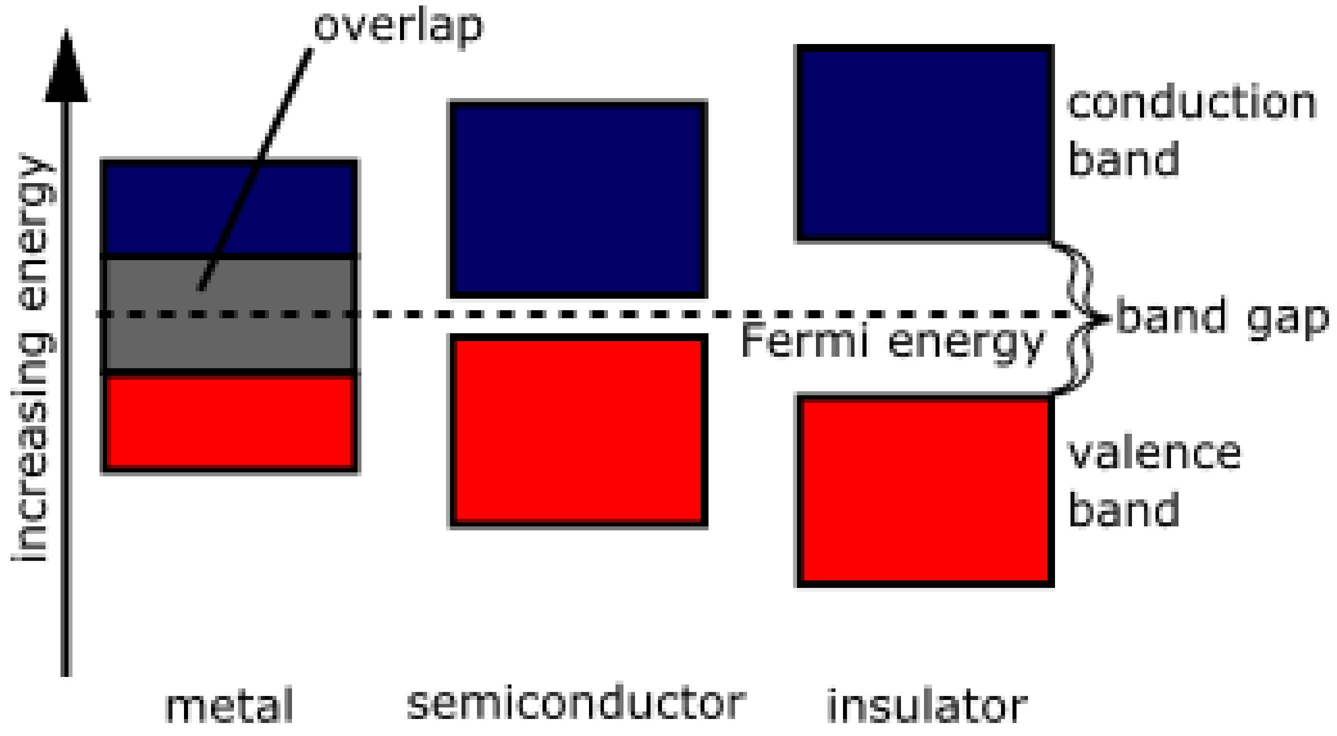
Why semiconductors?

- Conductivity can be controlled ⇒ control current
- Electronics revolution was all about precisely controlling the flow of electricity!
- Let us consider the example of Si
- Recall:
  - Valency of 4





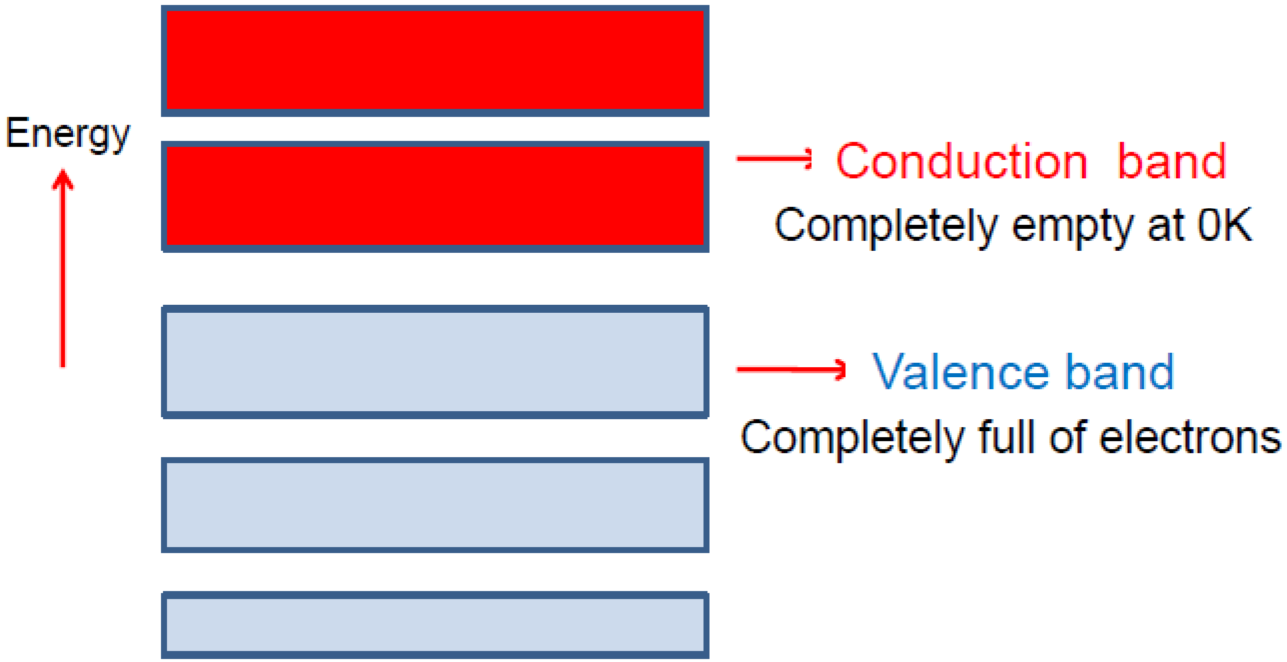
Metals, Semiconductors, & Insulators

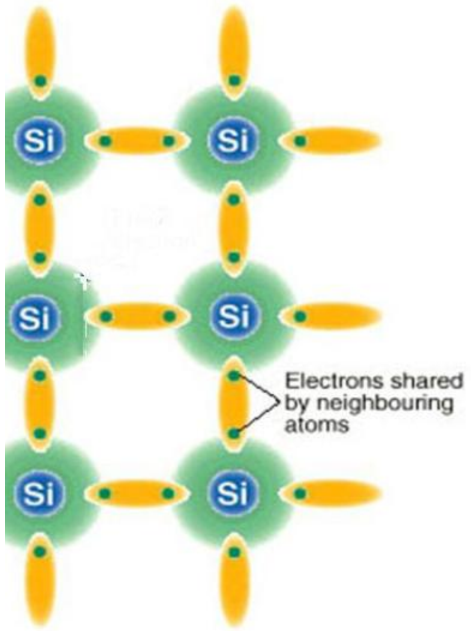


Electrons in the conduction band are free to move about in the lattice, and can therefore conduct current.

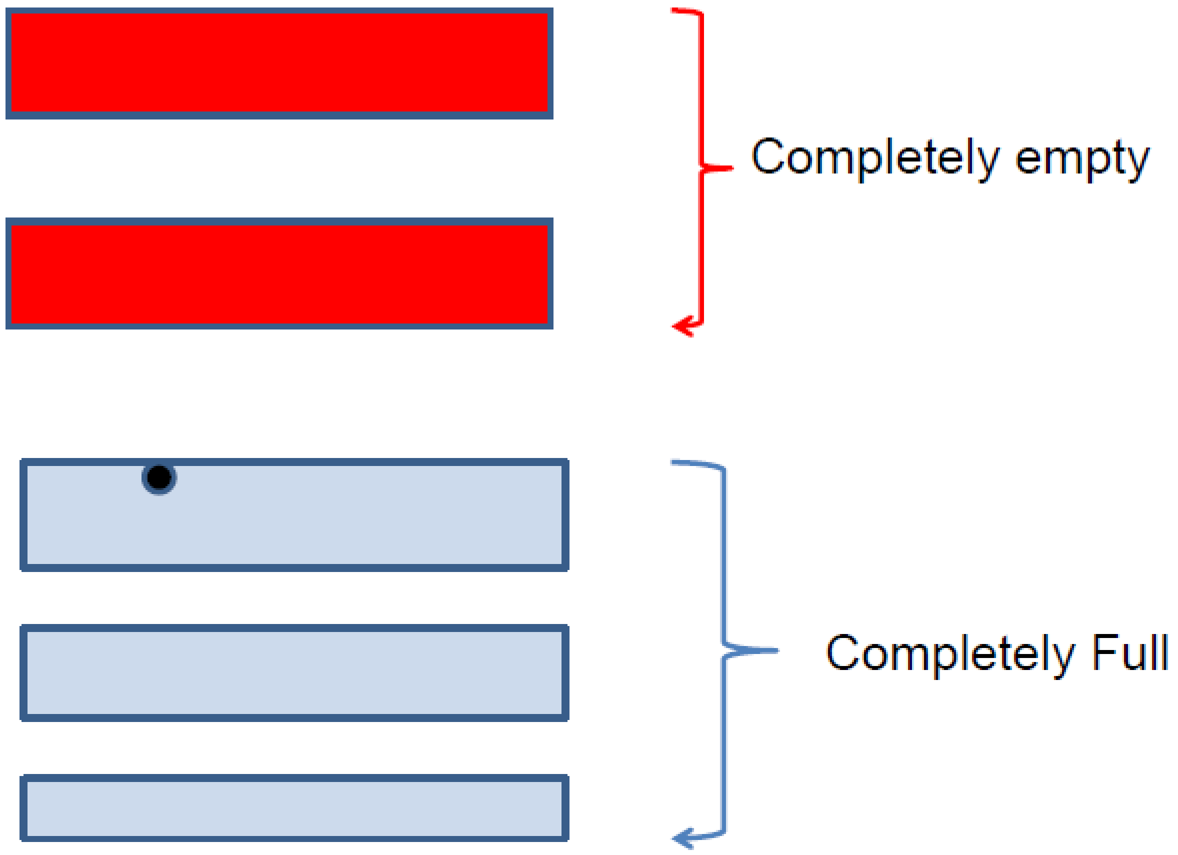
Silicon: band diagram

- Electrons in a silicon crystal occupy bands of energy



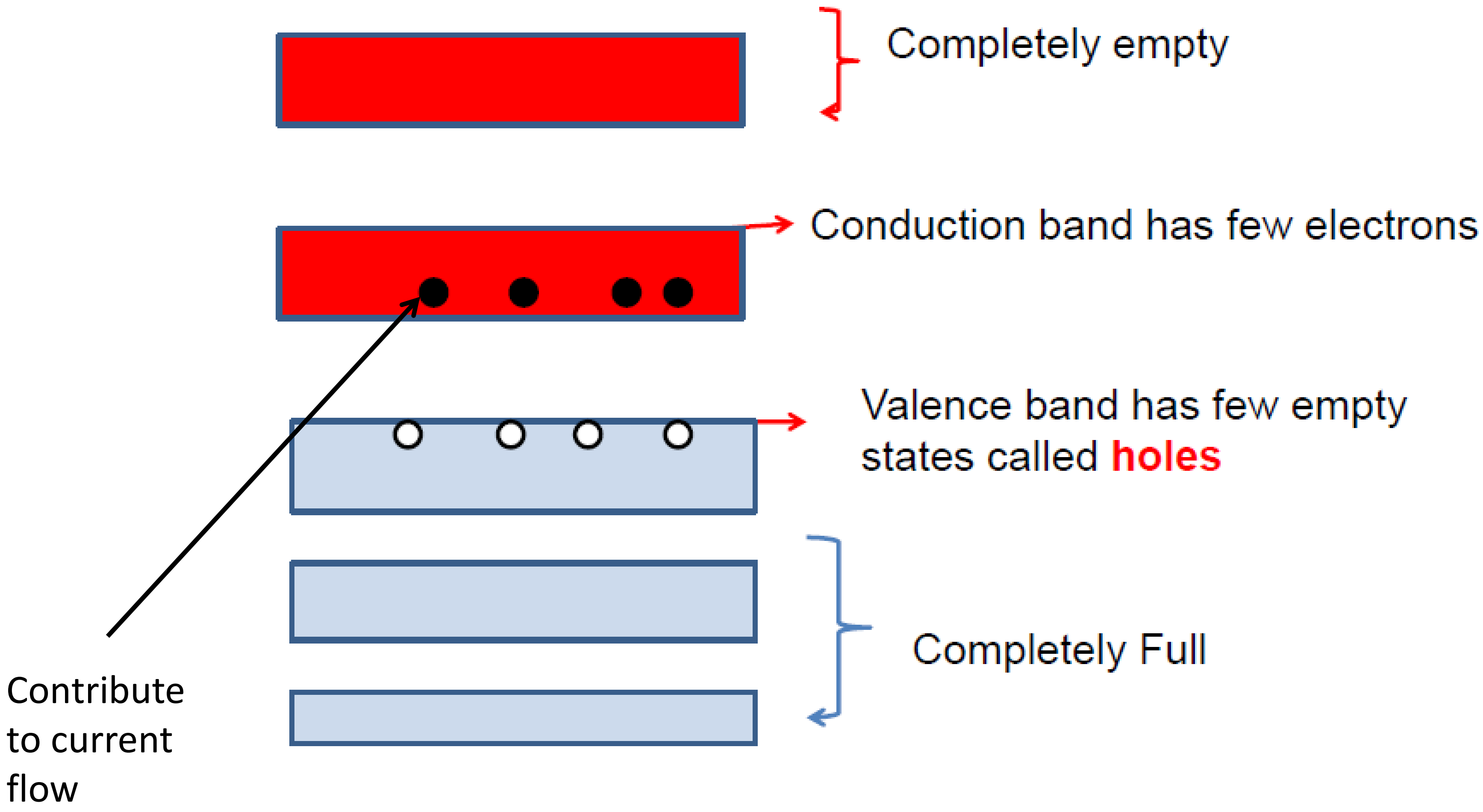


Silicon at 0K

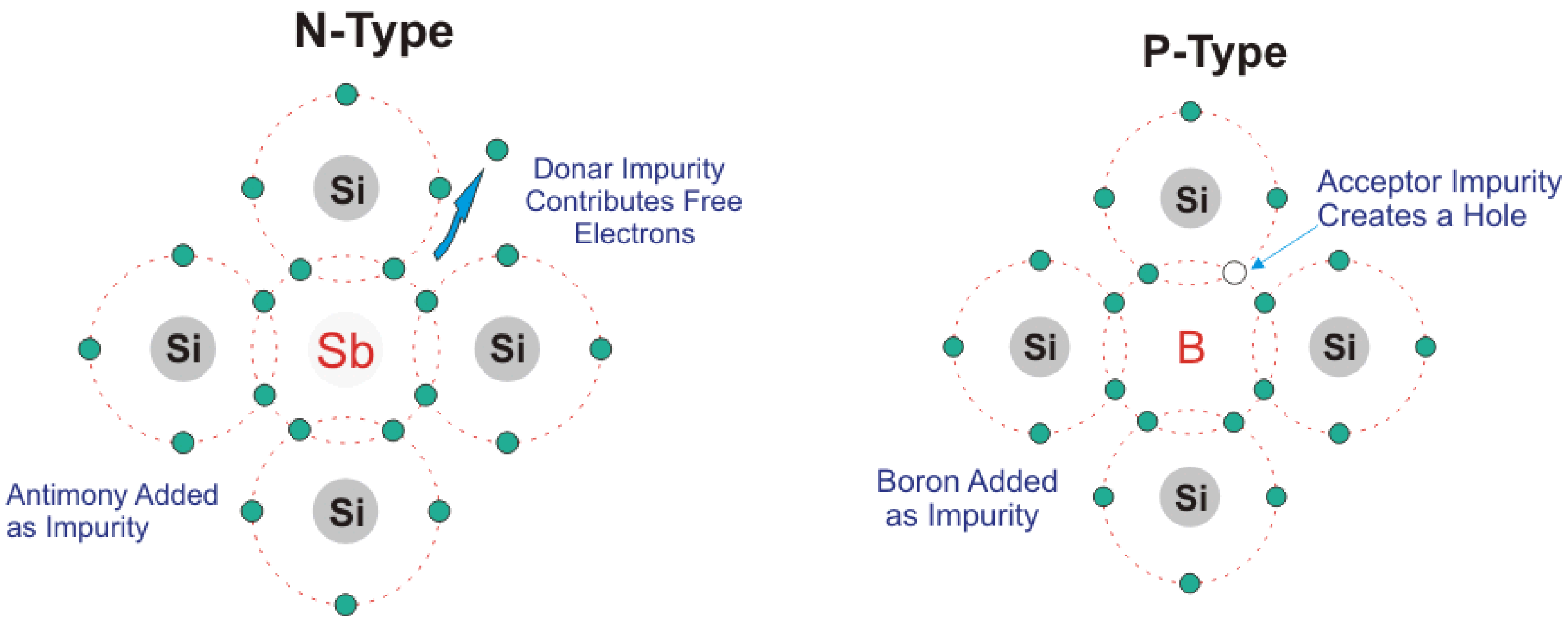


No current flows and Silicon acts like a perfect Insulator !

Silicon at 300K



Doping



Very small amounts of impurity atoms can cause a drastic change in electrical property of a semiconductor.