ELECTRONIC SYSTEMS and TECHNOLOGIES

Master in Management Engineering

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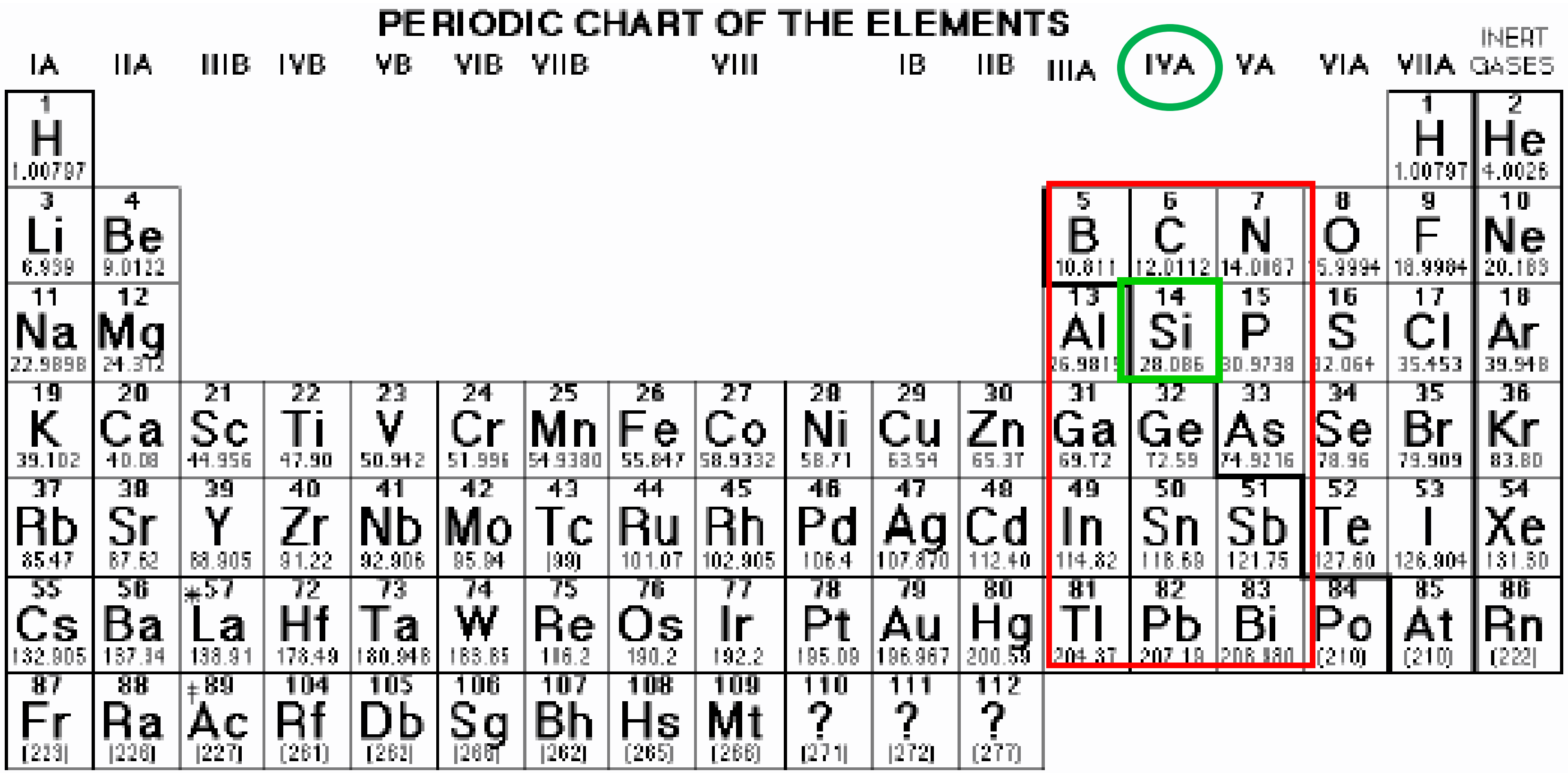
GROUND CONCEPTS ON ELECTRONICS

The semiconductor materials

The very BIG player



- Si^{14}: 14 electrons , $1s^2\ 2s^2 2p^6\ 3s^2 3p^2$
- Medium Electronegativity (tendency to “share” electrons more than “catch” or “release” them)

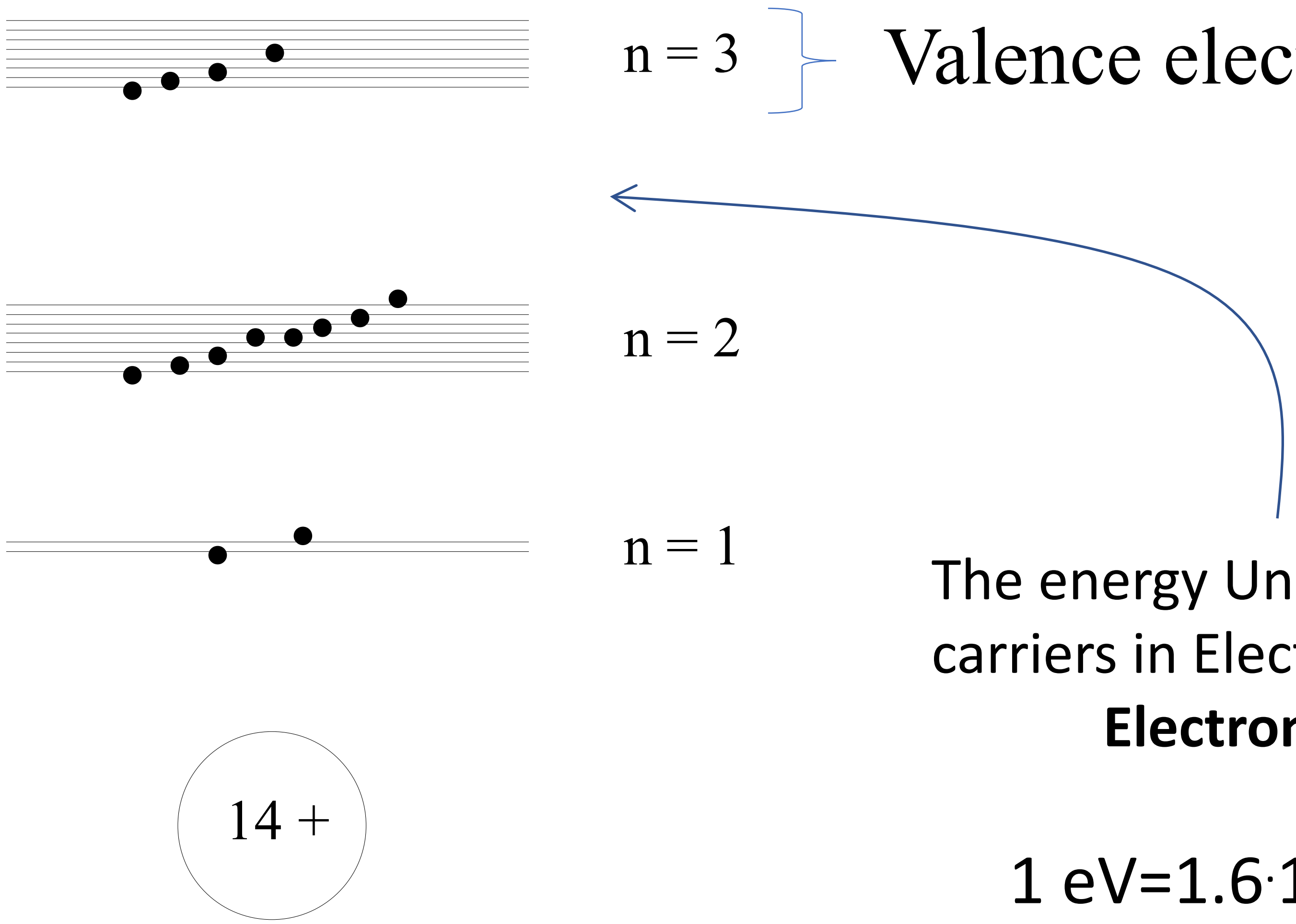
4 electrons in the outest shell

A closer view to a Silicon atom

8 possible states
occupied by 4 e^-

8 possible states
occupied by 8 e^-

2 possible states
occupied by 2 e^-



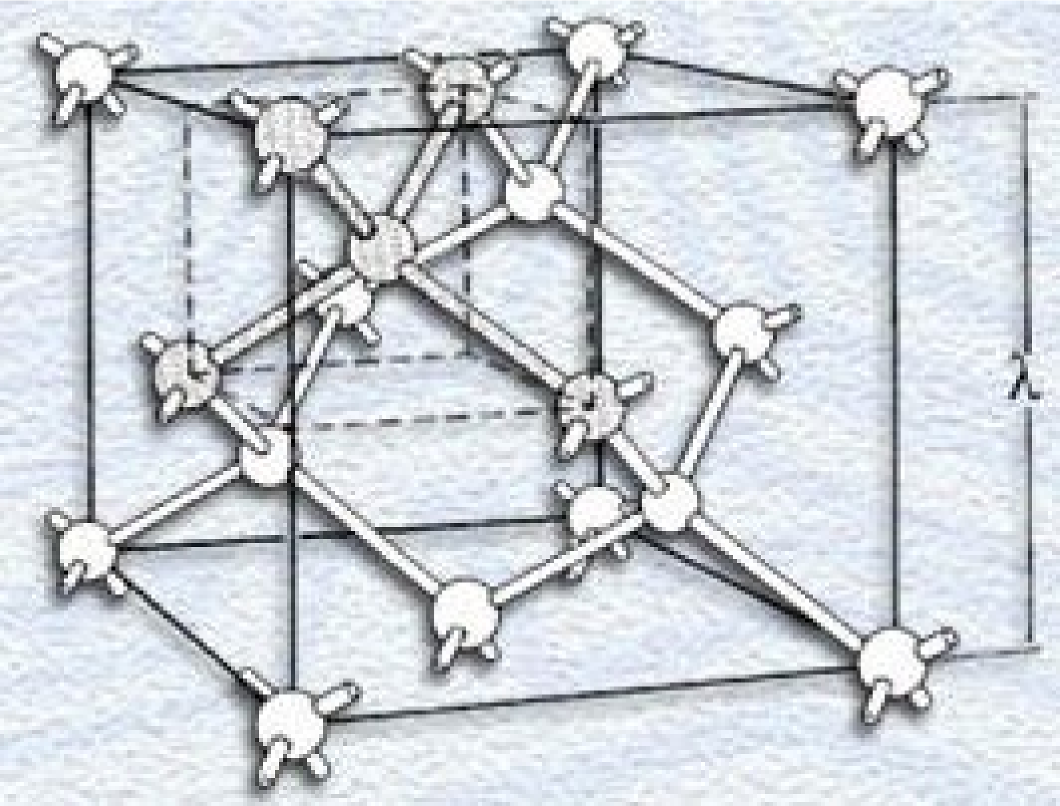
Valence electrons

Few eV

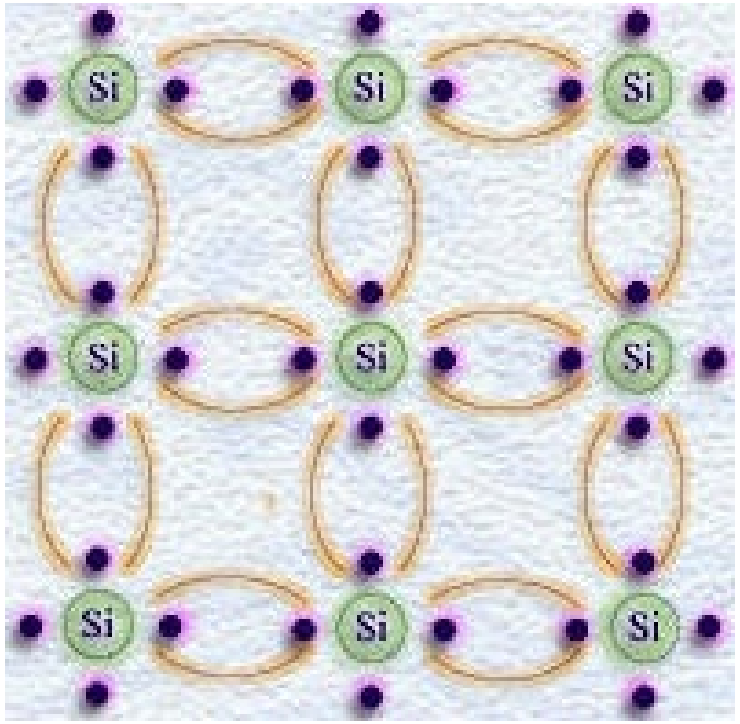
The energy Unit of charge carriers in Electronics is the **ElectronVolt, eV**

$1\ eV = 1.6 \cdot 10^{-19}$ Joules

Cristalline structure of Silicon



~ 0.5 nm



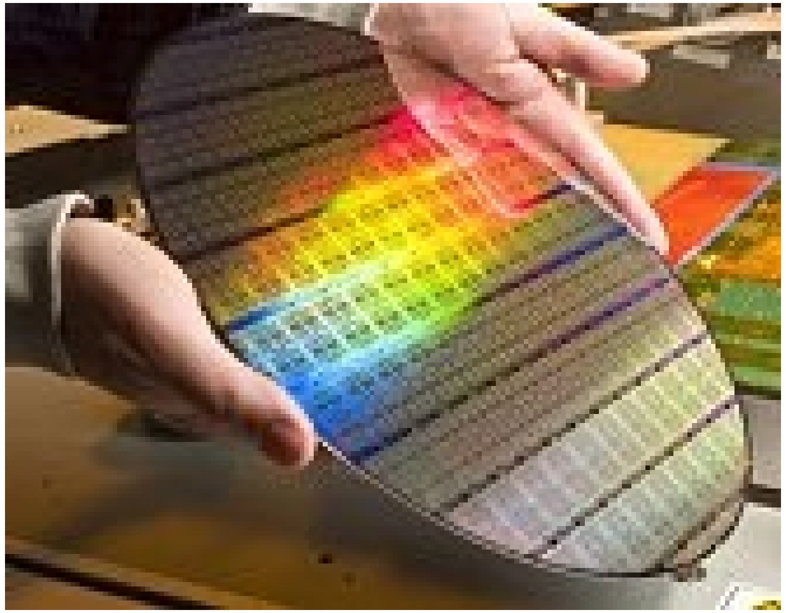
Very dense : $5x10^{22}$ atomi/cm^3

Silicon ingot

Silicon wafers in a carrier

Silicon Wafer

- Small size(76/50.8/25.4mm)
- 4 inch(100mm) Polished Wafer
- 5 inch(125mm) Polished Wafer
- 6 inch(150mm) Polished Wafer
- 8 inch(200mm) Polished Wafer
- 12 inch(300mm) Polished Wafer



GlobalWafers Italian Subsidiary, MEMC SPA, launches 300mm Expansion Plan

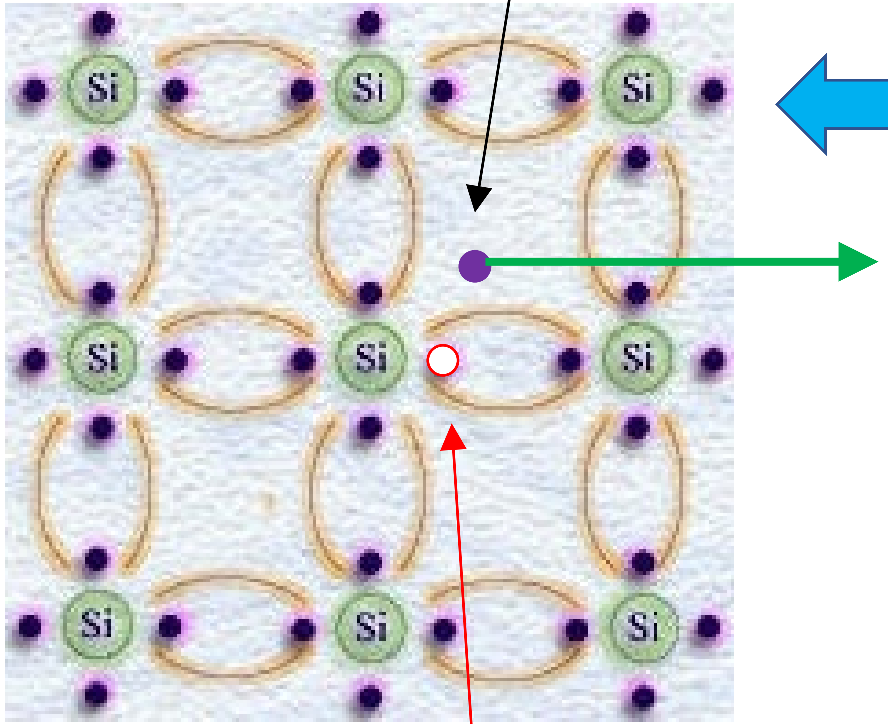
Novara (NO), Italy – 18 February 2022 – MEMC Electronic Materials SpA (MEMCSPA), GlobalWafers Group (GWC)

On February 10th 2022 , MEMCSPA Board of Directors, following up GWC BoD decision, has finally approved the expansion of its existing facility located in Novara (Italy), that's currently producing 200mm silicon wafers, by adding a new 300mm wafers production module.

The global race toward 300nm

Electrons and Holes and Currents

This electron has boken the valence bond and can move freely in the crystal

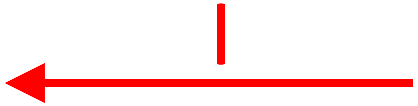


ELECTRON can be pulled by the Electric Field

HOLE
missing of a valence electron

The movement of charges produce a current

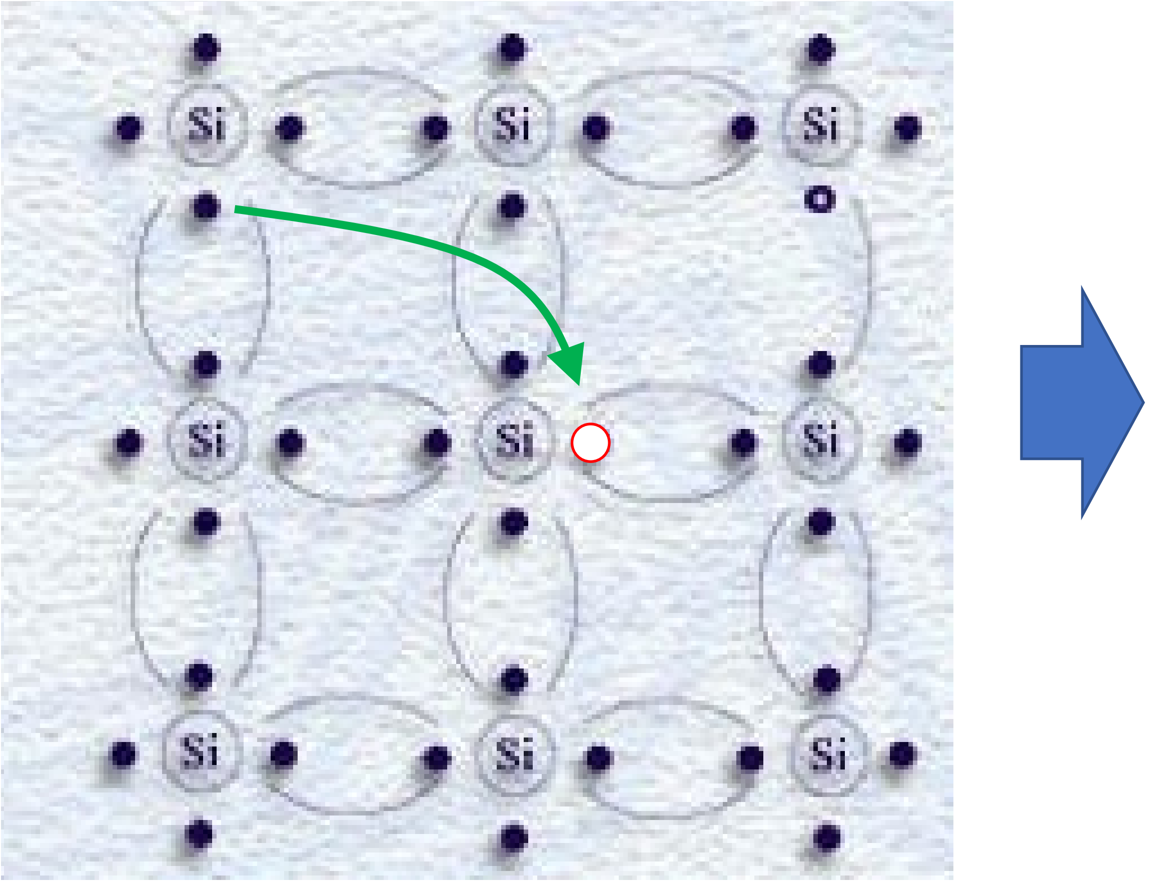
The direction of the Current is opposite to that of electrons

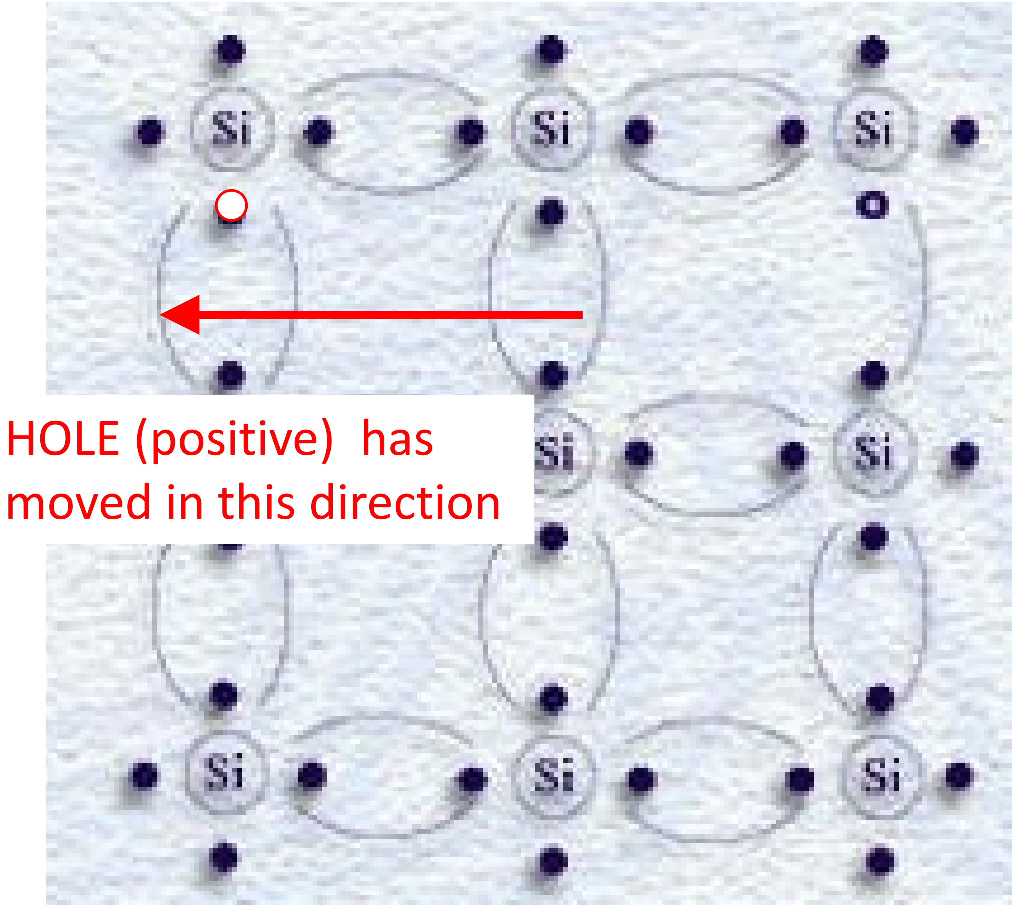


Conduction of Holes

A valence electron can occupy the site of the HOLE ….

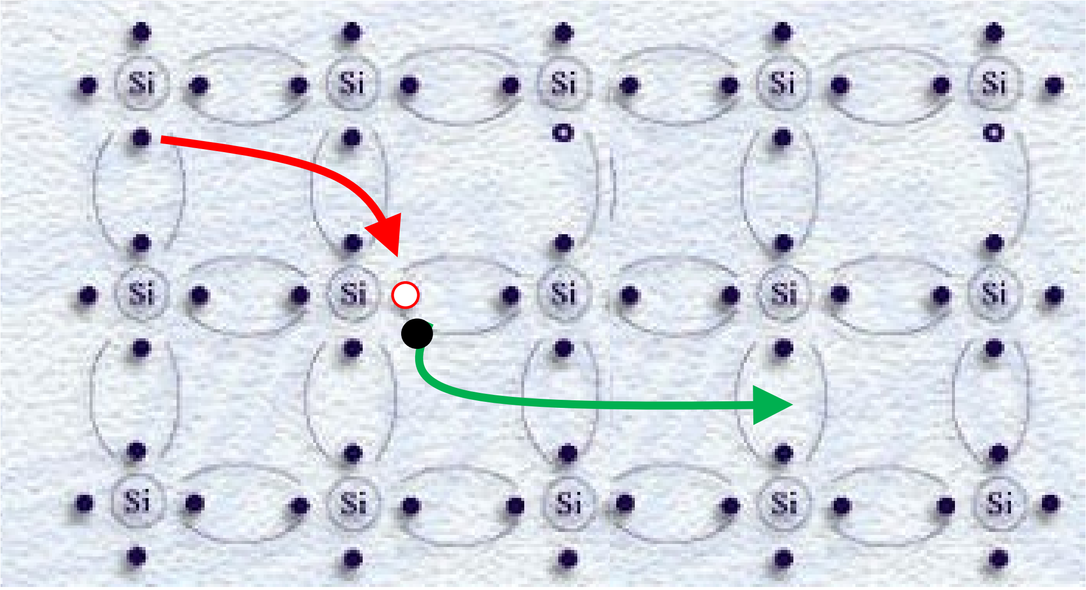
… freeing a HOLE in the site where it was





Same direction of the current

Meaning of «Semiconductor» (1)



Conduction by means of electrons **and** holes

Limited number of electrons and holes (*as compared to a metal, where all atoms generate an electron – 10^{23} electrons/cm^{3}*)

More electrons → higher possible current

Exercise 1

If the temperature of a pure silicon crystal is increased, the number of holes per cm^3 increases or decreases? And that of electrons?

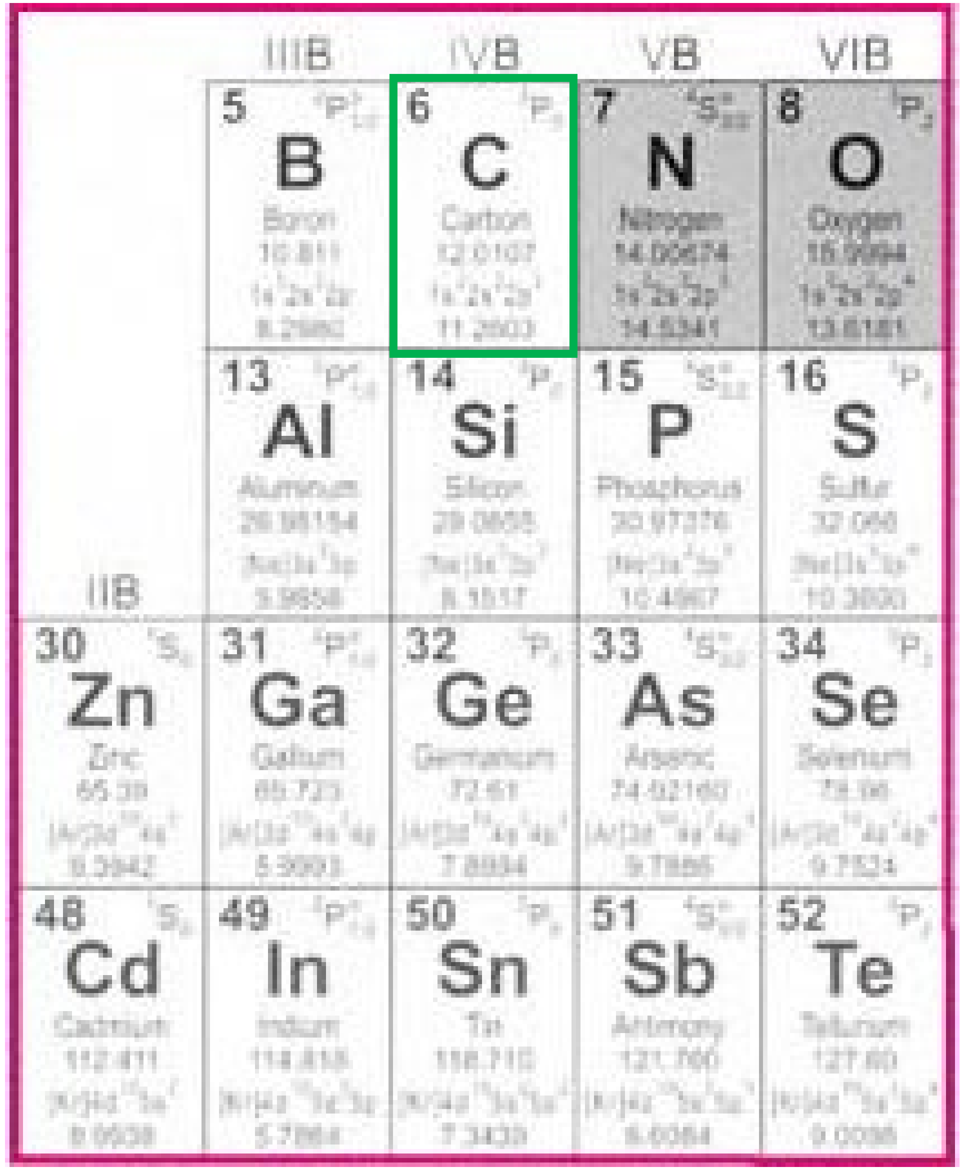
Exercise 2

The diamond is a crystal exactly the same as silicon but made with carbon atoms (C).

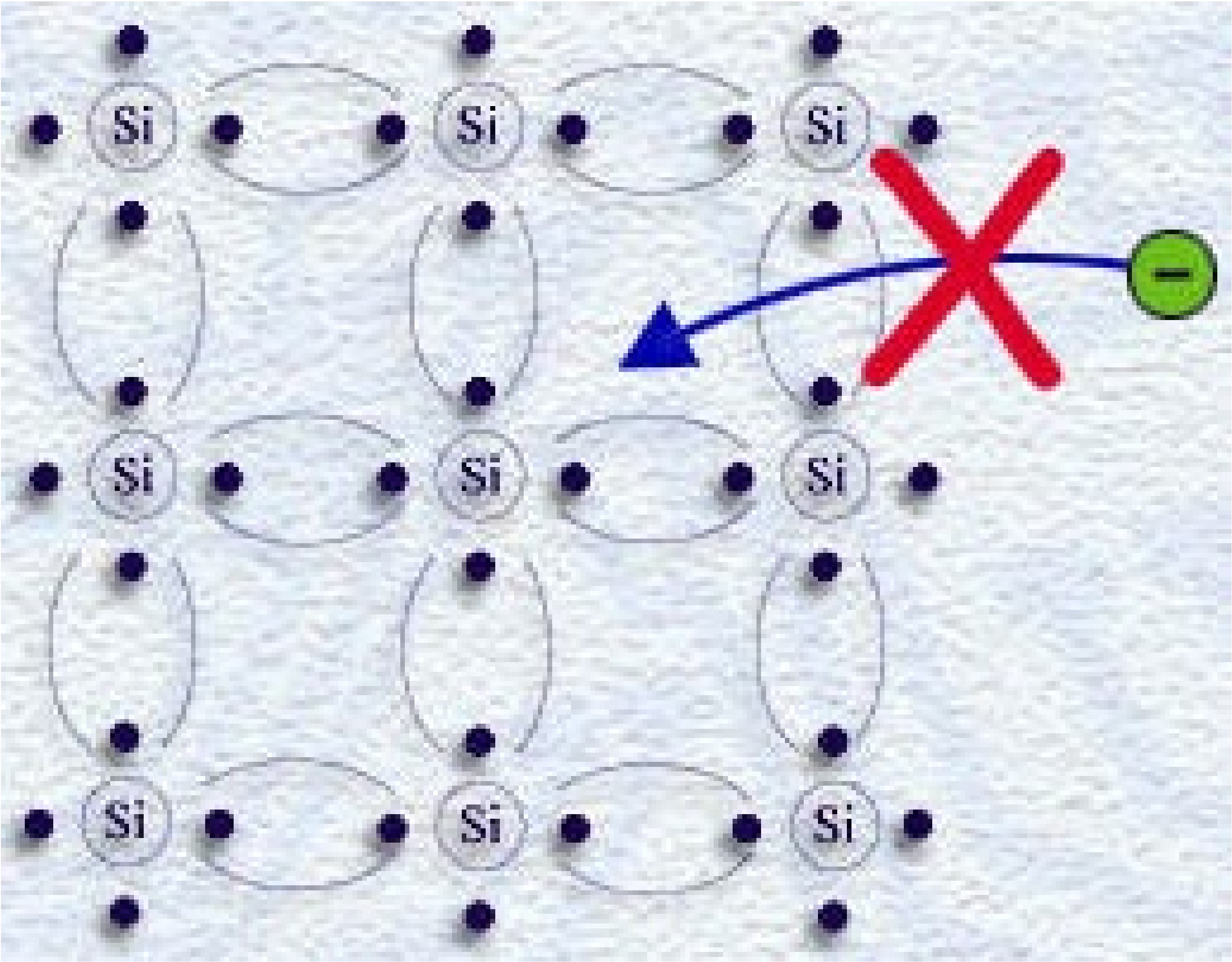
At room temperature it is considered an insulator.

Can you imagine why?

In what situation would it manifest semiconductor properties instead?



How to change the concentration of Electrons (or Holes)

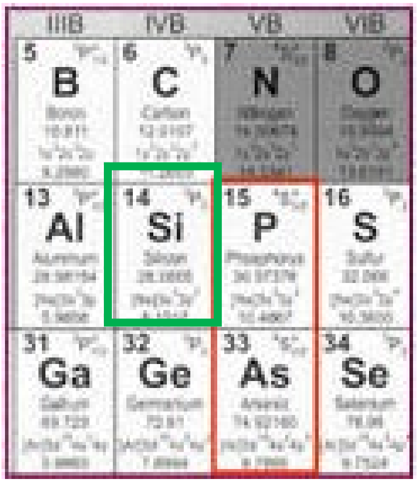


You can not
insert electrons !

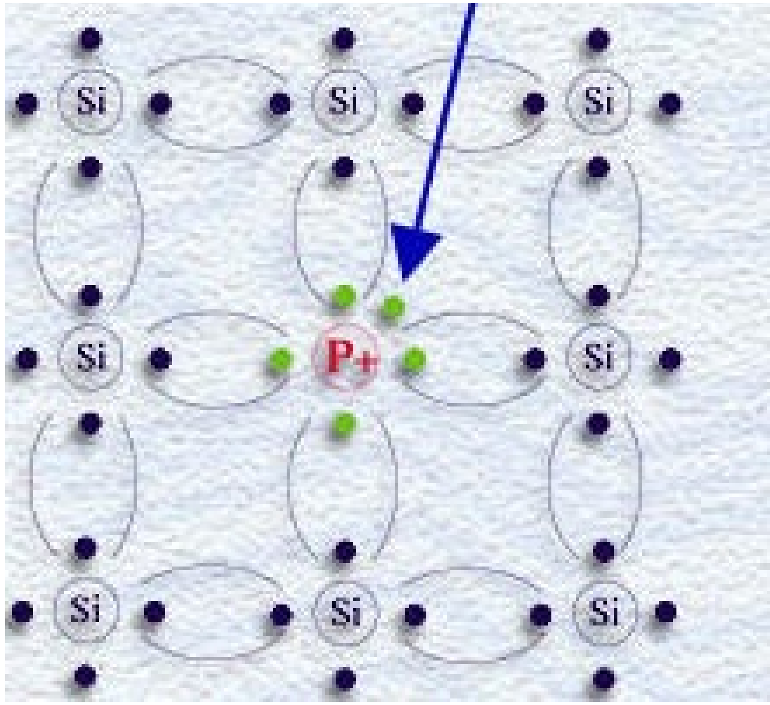
Your material
will charge up
and explode !

Phosphorus doping : n-type semiconductors

Substitution of one atom with another atom



This electron can easily be set free to move

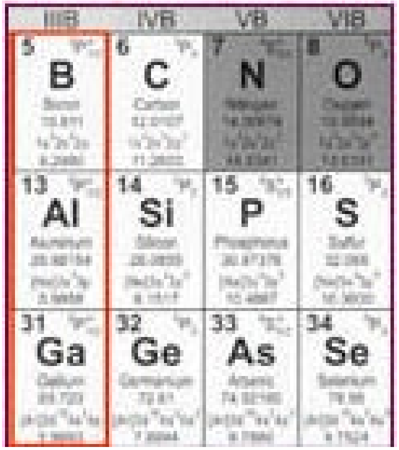


By doping with $N_D = 10^{16}$ P atoms/cm^3 we obtain
n (*density of free electrons*) $= 10^{16}$ electrons/cm^3

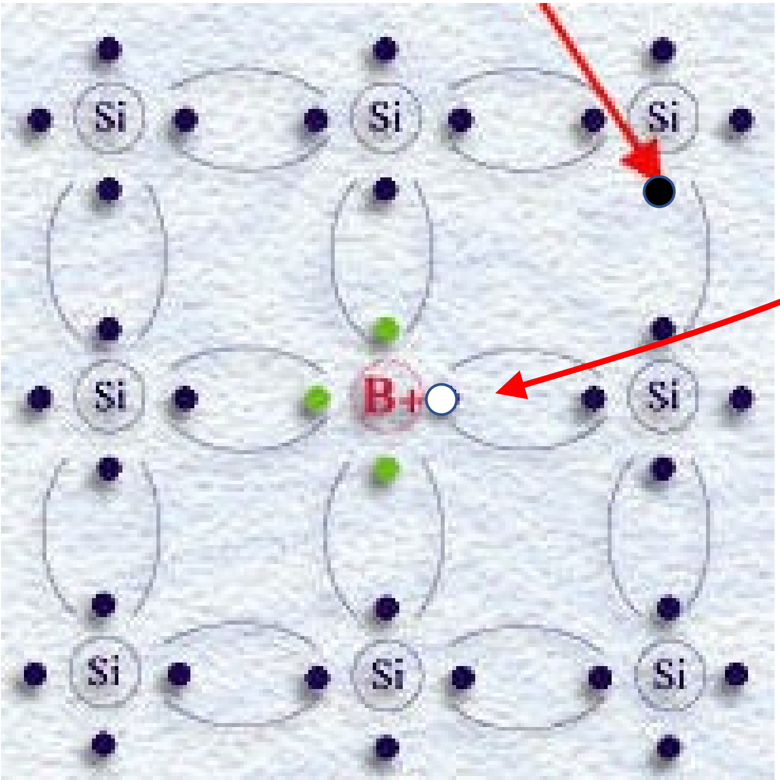
Locally, associated to the dopant ionized atom, we have a positive charge, ***globally*** compensated, somewhere in the crystal, by its free electron.

*The crystal, all together, remains **neutral**.*

Boron doping : p-type semiconductors



This valence electron can easily move to B

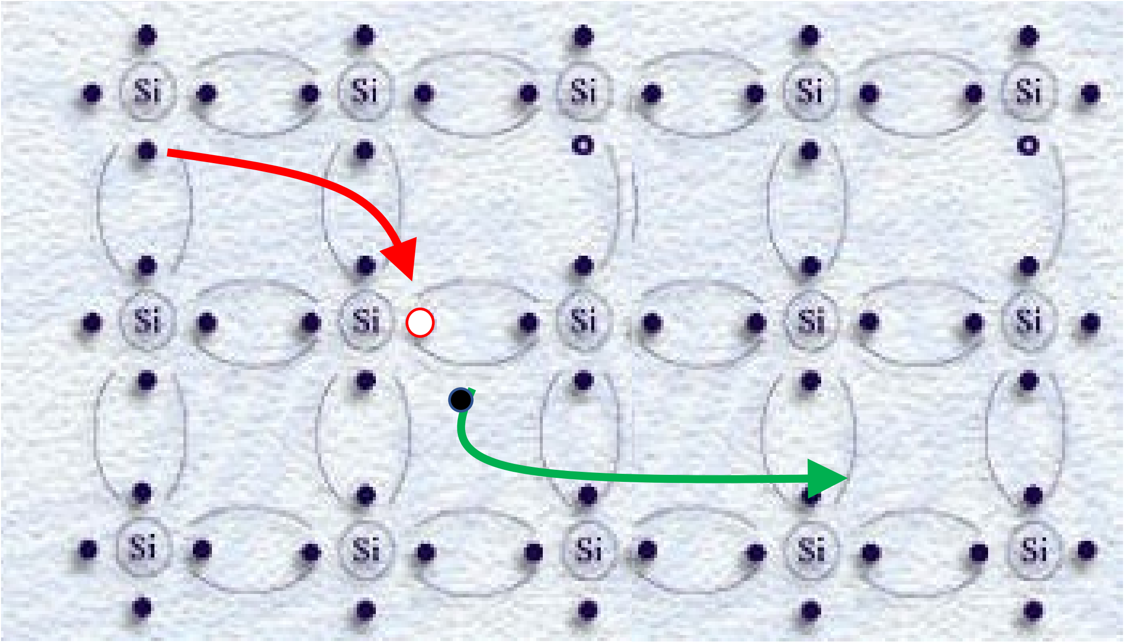


By doping with $N_A = 10^{15}$ B atoms/cm^3 we obtain
p (*density of free holes*) = 10^{15} holes/cm^3

Locally, associated to the dopant ionized atom, we have a negative charge, ***globally*** compensated, somewhere in the crystal, by its free hole.

*The crystal, all together, remains **neutral**.*

Meaning of «Semiconductor» (2)



Conduction by means of electrons **<u>and</u>** holes

Controlled number of electrons or holes, by the doping
(*in a metal instead the number is fixed to about 10^{23} electrons/cm^3*)

Practical considerations on doping

Industry has the ability to produce crystalline silicon with a very high purity :

1 impurity atom every 10^{10} Si atoms
(< 10^{12} atoms/cm^3 of impurities in the crystal)

With no other material, the technology has reached the same level !

In electronics we purify the silicon as much as possible and then we introduce the desired dopants. The position of the dopants in the lattice replacing the Si atoms is random.

density of Si atoms : $5 \cdot 10^{22}$ atoms/cm^3

density of dopant atoms : $10^{12} < N_A, N_D < 10^{19}$ atoms/cm^3

The dopant concentrations are small compared to the density of Si

Exercise 3

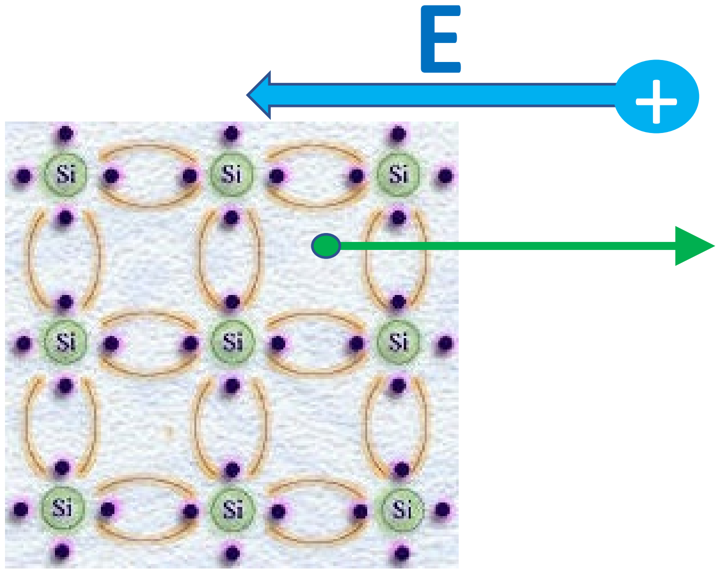
After having doped a Si crystal, kept at room temperature, with $5 \cdot 10^{16}$ atoms/cm^3 of phosphorus, how many free electrons are there in the crystal?

If the same Si crystal were kept at very low temperatures, close to 0°K, what would happen ?

How many electrons and how many holes would there be?

What if the same crystal were heated to very high temperatures (for example 500°C)?

How to move charges in a semiconductor crystal



ELECTRON can be pulled by the Electric Field

$$\vec{F} = q \cdot \vec{E} = m \cdot \vec{a}$$

In free space

$$\vec{a} = \frac{q}{m}\vec{E}$$

Electrons scatter with crystal atoms every τ and stop

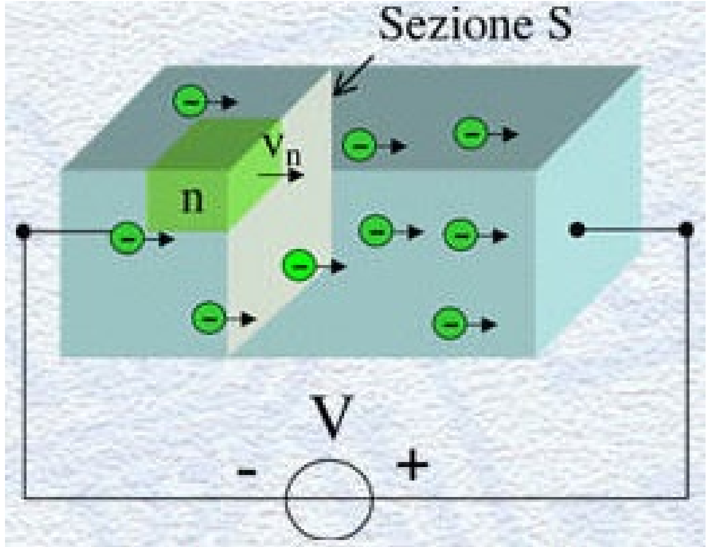
$$\vec{v} \cong \frac{q\tau}{m}\vec{E} \quad \Rightarrow \quad \vec{v} \cong \mu \cdot \vec{E}$$

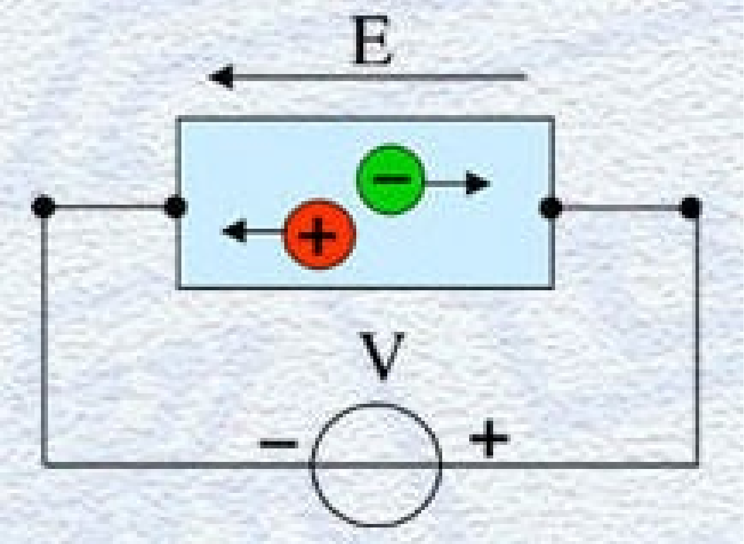
mobilità

$$\mu_n \cong 1300 \ \frac{cm^2}{V \cdot s}$$

$$\mu_p \cong 400 \ \frac{cm^2}{V \cdot s}$$

Currents in a semiconductor crystal





$$I = qnv_nS = q \cdot \frac{elettroni}{cm^3} \cdot \frac{cm}{s} \cdot cm^2$$

In n-type material (N_D) we have : $I \cong I_n = qn\mu_n E \cdot S$

In p-type material (N_A) we have : $I \cong I_p = qp\mu_p E \cdot S$

Conductivity σ

Resistivity ρ = 1/σ

Ohm's law at the microscale

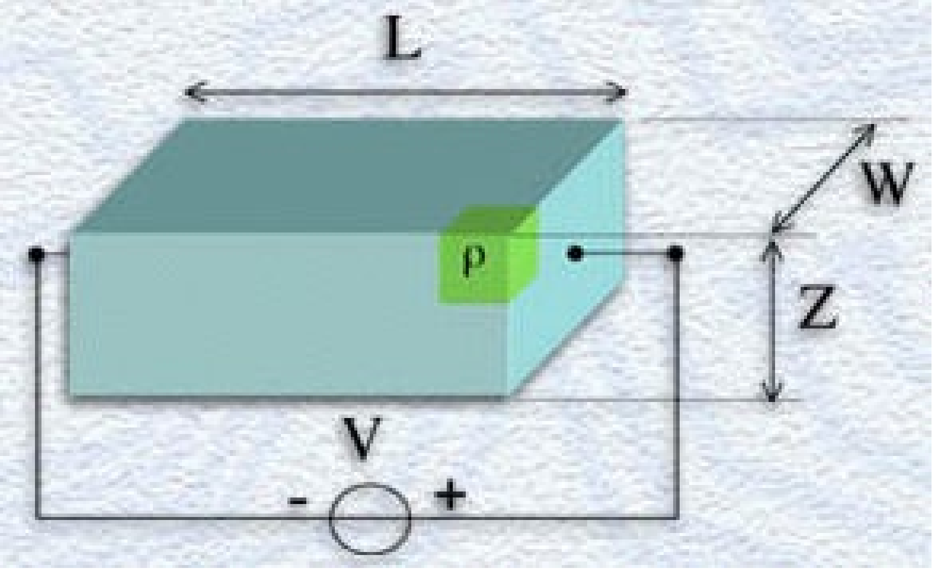
$$I_n = qn\mu_n ES$$

$$I_n = qn\mu_n \frac{V}{L} WZ$$

$$R = \rho \frac{L}{W \cdot Z}$$

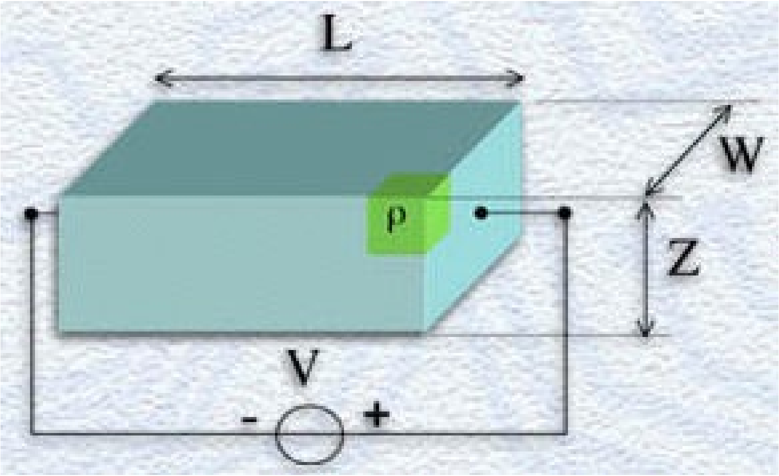
Resistance [Ω] of the device

Ohm's law : $I = \frac{V}{R}$



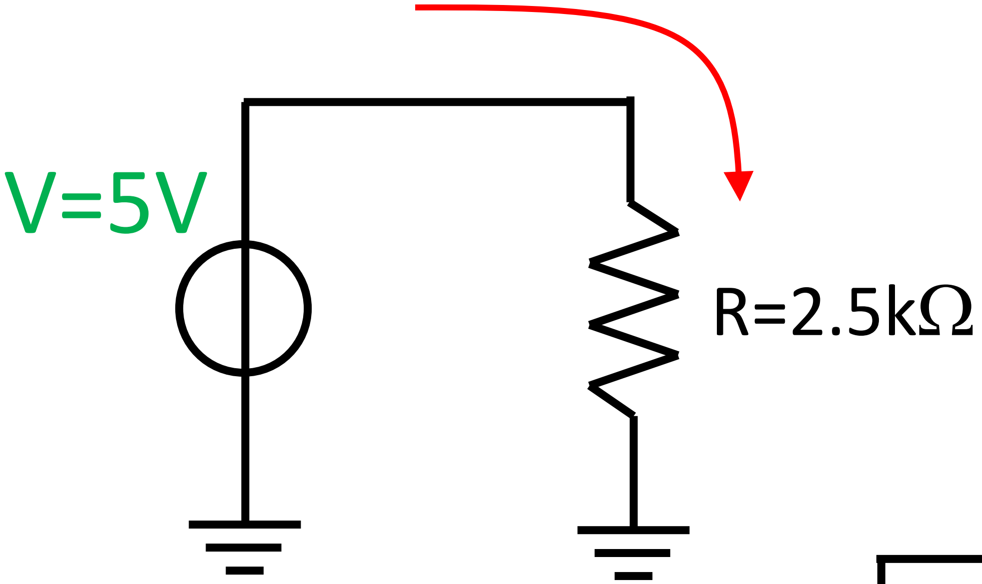
Exercise 4

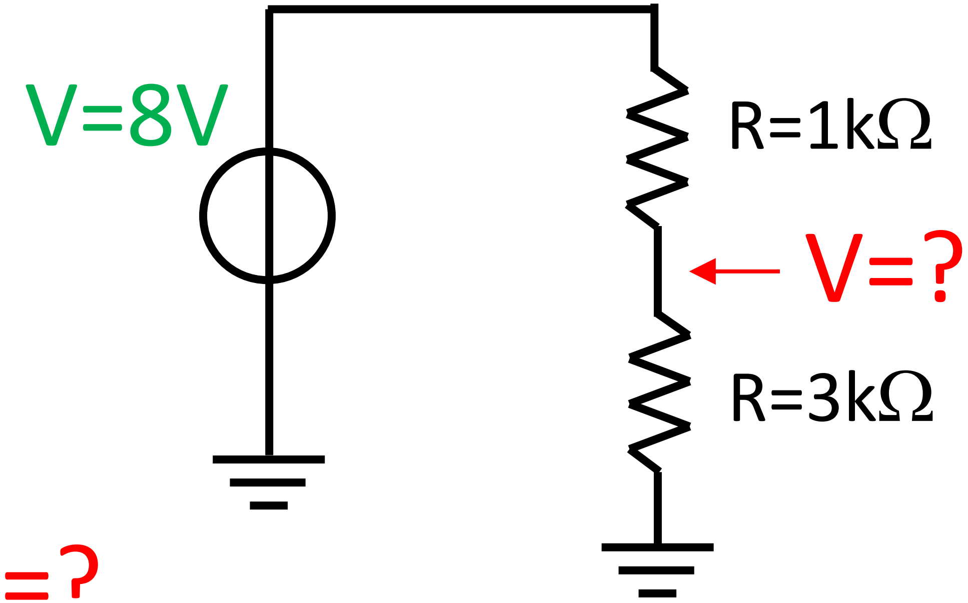
Given a doped ($N_D = 10^{15}$ atoms/cm^3) Silicon of dimensions W=10mm, Z=0.1mm and L=1mm, calculate the current when a voltage of 1V is applied.

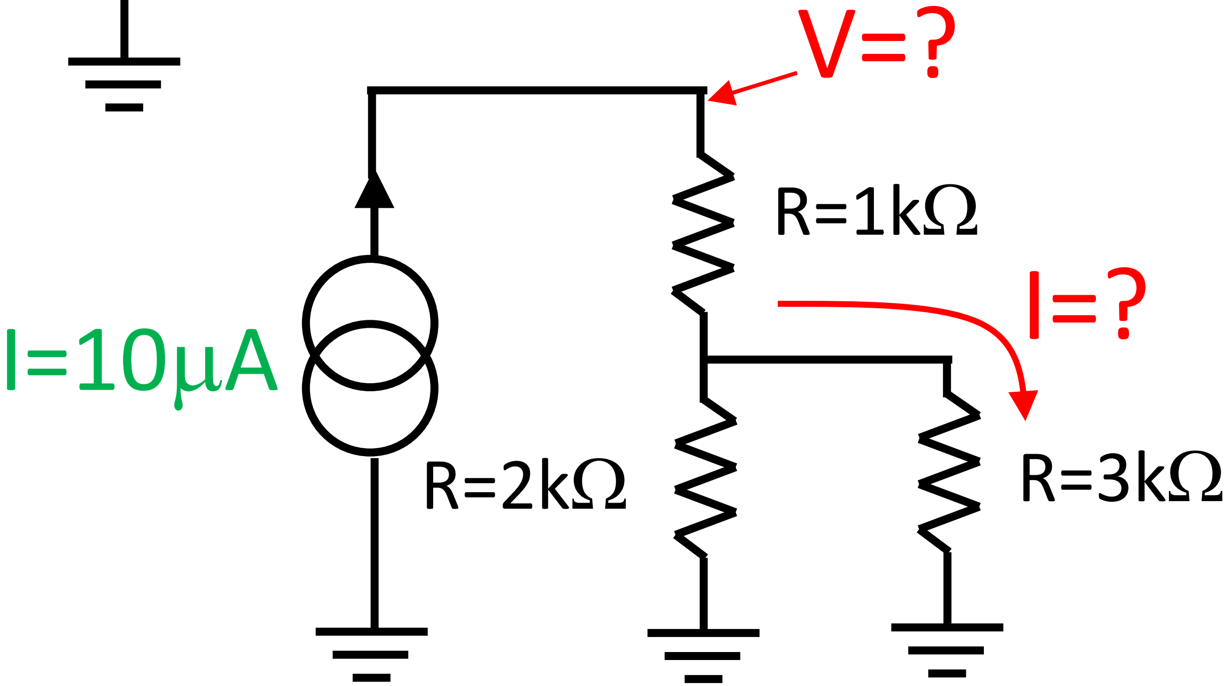


If the block had been doped $N_A = 10^{15}$ atoms/cm^3, the total current would have been the same or not?

Exercises 5 Recap of Ohm’s Law

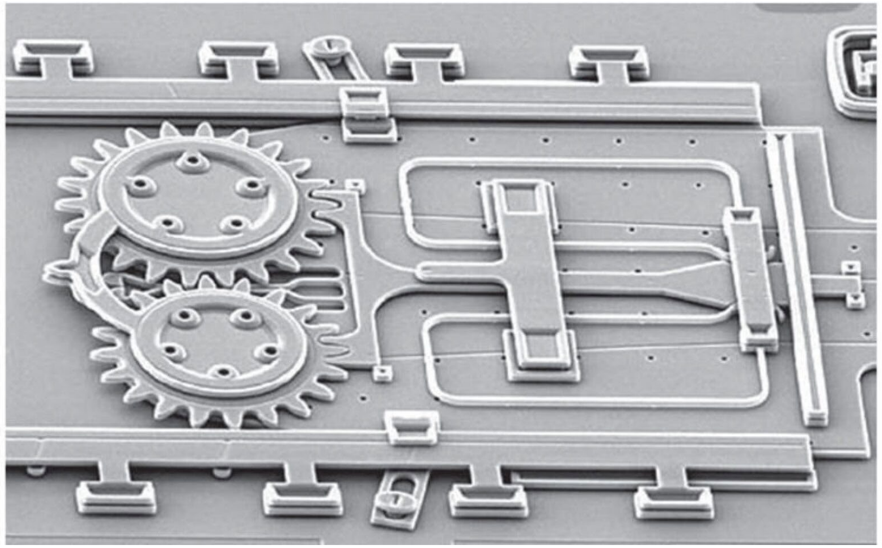






Why **Silicon** has been the **PERFECT MATERIAL**

Si crystal	semiconductor
Si Oxide (SiO_2)	insulator
Compatible with metals	conductor
Easy to etch	machining - MEMS



Disadvantages of Silicon

No production of light

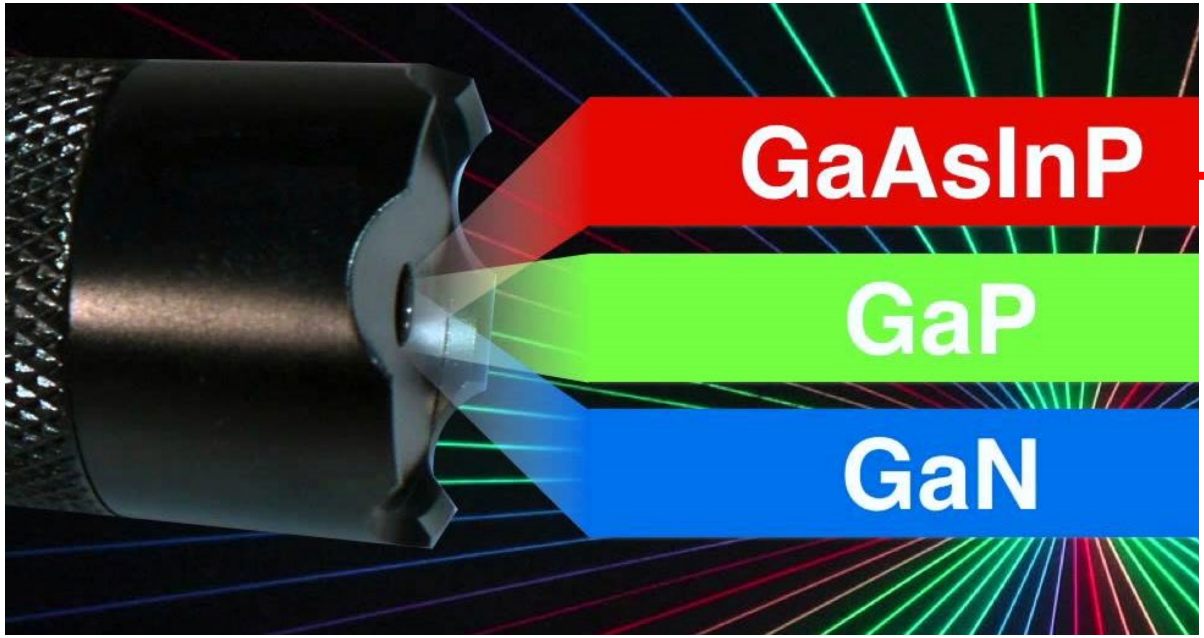
No magnetic properties

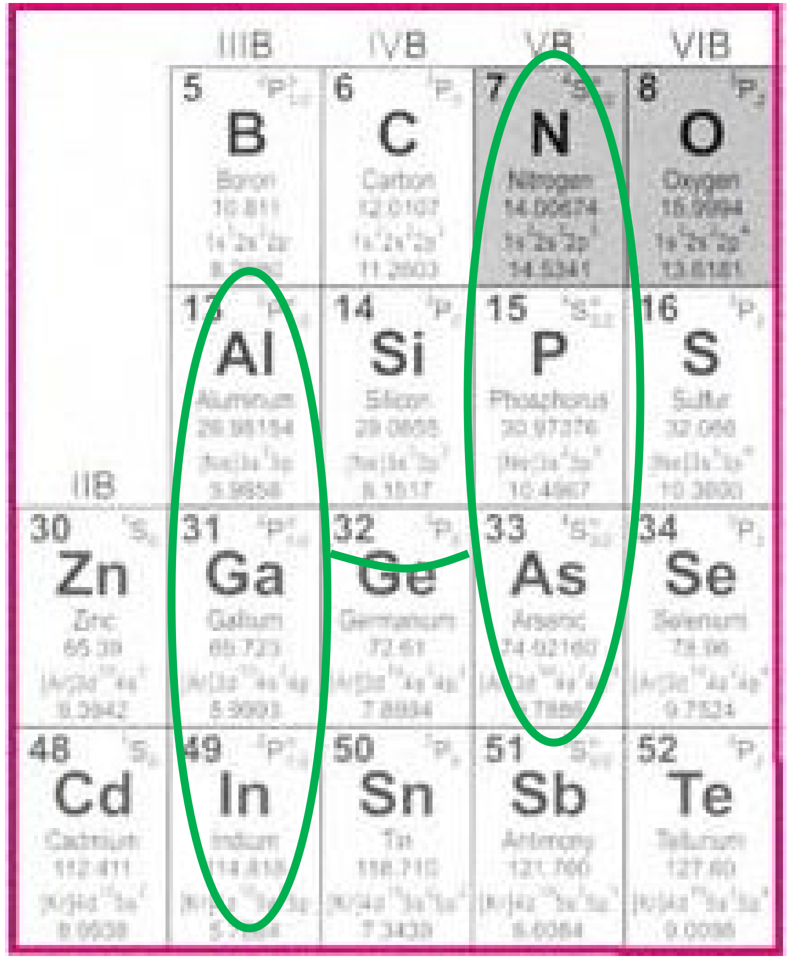
Semiconductors that emit light (for Diode, LED, Laser)

Few semiconductors have quantum properties that allow light emission

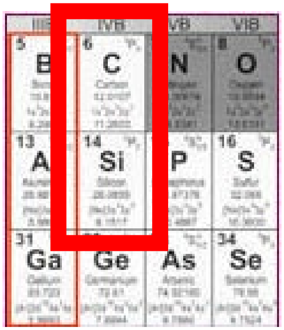
Different bonding forces → Different colors

Near Infrared & Telecom range





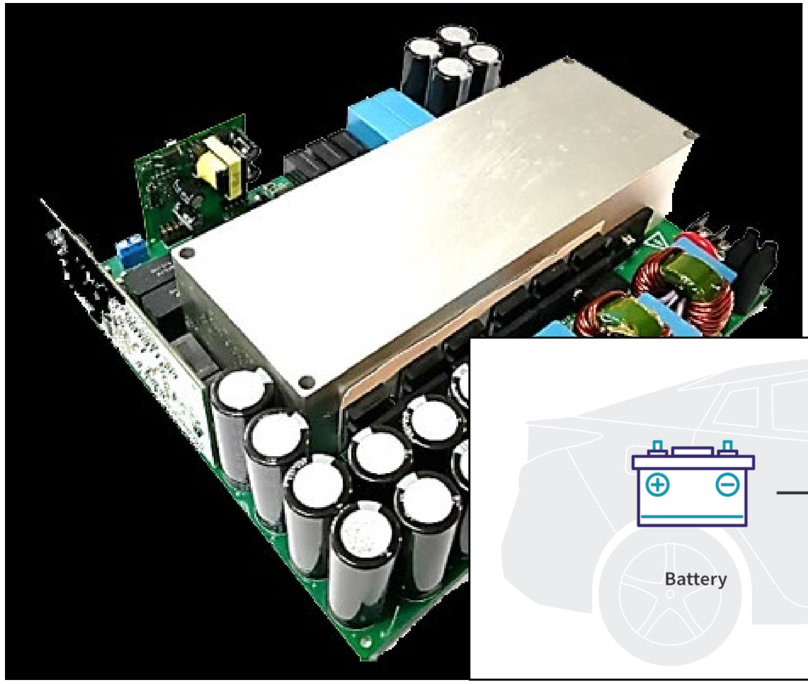
Semiconductors for high voltages & temperature

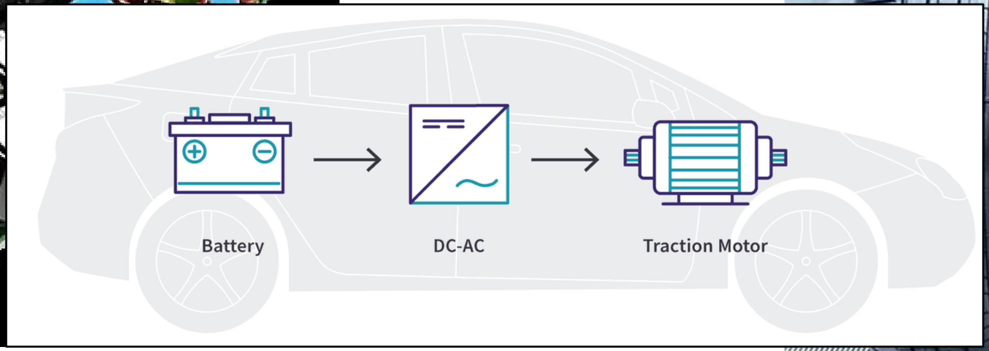


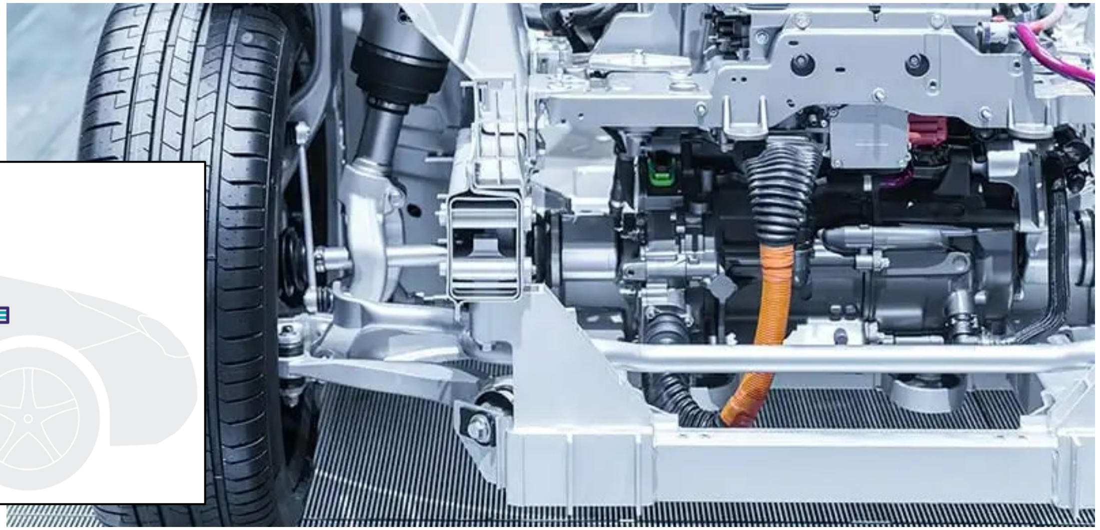
Silicon Carbide (SiC) devices deliver high-voltage and high-current, resisting at high-temperature as requested to build efficient automobiles.

An EV's powertrain is responsible for taking energy stored in the vehicle's battery system and supplying it to the motors.

The amount of power to move a fully loaded vehicle is enormous, and delivery needs to be instantaneous.







The SEMICONDUCTOR : a new technological material, never existed before, where by doping with neutral atoms you obtain an equal amount of electrons. To be moved easily with an electric field !

End of the lesson