Tutorials

- There will be 4 tutorials for this course module;
- They are to be arranged in weeks 7, 9, 13, and 15 (this arrangement is tentative, as it may have to be changed depending on the development of the pandemic and the availability of TAs);
- Questions in homework assignments will be discussed in tutorials.

Office Hours

- I will arrange regular office hours on Microsoft Teams starting from week 4. It is probably going to be Tuesday 19:00 – 20:00 (Beijing time). I will confirm it in the next few days.
- If you have any questions on the course materials, any suggestions and feedback, and any issues related to a course module I teach, please feel free to drop by and discuss them with me.
- Language used during office hours: English (at least I will be speaking English).

EE204FZ
Lecture 2
p-n Junction Diodes

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Linear Devices

- Linear electronic devices are those whose output signal is a linear function of the input signal (or what we often say, a “straight line”).
- Important properties of linear devices:
  - Output signal is proportional to input signal;
  - Linear devices obey the superposition principle;
  - In AC operation, the input and output signals appear at the same frequency (no frequency conversion).
- Typical linear electronic devices include resistors, capacitors, and inductors when driven at low currents.

Nonlinear Devices

- Nonlinear devices are those whose output signal is not linearly proportional to the input signal.
- Important properties of nonlinear devices:
  - Output signal is not a linear function of input signal;
  - Nonlinear devices in general do not obey the superposition principle;
  - In AC operation, the input and output signals do not appear in the same frequency (frequency conversion).
- Typical nonlinear electronic devices include diodes, transistors, mixers, etc. All devices discussed in this course module are, strictly speaking, nonlinear devices (nonlinearity leads to functionality).

Questions

- Is a p-n junction a diode?

- Is a diode a p-n junction?

What is a Diode?

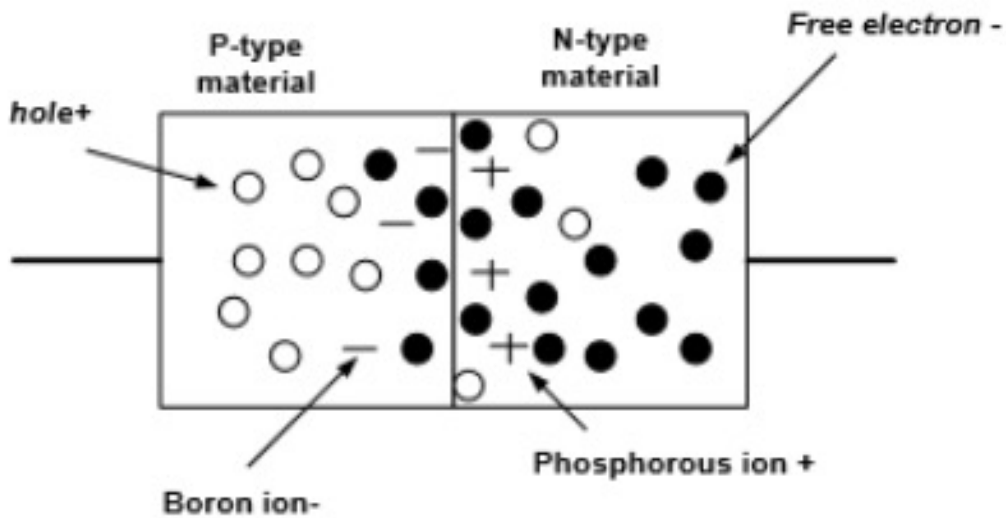
- A diode is a **two-terminal** electronic component that conducts current primarily in **one direction**.
- Diode has low (ideally zero) resistance in one direction and high (ideally infinite) resistance in the other direction.
- Types of diodes:
    - Thermionic diodes (vacuum tubes);
    - Semiconductor diodes:
        - Point-contact diodes;
        - Schottky diodes;
        - **p-n junction diodes.**

p-n Junction

- If a piece of intrinsic silicon is doped so that part is n type and the other part is p type, a p-n junction is formed at the boundary between the two regions (a p-n junction diode is created).
- The p region has many holes (majority carriers) and only a few free electrons (minority carriers) while the n region has many free electrons (majority carriers) and only a few holes (minority carriers).

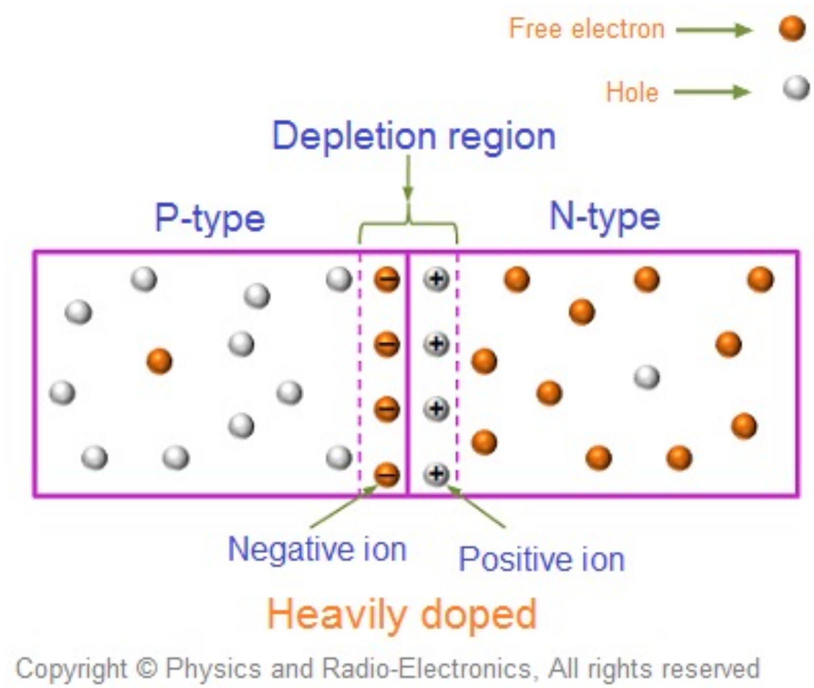
p-n Junction

- The free electrons in the n region randomly drift in all directions. At the instance of p-n junction formation, the electrons near the junction begin to diffuse across and combine with holes in the p region near the junction.
- Before the p-n junction is formed, both sides are neutral in terms of net charge.
- After the p-n junction is formed, the region in the n region which loses free electrons form a layer of positive charges. The region in the p region where holes are combining with electrons forms a layer of negative charges.
- These two layers of charge form the depletion region.



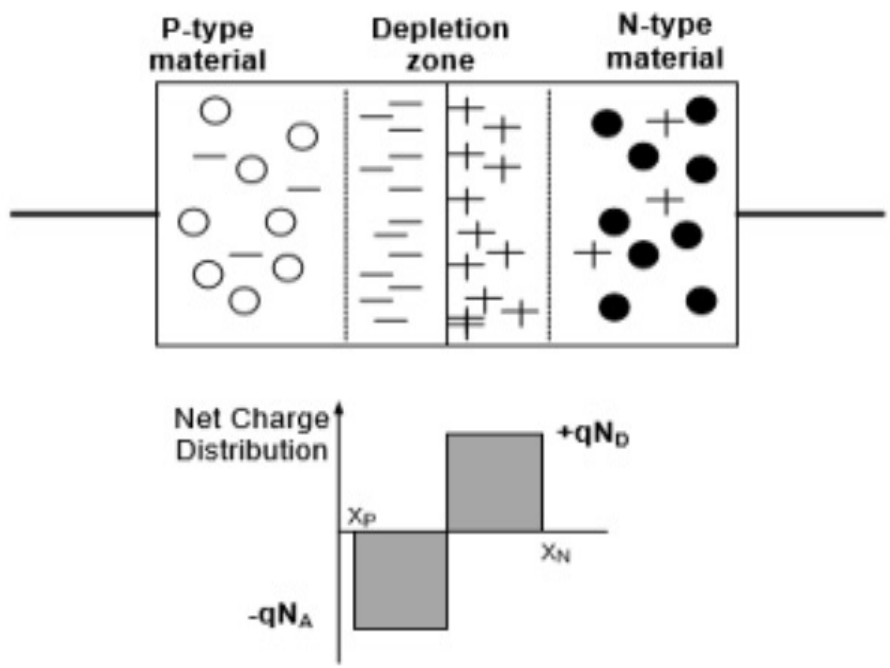
Depletion Region

- The depletion region is very thin (~1 μm) compared to the n and p segments. It acts as a barrier to the further movement of majority carriers.
- The barrier potential is the potential difference that leads to the electric field across the depletion region. It is measured in volts (V). A certain amount of electric potential difference equal to the barrier potential (and the correct polarity) must be applied to a p-n junction before electrons can flow across the junction.



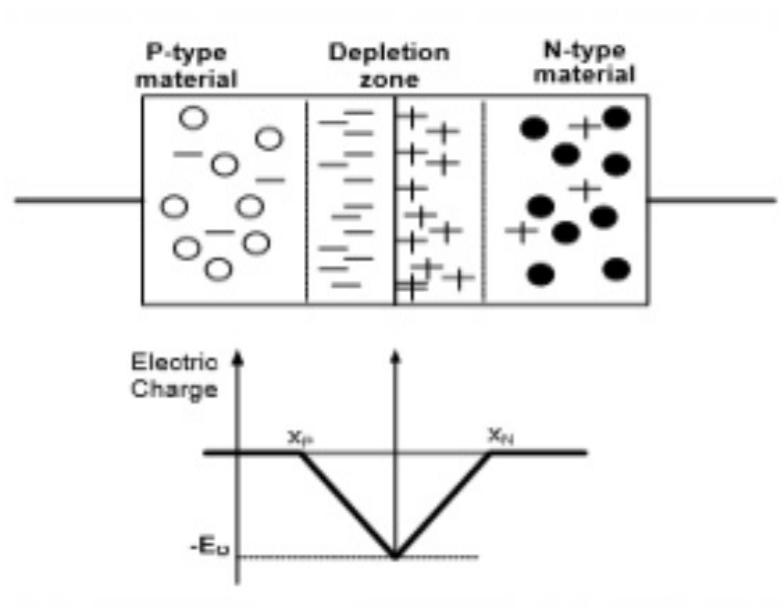
Depletion Region

- As an electric field exists across the junction and the positive and negative charge densities can be separated. The figure here shows the charge distribution in the p-n junction assuming that the p-type and the n-type materials are doped to similar levels. Note if the doping is equivalent on both sides then $x_p = x_N$.



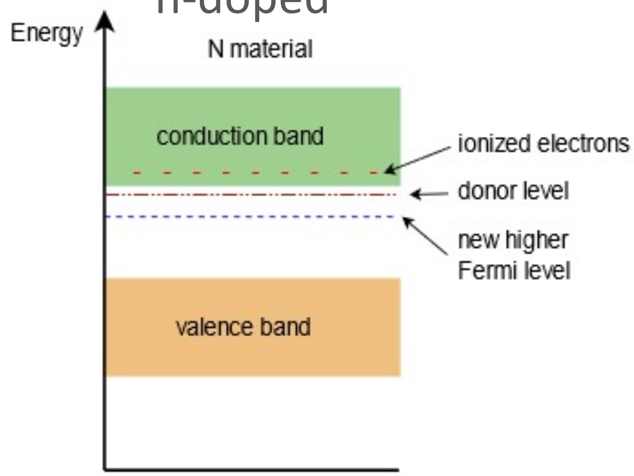
Width of the Depletion Region

- The depletion region extends into the p-type area to a point designated as x_P and extends into the n-type area to a point designated as x_N. The total width of the depletion region is given by $W = x_P + x_N$.
- The overall charge in the p-type area of the depletion region is equal to the number of ionised acceptor atoms (N_A) per unit area multiplied by the p-type area involved while the charge in the n-type area of the depletion region is equal to the number of ionised donor atoms (N_D) per unit area multiplied by the n-type area involved.

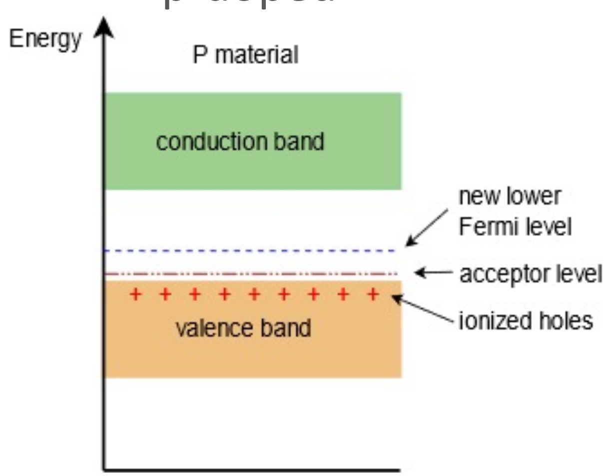


Band Diagram of a p-n Junction

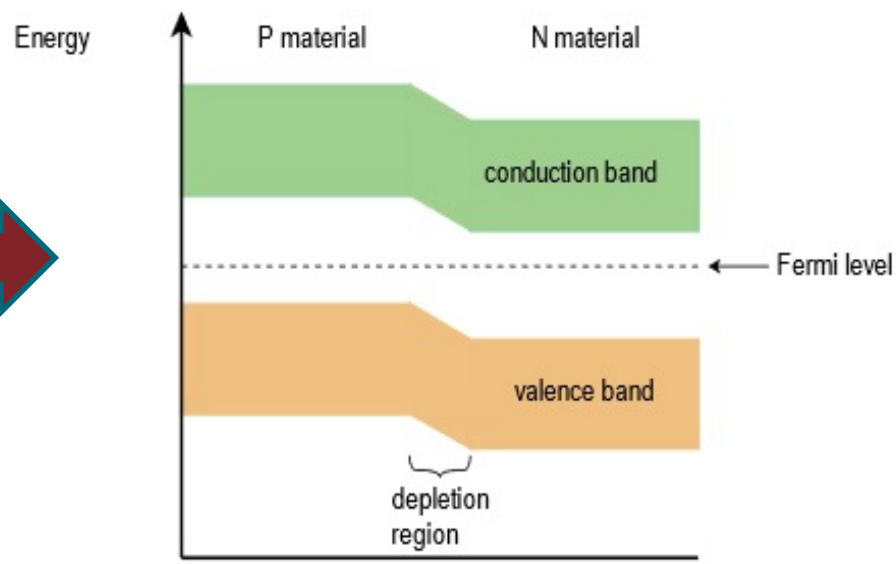
n-doped



p-doped



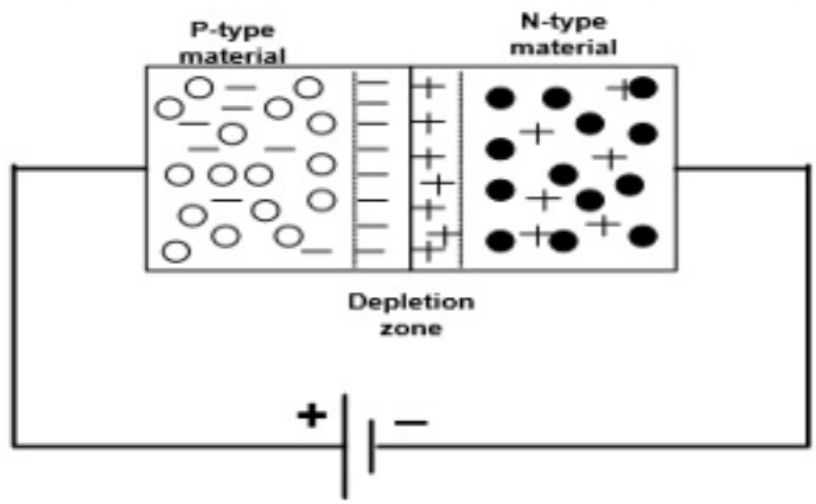
p-n junction



https://eng.libretexts.org/Bookshelves/Electrical_Engineering/

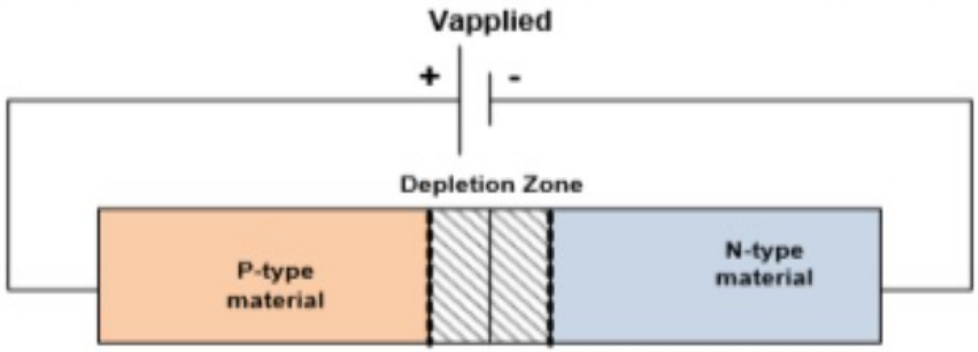
Forward Biasing a p-n Junction

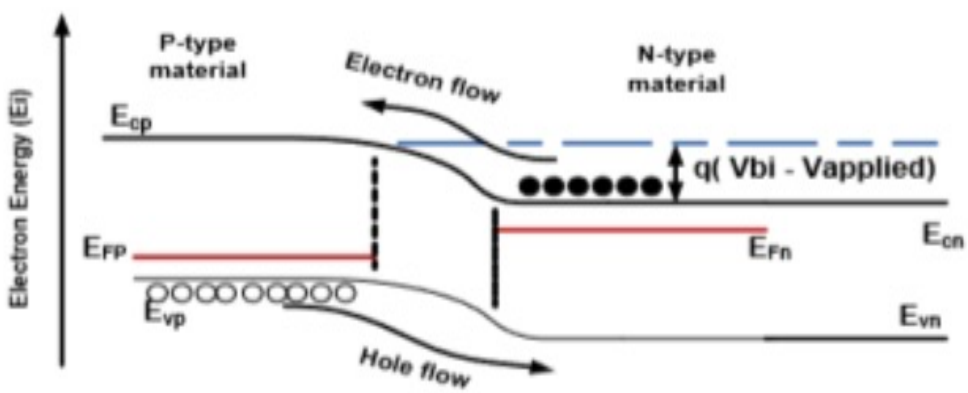
- When a forward bias voltage is applied to a p-n junction, the potential barrier of the p-n junction is lowered allowing electrons and holes to flow across the depletion region. When holes flow from the p-type material across the p-n junction into the n-type material they will then become minority carriers in the n-region. They will also be replenished by the positive terminal of the battery as they diffuse into the n-region. Similarly, when electrons flow from the n-type material across the p-n junction into the p-type material they will then become minority carriers in the p-region. They will also be replenished by the negative terminal of the battery connected to the n-type material and a major diffusion of electrons to the p-region takes place.



Forward Biasing a p-n Junction

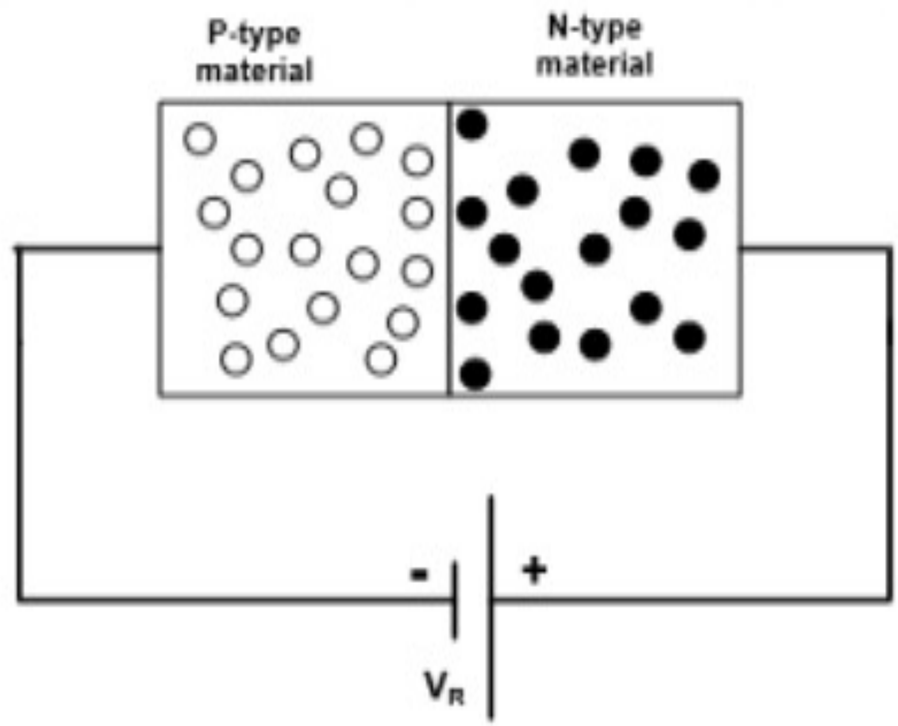
- Note that the potential barrier is much reduced and all the applied potential difference is across the junction.





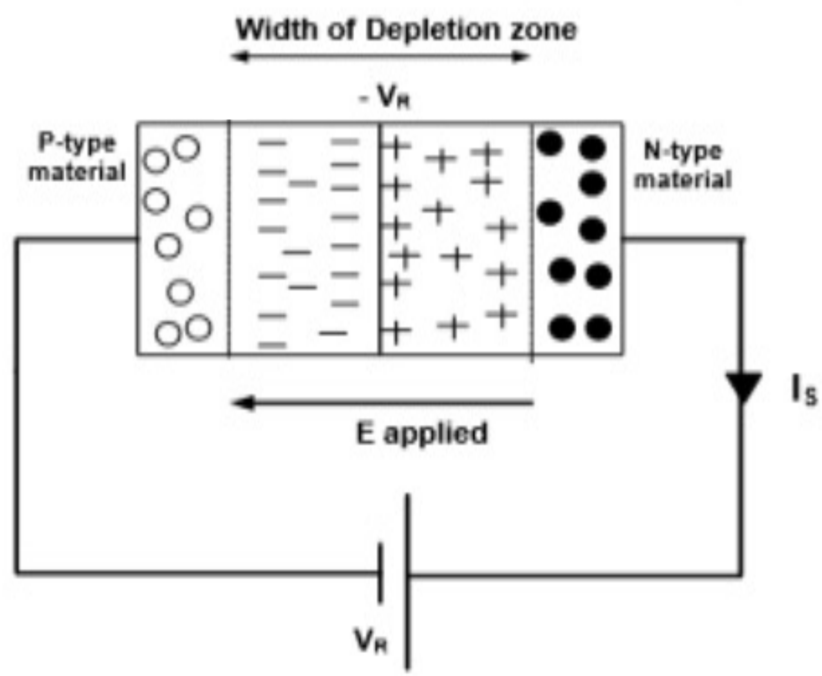
Reverse Biasing a p-n Junction

- Consider the case where a positive electric potential is applied to the n-region with respect to the p-region. In this case the diode is considered to have a reverse bias applied.



Reverse Biasing a p-n Junction

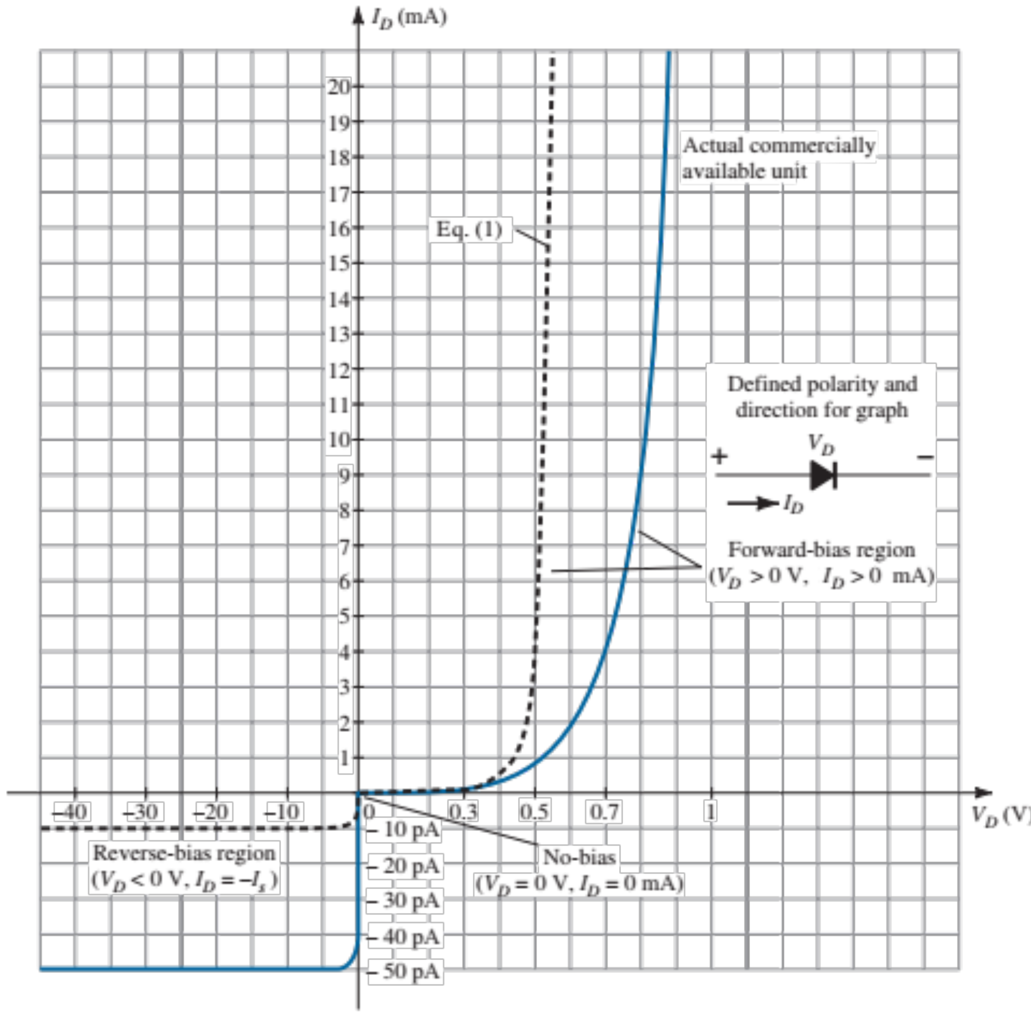
- The negative potential will cause holes in the p-type material to move away from the junction and towards the contact which will result in more exposed negative acceptor ions and thus creating a wider depletion zone. Similarly, the positive potential will cause electrons in the n-type material to move away from the junction and towards the contact which will result in more exposed positive donor ions, and thus creating a wider depletion zone on the n side as well.



(Shockley) Diode Equation

$$I_D = I_S(e^{\frac{V_D}{nV_T}}\text{-}1)$$

- I_D is the diode current;
- I_S is the reverse saturation current;
- V_D is the electric potential difference across the diode;
- n is called the ideality factor. It usually takes a value between 1 and 2 (at RT, $n \approx 1$ for Ge and $n \approx 2$ for Si);
- $V_T = \frac{k_B T}{q}$ (~26 mV at RT) is the thermal voltage and $q = 1.602 \times 10^{-19}$ C is the electron charge.



Summary: p-n Junction

- The p-n junction serves an important role in electronic systems and in the understanding of the behaviour of semiconductor devices. It is used in rectification, switching, photonics, as well as being a building block of the Bipolar Junction Transistor (BJT), the Junction Field Effect Transistor (JFET) and the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) which we will cover in this course!