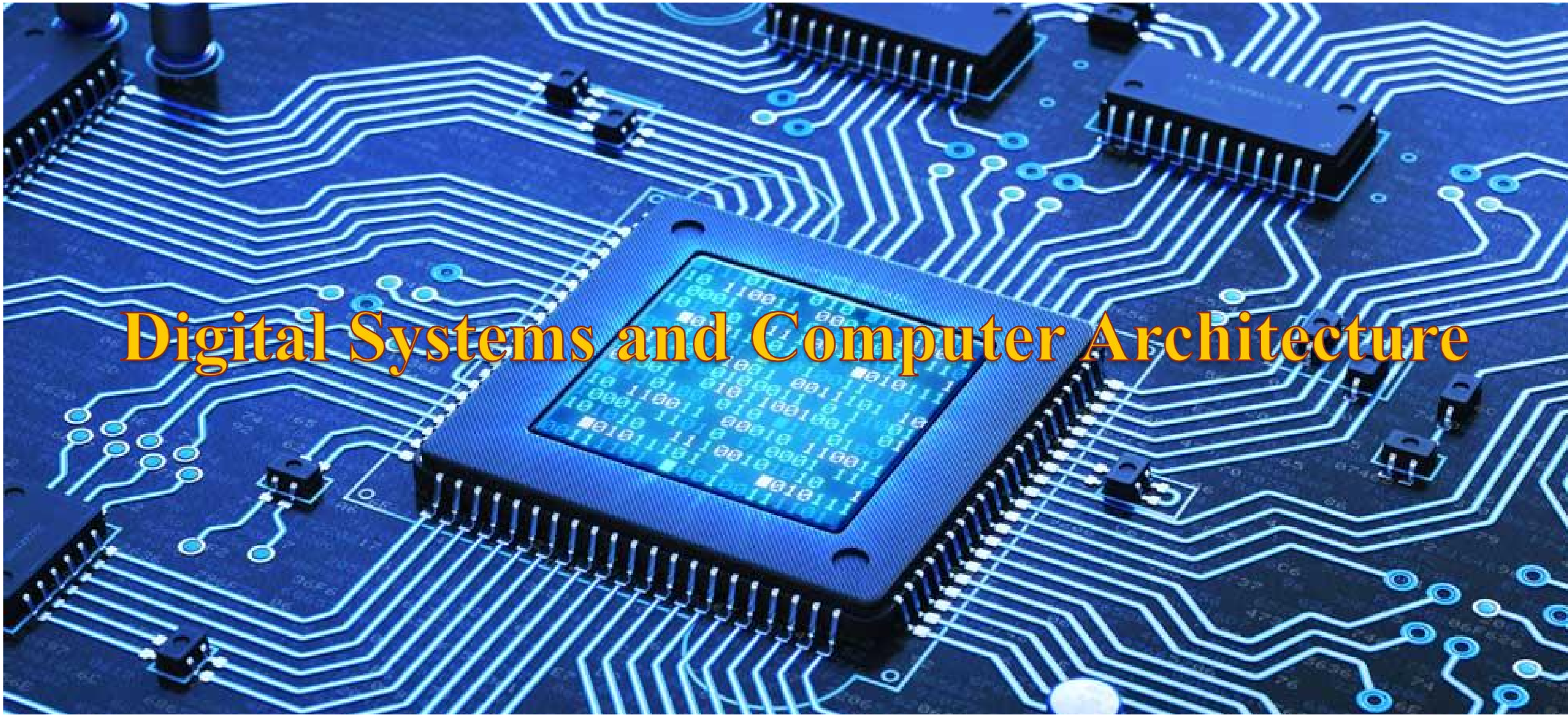


Digital Systems and Computer Architecture

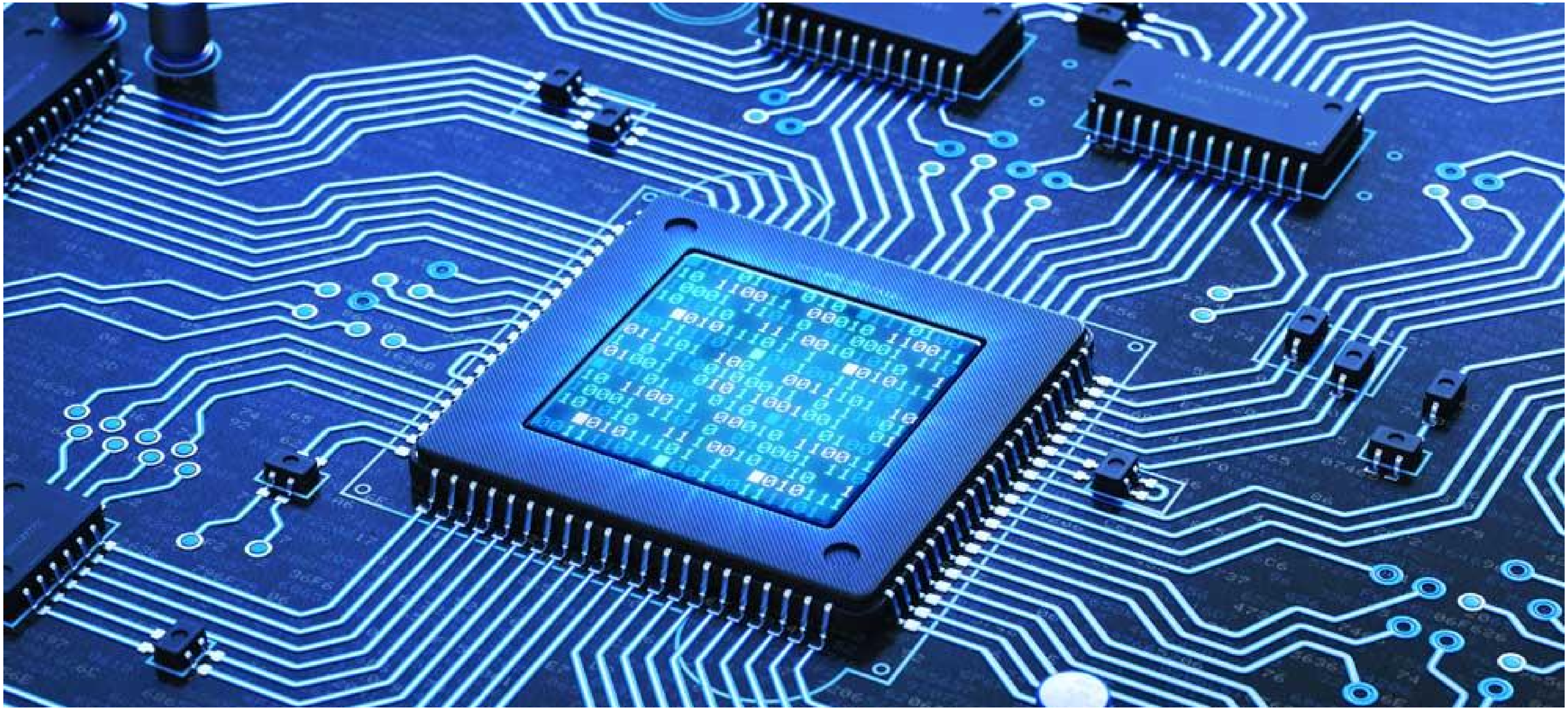
Session 1.6

Module 1b

Semiconductors, p-type and n-type Materials

Session 1.6: Focus

- Conductors, insulators and semiconductors
  - Atomic structure
  - Conductivity of copper
  - Conduction and valence bands
  - Resistivity (ρ)
- Intrinsic or pure semiconductors
  - Doping materials
  - Trivalent elements
  - Pentavalent elements
- Doped semiconductors
  - p-type and n-type
  - Types of doping



Conductors, Insulators and Semiconductors

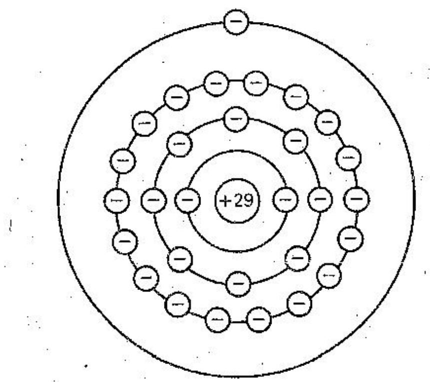
Conductors

- Good conductor of electricity.
- Offers almost **no resistance** to the **flow of current** of electrons.
  - **Resistivity** (**ρ**) of **Copper** (Cu) is **1.7 × 10^{-8} Ω-m.**
  - Resistance (**R**) = $\frac{\rho l}{A}$ ***l*** = length
    A = Cross-sectional area

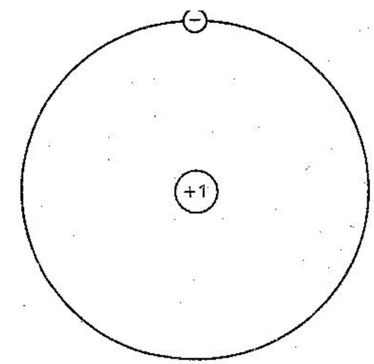
Copper – Atomic structure

Bohr Model

Copper (Cu)
No. of protons: 29
No. of electrons: 29
No. of neutrons: 35
Atomic number: 29



Copper (Cu) atom

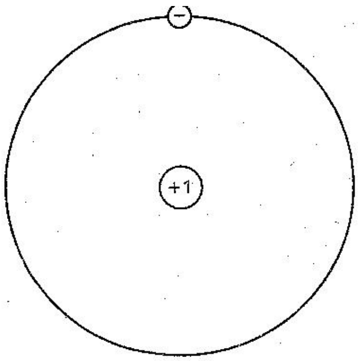


Copper core diagram

- In Electronics all that matter is in the **outer most orbit** which is called the **valence orbit.**
- Valence orbit **controls** the **electrical properties** of the atom.
- **Core** is defined as **nucleus** and **all** the **inner orbits.**
- **Core** of Copper is net **+ve**, because it has **29 protons** and **28 electrons.**
  - But, the **atom** is **electrically neutral** with **core + the valence electron.**

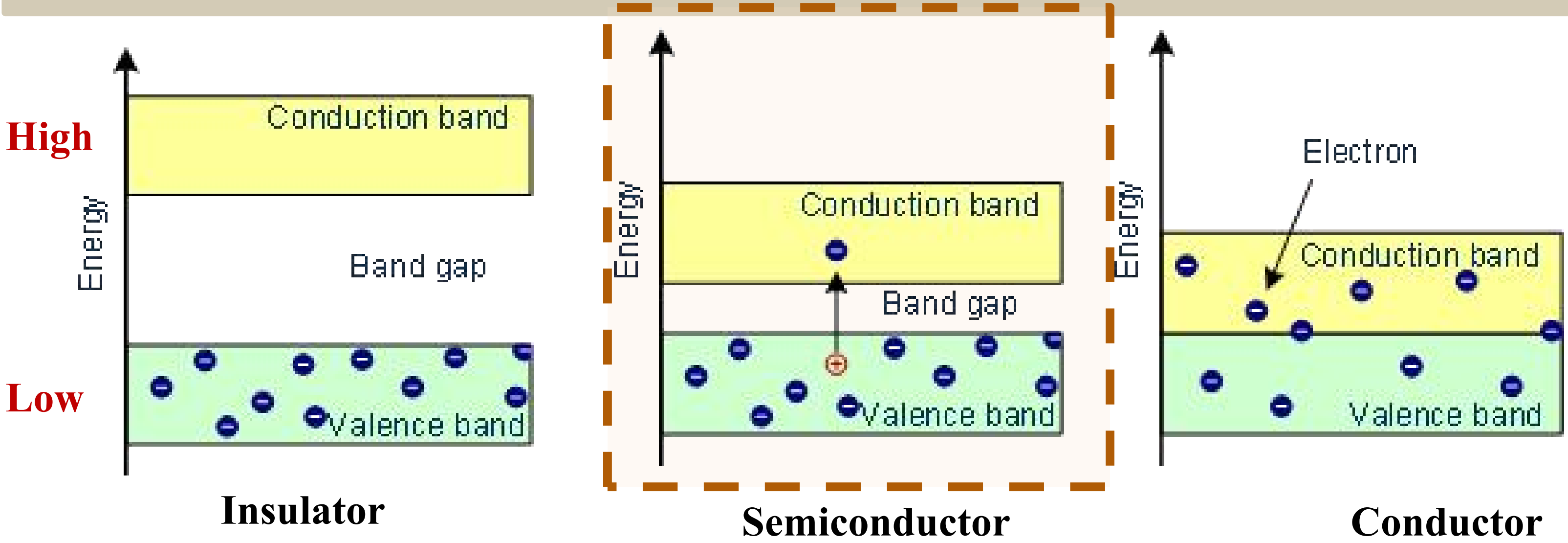
Why is Conductivity high for Cu?

- Since the attraction between the core and the single valence electron is very weak.
  - An outside force can easily dislodge this valence electron from the copper atom.



- Thus, **an valence electron** from **each atom** of **Cu** becomes a **free electron**, constituting **flow of current.**
  - **Valence electron** of **Cu** is also called as **free electron.**
  - **Copper** is a **good conductor** because of the presence of more free electrons.
- Other **good conductors** are:
  - **Silver** (Ag), **Gold** (Au), **Aluminum** (Al)

Conduction and Valence Bands



- Band structure shows the energy levels of electrons.
- **Electrons** in the **conduction band** have **higher energy** compared to the **electrons** in the **valence band.**
  - Electrons in conduction band have more kinetic energy to move around freely, because of reduced attractive force from the positively charged nucleus.
- **Band gap** is the **energy** an **electron** needs to **gain** to **move** into the **conduction band** from the **valence band.**

Insulators

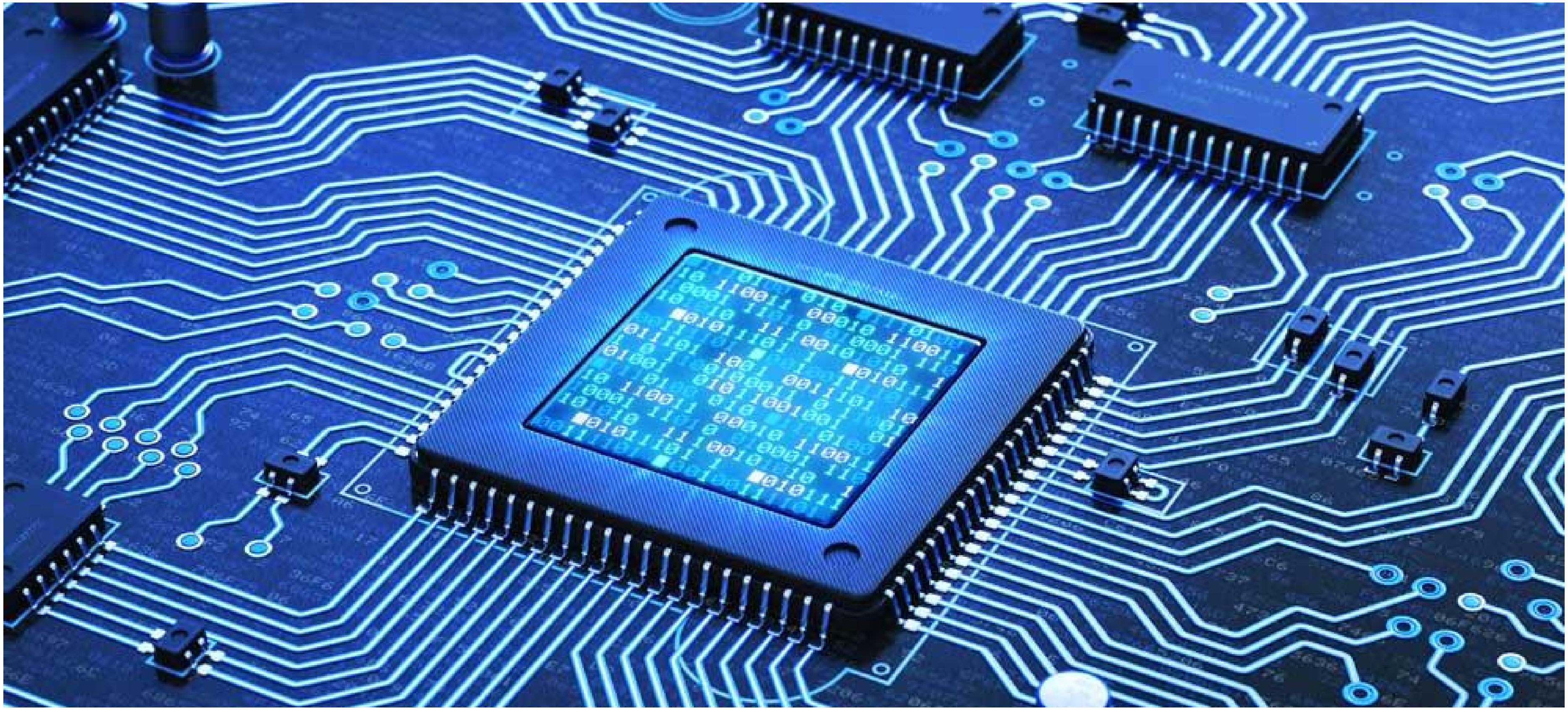
- It offers almost **infinite resistance** to the **flow of current** of electrons
  - **Glass resistivity** (ρ) - is **10^{12} Ω-m.**
- Need much higher energy to dislodge an electron from the **valence band** to **conductance band**, due to large gap between them.

Resistivity Comparison (ρ)

Material	Resistivity at 25^o C	Type of material
Silver	$1.6\ 10^{-6}$	Conductor
Silicon	55,000	Semiconductor
Germanium	55	Semiconductor
Mica	$2\ x10^{12}$	Insulator

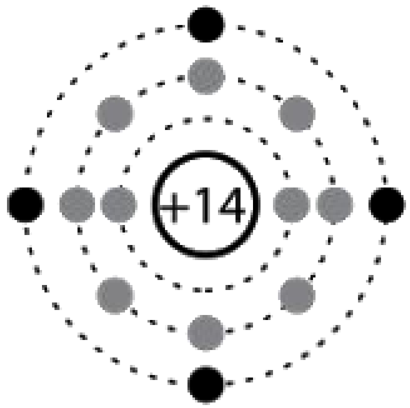
- **Semiconductors** have resistivity which is between the resistivities of conductors and insulators.
- **Electronic devices** are made of **semiconductors** due to this amazing property, which you will study further …

Note: Resistivity (ρ) is given here in **Ω cm**

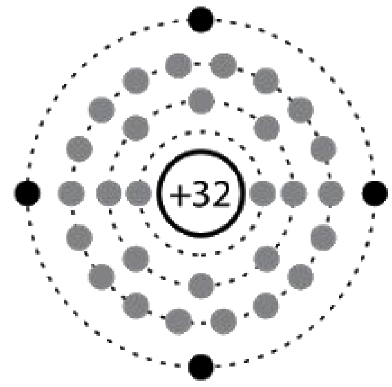


Intrinsic Semiconductors

Semiconductor Materials



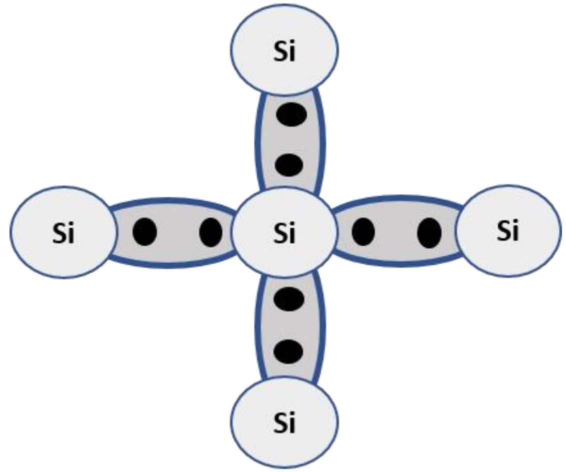
Silicon



Germanium

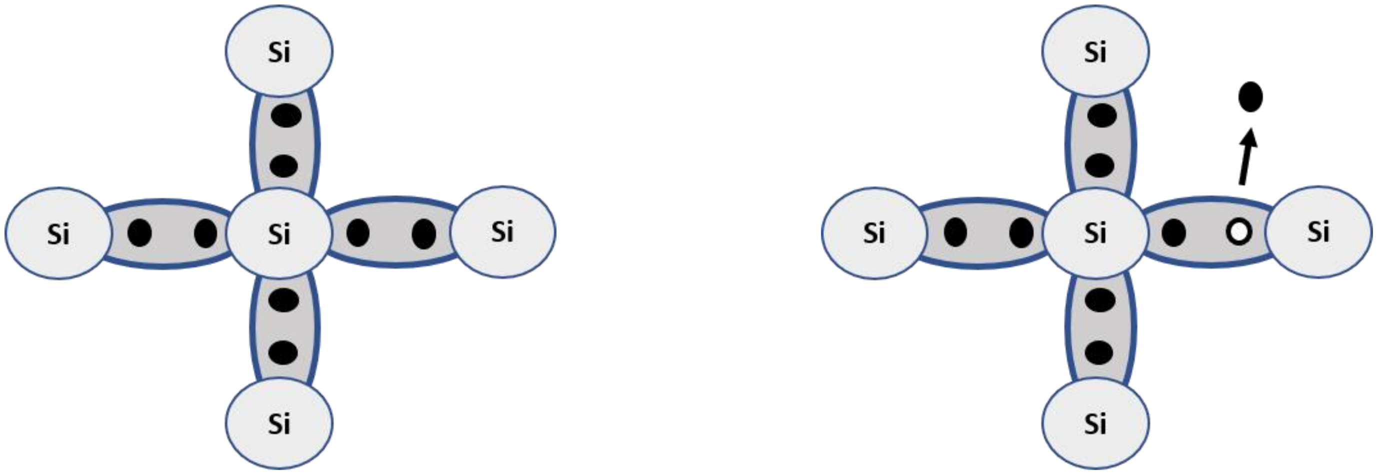
- **Atomic number** of **Silicon** (**Si**) = **14**
  - Stable electron configuration of **Si** is: **2-8-4**
- **Atomic number** of **Germanium** (**Ge**) = **32**
  - Stable electron configuration of **Ge** is: **2-8-18-4**

Intrinsic or Pure Semiconductor

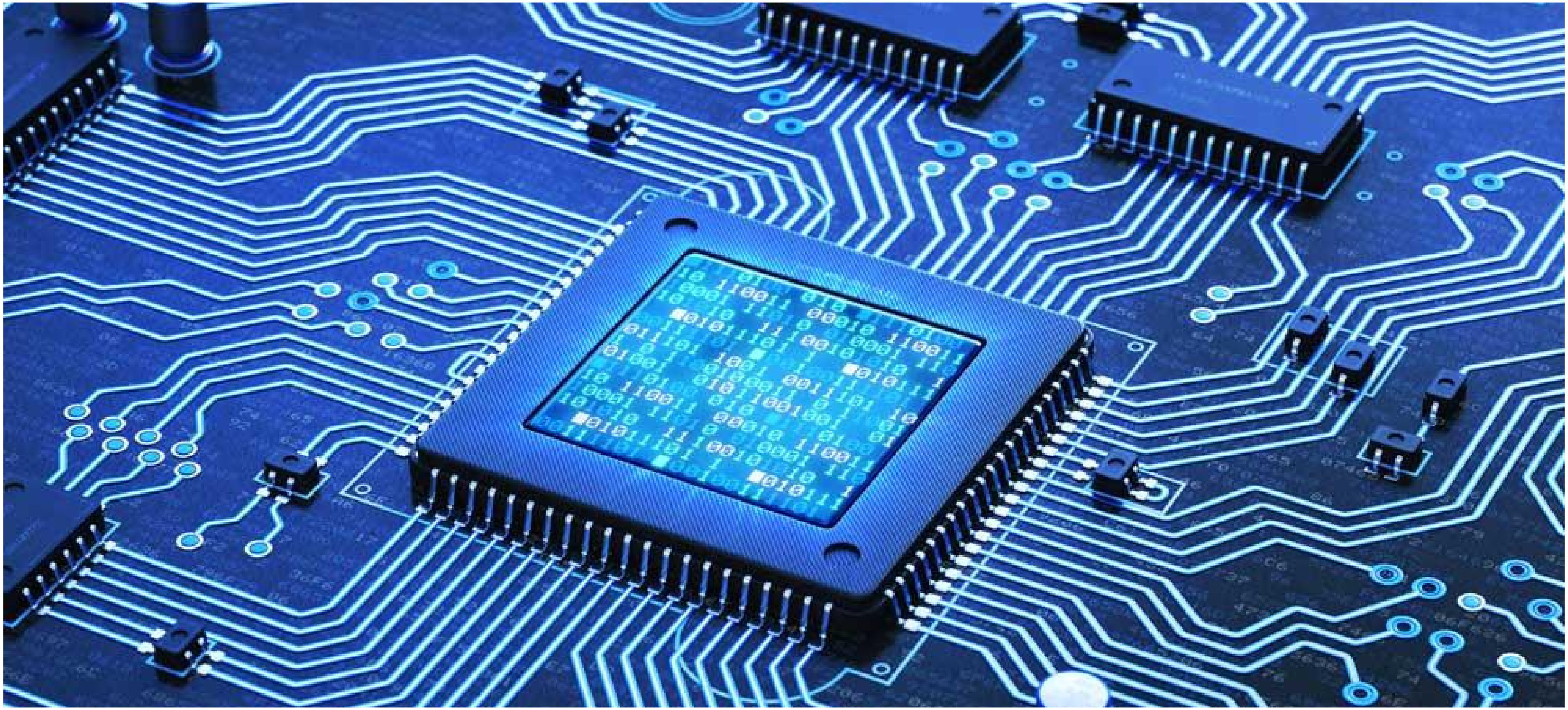


- An intrinsic semiconductor is an **undoped** or a **pure** semiconductor.
- **Undoped** means that the silicon material is not doped or mixed with any other materials or impurities.

Hole due to the Dislodging of an Electron

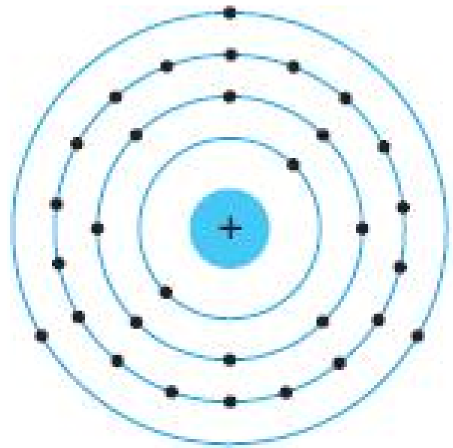


- In a pure silicon crystal, occasionally electrons from the valence band get dislodged due to heat or light.
- Then, the released electron gains enough energy to go into the conduction band, becoming a free electron.
- The departure of the electron creates a vacancy in the valence band called a **hole**.



Doping Materials

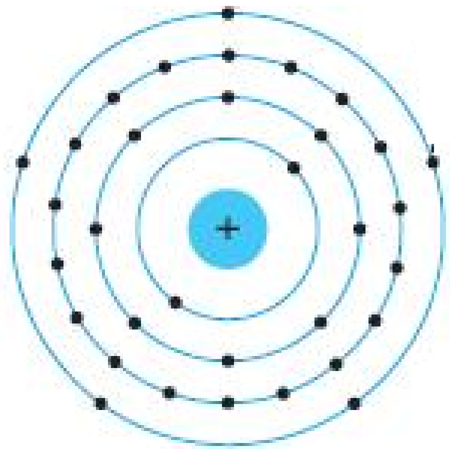
Trivalent Elements



Gallium

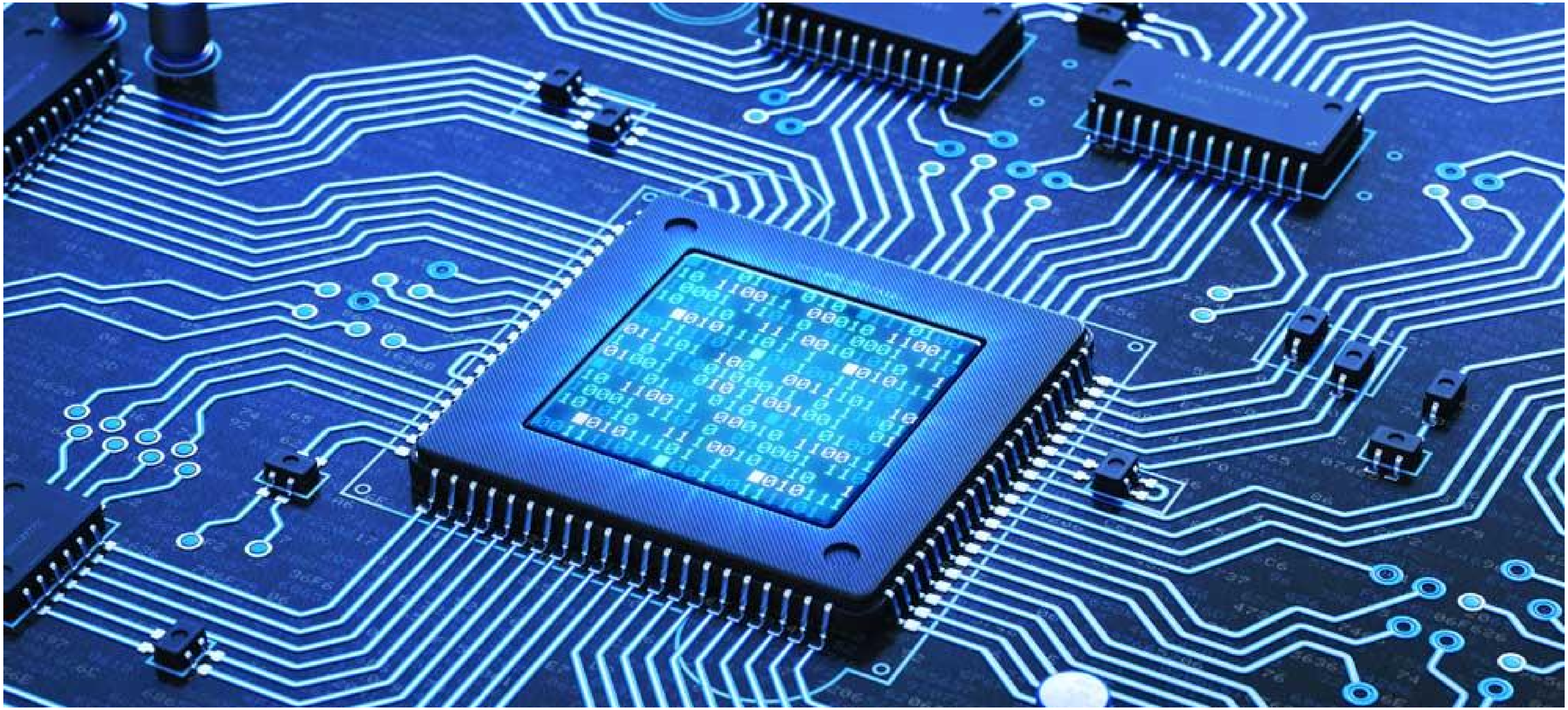
- **Atomic number** of **Gallium = 31** **Trivalent**
  - Stable electron configuration of **Ga** is: **2-8-18-3**
  - Other **trivalent** elements are: Aluminium, Boron and Gallium

Pentavalent Elements



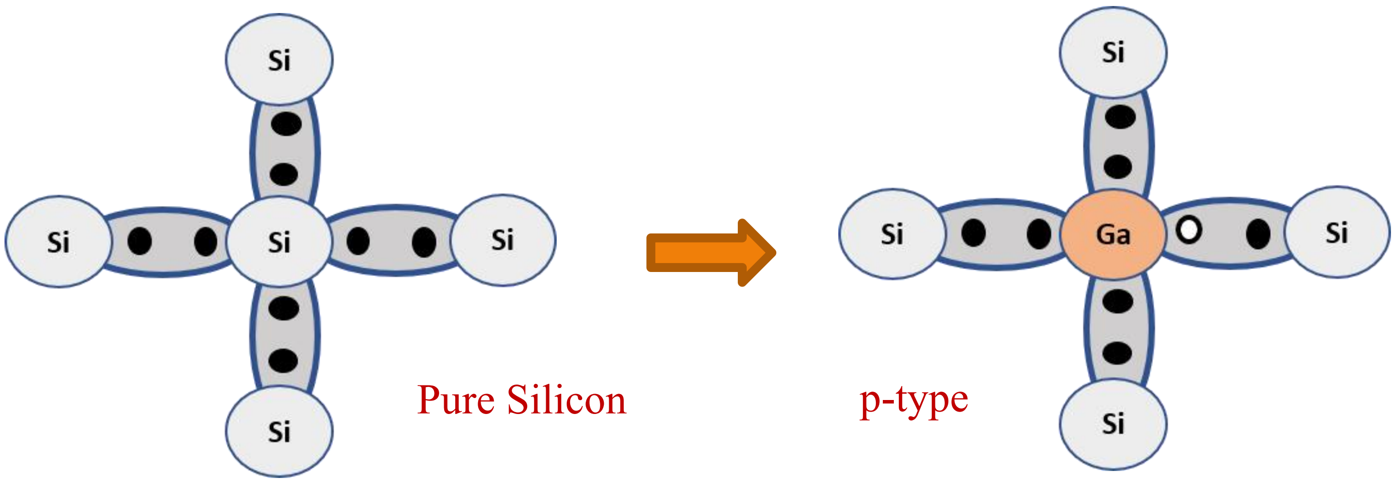
Arsenic

- **Atomic number** of **Arsenic = 33** **Pentavalent**
  - Stable electron configuration of **As** is: **2-8-18-5.**
  - Other **pentavalent** elements are: Arsenic, Antimony and Phosphorus.



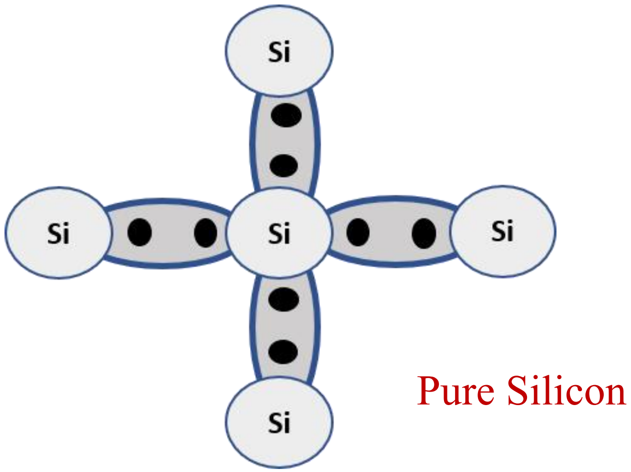
Doped Semiconductors

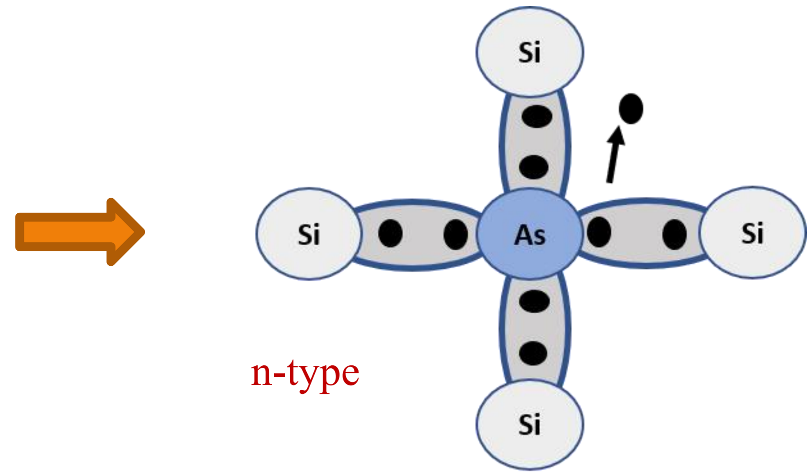
p-type Semiconductor



- **Doping** is the process of adding different materials (impurities) to a semiconductor materials (Si, Ge, etc.).
- When the Silicon is added with **trivalent** impurities (**Ga**, Gallium), each trivalent atom dislodges one silicon atom, thus adding a **hole**.
- Holes are nothing but absence of electrons, thus considered to be positively charged.
- So, **trivalent** elements are called as **p-type** materials.

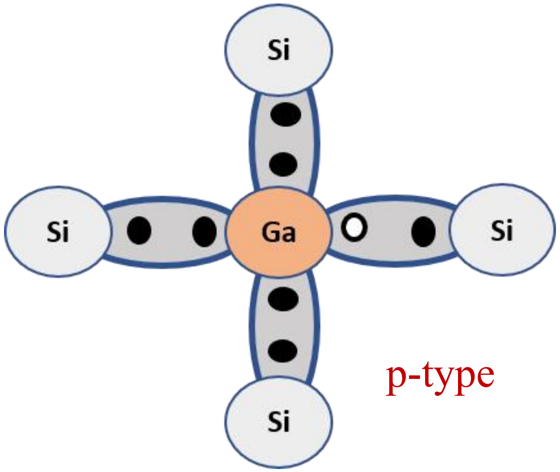
n-type Semiconductor



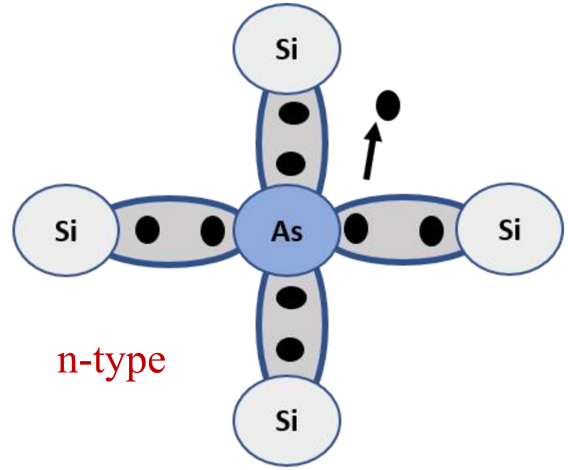


- When the Silicon is added with **pentavalent** impurities (**As**, Arsenic), each pentavalent atom dislodges one silicon atom, thus adding an **electron**.
- So, **pentavalent** elements are called as **n-type** materials.

Types of Doping



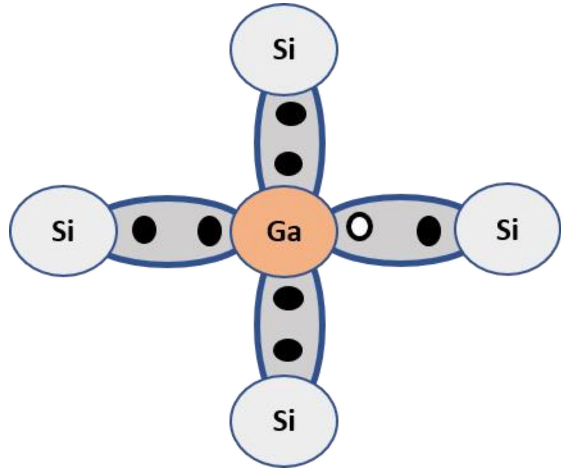
p-type



n-type

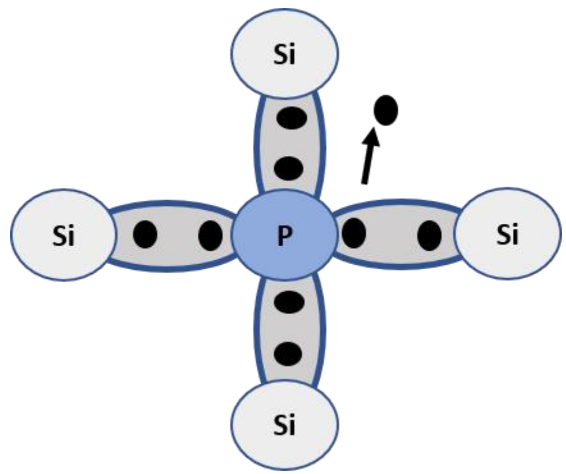
- Trivalent or Pentavalent elements are used to dope Semiconductor materials (Silicon or Germanium).
- Doping changes the electrical properties of semiconductor material, by adding either more free electrons or holes.
- **Pentavalent** elements are called **donor** impurities since they contribute one free electron for every atom added.
  - Whereas **trivalent** elements are called **acceptors** because it adds one hole per an atom of impurity.

p-type Material

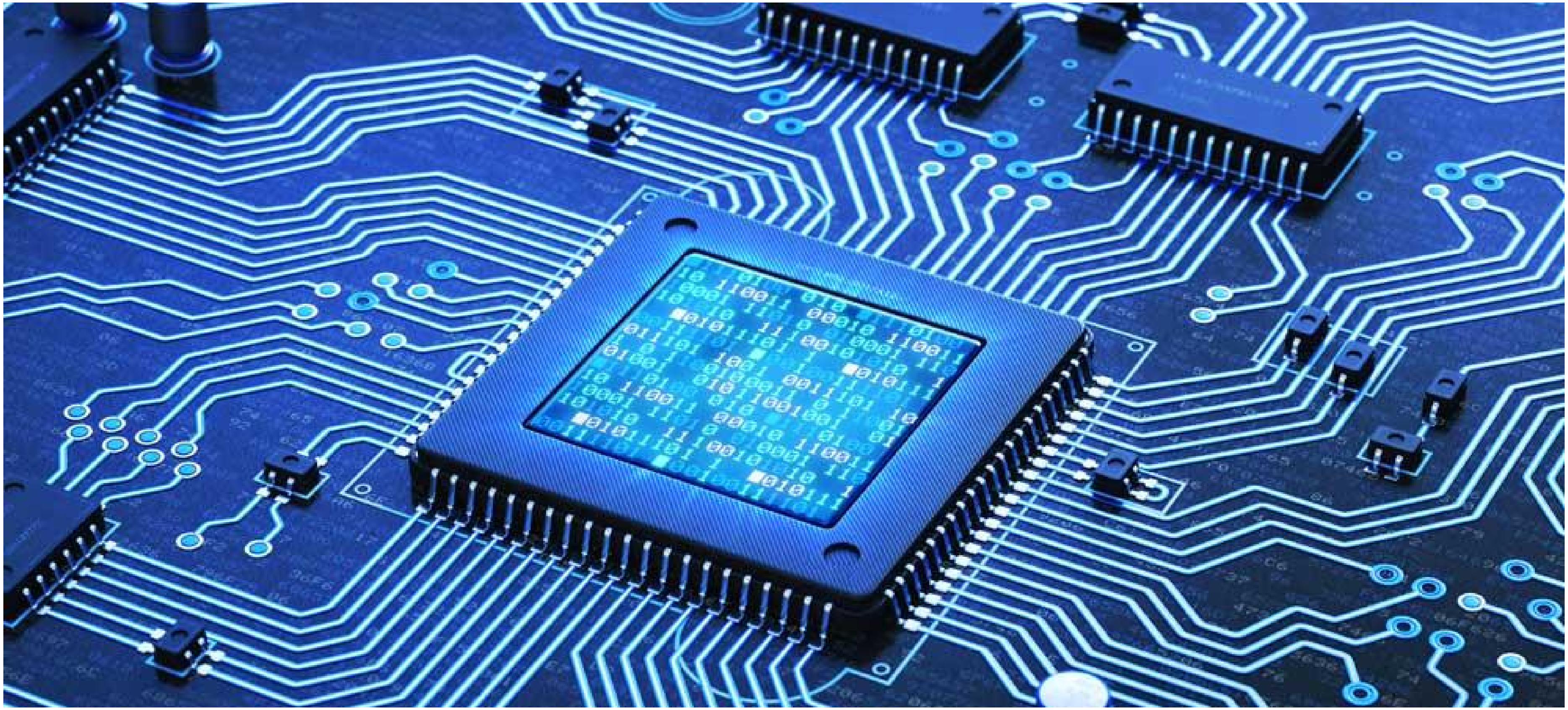


- In the **p-type** material **holes** are **majority carriers** and the **electrons** are **minority carriers**

n-type Material



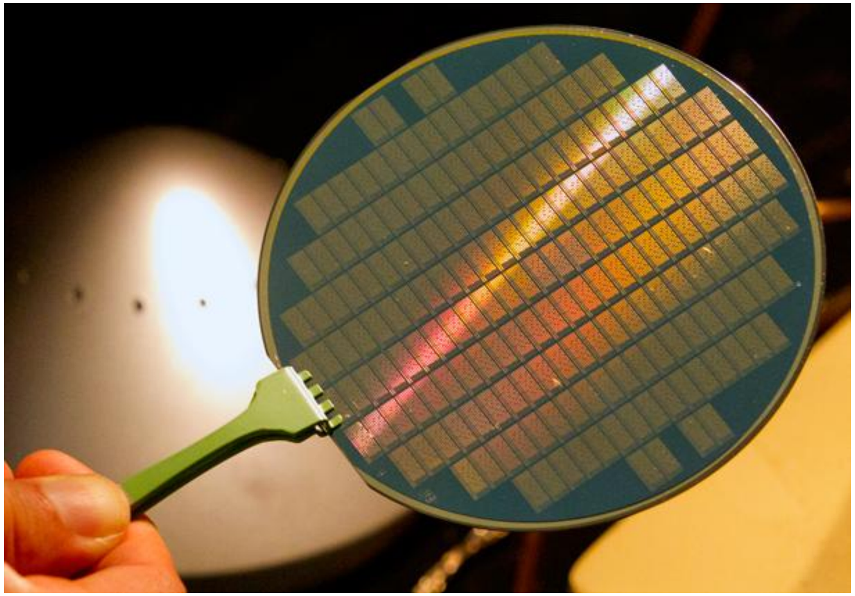
- In the **n-type** material **electrons** are **majority** carriers and the **holes** are **minority** carriers.



Silicon Wafer

Silicon Material to Wafer

Each individual squares are one independent Integrated Chip (**IC**) etched on to a thin **wafer** of **Silicon** material



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