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Basic Knowledge of Discrete Semiconductor Device

Chapter I

Basis of Semiconductors

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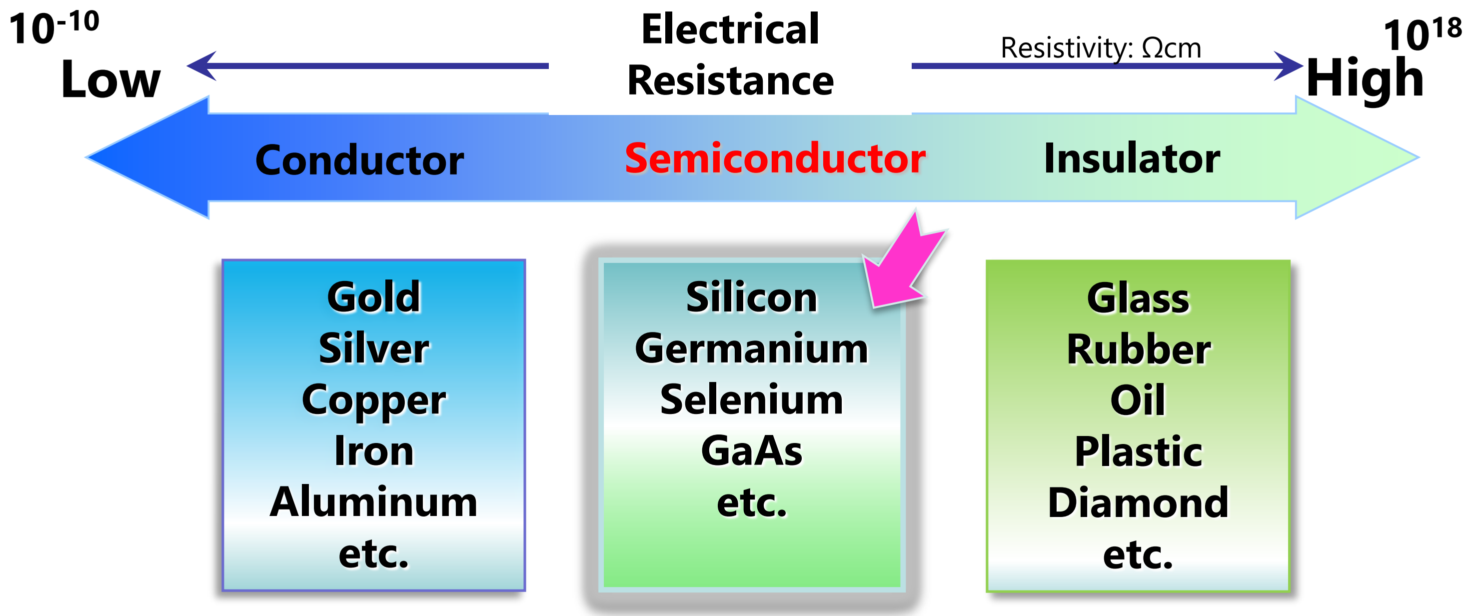
What is a Semiconductor?

A “semiconductor" is a substance with characteristics intermediate between those of a "conductor" that conducts electricity like metal and an "insulator" through which electricity hardly flows. The ease with which electricity flows is related to the magnitude of the substance’s electrical resistance. If the electrical resistance is high, the current hardly flows, and if the electrical resistance is low, the electric current flows easily.

When electrical conductivity is expressed by resistivity, semiconductors are distributed in the range of 10^{-4} to 10^{8} Ωcm, whereas conductors are 10^{-8} to 10^{-4} Ωcm and insulators are 10^{8} to 10^{18} Ωcm.



Semiconductor Materials

Silicon (Si) and germanium (Ge) are well-known semiconductor materials. When they are pure crystals, these substances are close to insulators (intrinsic semiconductors), but doping a small amount of dopant causes the electrical resistance to drop greatly, turning them into conductors.
Depending on the kind of dopant, n-type or p-type semiconductor can be made.
Semiconductors made of several elements are called compound semiconductors, as opposed to those made of a single element such as silicon semiconductors. There are combinations such as Group III and Group V of the periodic table, Group II and Group VI, Group IV, etc.

*Doping phosphorus (P) of **Group V** into silicon (Si) of **Group IV** makes **n-type semiconductor**.

*Doping boron (B) of **Group III** into silicon (Si) of **Group IV** makes **p-type semiconductor**.

Element(s)	Material
Single	Si, Ge
Compound	Group II-VI **ZnSe CdTe**
	Group III-V **GaAs InGaN InP**
	Group IV-IV **SiC**

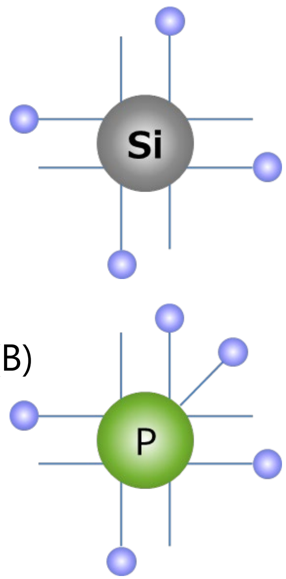
Group II	Group III	Group IV	Group V	Group VI
Be Beryllium	**B** Boron	**C** Carbon	**N** Nitrogen	**O** Oxygen
Mg Magnesium	**Al** Aluminum	**Si** Silicon	**P** Phosphorus	**S** Sulfur
Zn Zinc	**Ga** Gallium	**Ge** Germanium	**As** Arsenic	**Se** Selenium
Cd Cadmium	**In** Indium	**Sn** Tin	**Sb** Antimony	**Te** Tellurium
Hg Mercury	**Tl** Thallium	**Pb** Lead	**Bi** Bismuth	**Po** Polonium

n-type Semiconductor

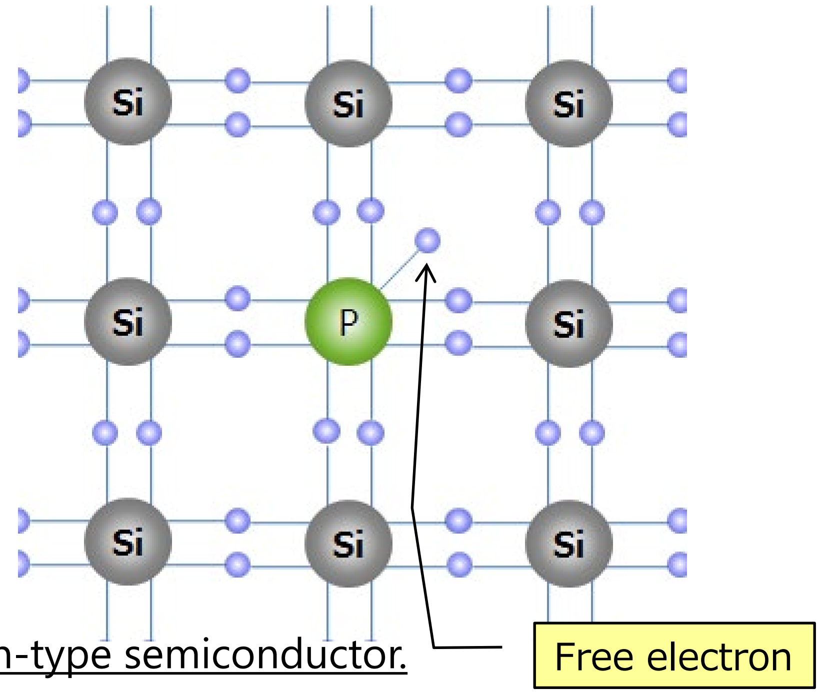
What is an n-type Semiconductor?
An n-type semiconductor is an intrinsic semiconductor doped with phosphorus (P), arsenic (As), or antimony (Sb) as an impurity. Silicon of Group IV has four valence electrons and phosphorus of Group V has five valence electrons.
If a small amount of phosphorus is added to a pure silicon crystal, one of the valence electrons of phosphorus becomes free to move around (free electron*) as a surplus electron. When this free electron is attracted to the "+" electrode and moves, current flows.

Silicon (Si): four valence electrons

Phosphorus: (B) five valence electrons



Adding phosphorus to pure silicon crystal results in a surplus electron. And it becomes a free electron.

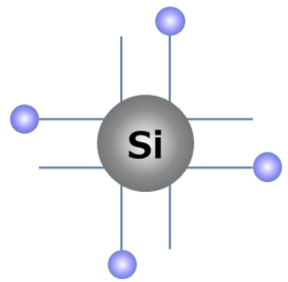


* This free electron is the carrier of an n-type semiconductor.

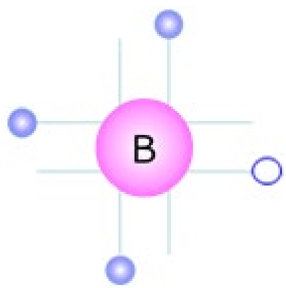
p-type Semiconductor

What is a p-type Semiconductor?
A p-type semiconductor is an intrinsic semiconductor doped with boron (B) or indium (In). Silicon of Group IV has four valence electrons and boron of Group III has three valence electrons. If a small amount of boron is doped to a single crystal of silicon, valence electrons will be insufficient at one position to bond silicon and boron, resulting in holes* that lack electrons. When a voltage is applied in this state, the neighboring electrons move to the hole, so that the place where an electron is present becomes a new hole, and the holes appear to move to the "–" electrode in sequence.

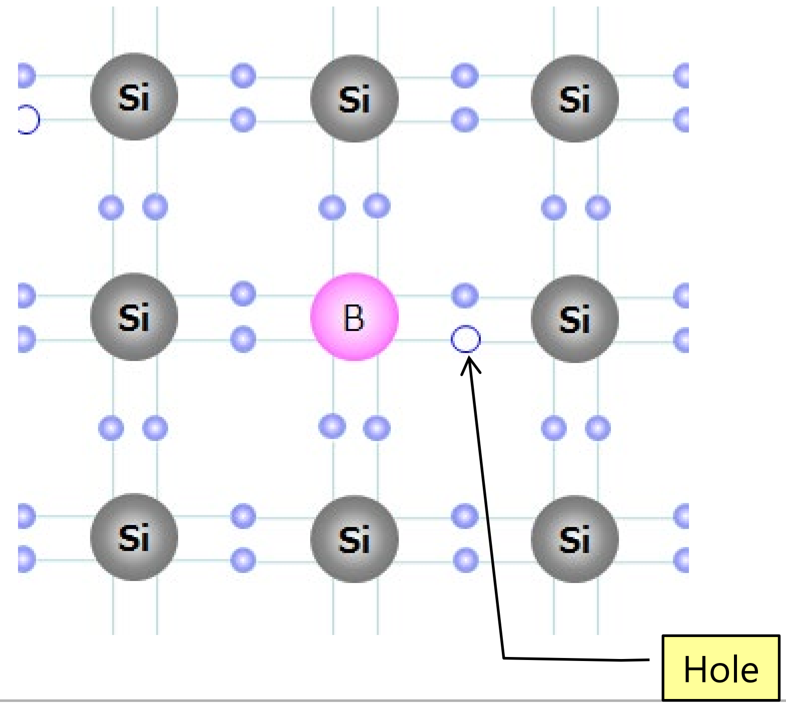
Silicon (Si):
Four valence electrons



Boron (B):
Three valence electrons



Adding boron to pure silicon crystal results in lack of an electron. And it becomes a hole.



* This hole is the carrier of a p-type semiconductor

What is a Compound Semiconductor?

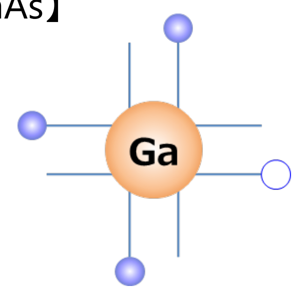
Apart from silicon, there are compound semiconductors that combine Group III and V elements and Group II and VI elements. For example, GaAs, InP, InGaAlP, etc. have been conventionally used for high-frequency devices and optical devices.
In recent years, InGaN has been attracting attention as a material for blue LEDs and laser diodes, and SiC and GaN as materials for power semiconductors have been noted and commercialized.

Typical compound semiconductors

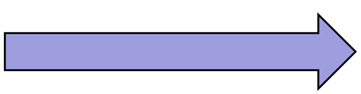
Group II-VI: ZnSe　 Group III-V: GaAs, GaN, InP, InGaAlP, InGaN　 Group IV-IV: SiC, SiGe

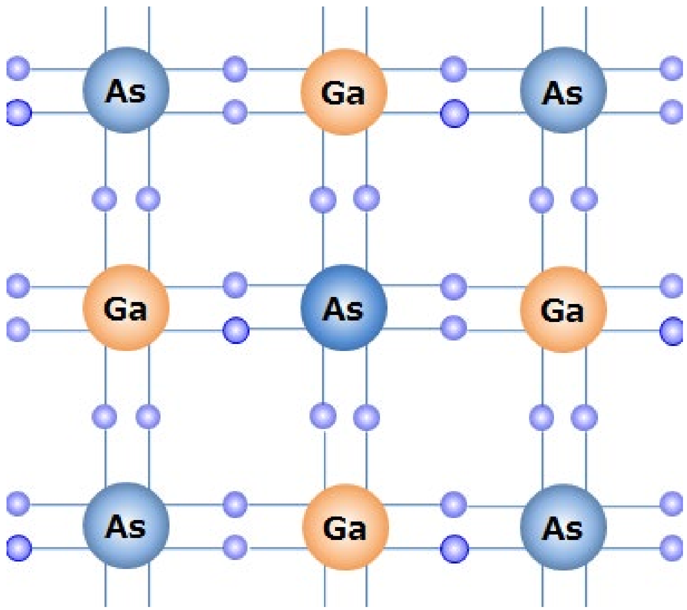
【Example of GaAs】

Gallium:
three valence electrons

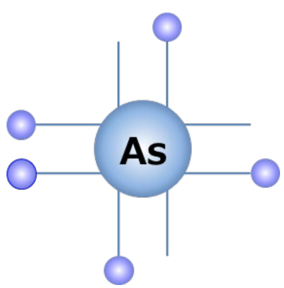


More gallium than arsenic makes
p-type semiconductor.





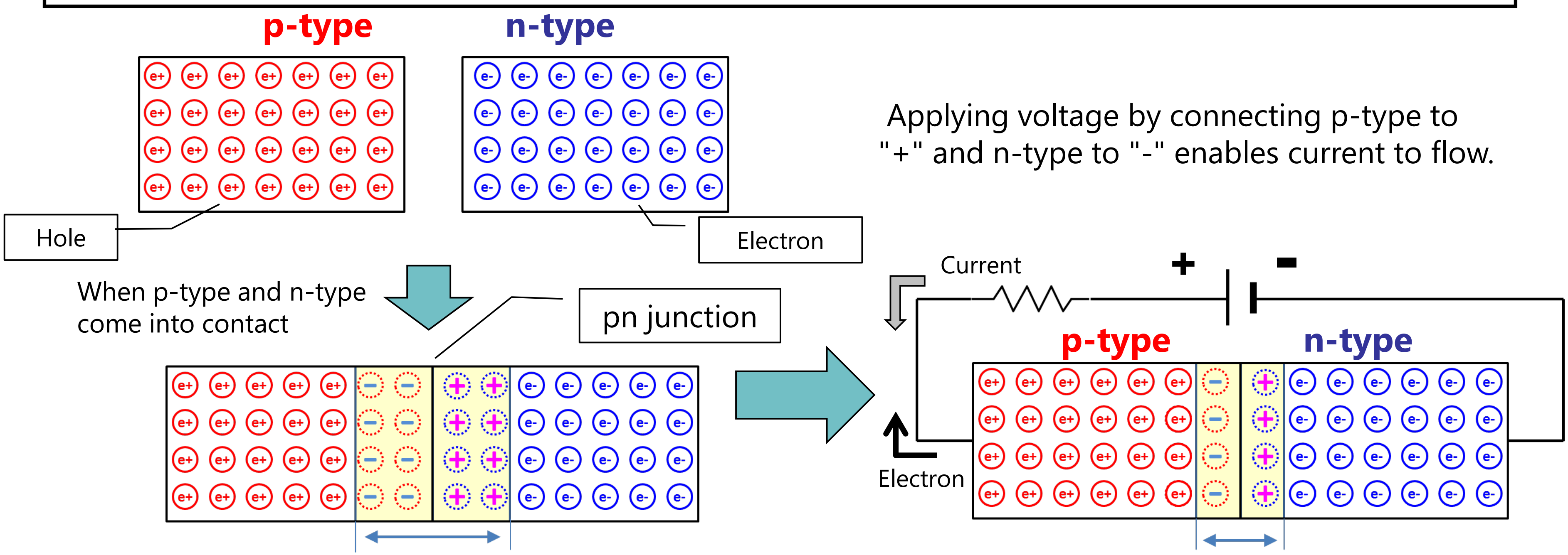
Arsenic:
five valence electrons



More arsenic than gallium makes
n-type semiconductor.

What is a pn Junction?

The contact surface between a p-type and an n-type semiconductor is called a PN junction. When p-type and n-type semiconductors are bonded, holes and free electrons, which are carriers, are attracted and bound and disappear near the boundary. Since there are no carriers in this area, it is called a depletion layer and it is in the same state as an insulator. In this state, connecting the "+" pole to the p-type region, connecting the "-" pole to the n-type region and applying a voltage cause electrons to flow sequentially from the n-type to the p-type region. The electrons will first disappear by combining with holes, but excess electrons move to the "+" pole and current will flow.



Depletion layer is made near the junction.

Depletion layer becomes narrower.

Types of Semiconductor Devices

Electronic parts using semiconductors are called semiconductor devices.
Many kinds of semiconductor devices have been developed in line with the expansion of application fields and the progress of electronic equipment. "Discrete semiconductors" are single devices with a single function, such as transistors and diodes. "Integrated circuits (ICs)" are devices with multiple functional elements mounted on one chip. Typical ICs include memories, microprocessors (MPUs), and logic ICs. LSIs raised the degree of integration of ICs. Classification by general function/structure is shown below.

Semiconductor Devices

Discrete devices

- Diodes
  - General-purpose rectifiers
  - High-speed rectifiers
  - Switching diodes
  - Zener diodes
  - TVS diodes
  - Variable-capacitance diodes
- Transistors
  - MOSFETs
  - Junction FETs
  - Bipolar transistors
  - IGBTs
- Thyristors
- Modules

Optical devices

- Light-emitting devices
  - LEDs
  - Laser diodes
- Photodetectors
  - Photodiodes
  - Phototransistors
  - Photothyristors
  - Phototriacs
  - Image sensors
- Composite optical devices
  - Photocouplers
  - Photorelays
  - Photointerrupters
- Optical communication devices

Microwave devices

- Discrete
  - High-frequency diodes
  - High-frequency transistors
- ICs
  - GaAs ICs
  - MMICs
- Modules

Sensors

- Sensor
  - Thermal sensors
  - Pressure sensors
  - Acceleration sensors
  - Magnetic sensors
  - Illuminance sensors
  - Accessing sensors

ICs

- Memories
  - Volatile memories
  - Non-volatile memories
- MPUs
- Logic ICs
  - General-purpose logic ICs
    - Bus switches
    - CMOS logic ICs
- Analog ICs
  - General-purpose linear ICs
    - Power Supply ICs
    - Op. Amps
    - Driver ICs
  - Mixed-signal ICs

Hybrid ICs

- Thin membrane
- Thick membrane

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