Electronics Fundamentals

Lectures 2 and 3

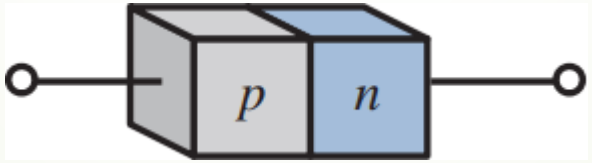
College of Cybersecurity Engineering

Second stage

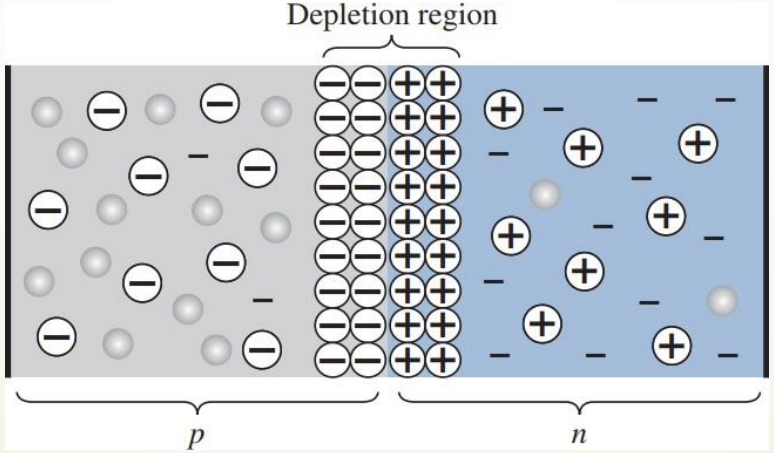
Presented by
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Semiconductor diode

- The semiconductor diode is created by simply joining an n-type and a p-type material together.
- In another word, The semiconductor diode is created by joining of one material with a majority carrier of electrons to one with a majority carrier of holes.



- At the instant the two materials are “joined” the electrons and the holes in the region of the junction will combine, resulting in a lack of free carriers in the region near the junction, as shown in the figure below.
- The only particles displayed in this region are the positive and the negative ions remaining once the free carriers have been absorbed.



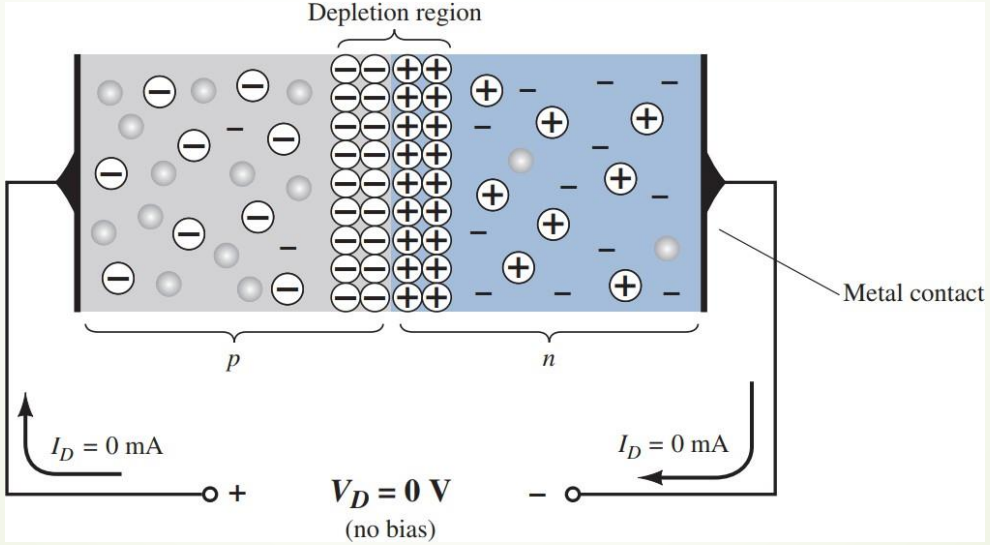
- This region of uncovered positive and negative ions is called the depletion region due to the “depletion” of free carriers in the region.

Biasing in Semiconductor diode

- The term bias refers to the application of an external voltage across the two terminals of the device to extract a response.
- In this course we will study three states of biasing:
  1. No – Biasing
  2. Forward – Biasing
  3. Reverse – biasing

No – Biasing (VD = 0)

- At no – biasing condition, the diode terminals are isolated from the polarity of the source as shown in the figure below

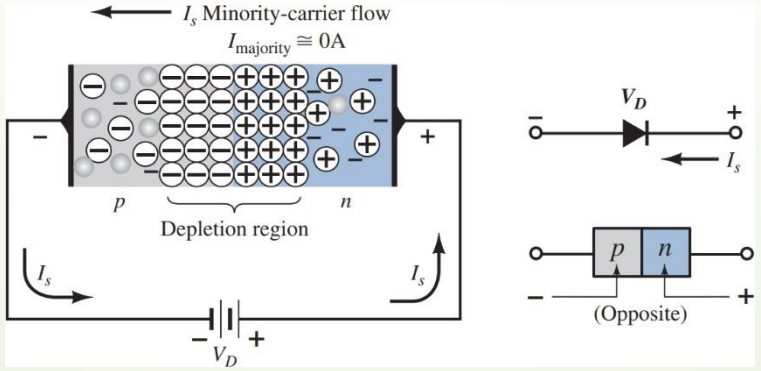


- Under no-bias conditions, any minority carriers (holes) in the n-type material that find themselves within the depletion region for any reason will pass quickly into the p-type material. The closer the minority carrier is to the junction, the greater is the attraction for the layer of negative ions and the less is the opposition offered by the positive ions in the depletion region of the n-type material.
- And also, any minority carriers (electrons) in the p-type material that find themselves within the depletion region for any reason will pass quickly into the n-type material.The closer the minority carrier is to the junction, the greater is the attraction for the layer of Positive ions and the less is the opposition offered by the negative ions in the depletion region of the p-type material.

- The majority carriers (electrons) of the n-type material must overcome the attractive forces of the layer of positive ions in the n-type material and the shield of negative ions in the p-type material to migrate into the area beyond the depletion region of the p-type material. However, the number of majority carriers is so large in the n-type material that there will invariably be a small number of majority carriers with sufficient kinetic energy to pass through the depletion region into the p-type material.
- Again, the same type of discussion can be applied to the majority carriers (holes) of the p-type material.

- As the magnitude of the both minority charges is the same, but in opposite direction, then the resultant of the net flow of the minority charges is zero
- In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero. In other words, the current under no-bias conditions is zero.

- If an external potential of ***V*** is applied across the *p*–*n* junction such that the positive terminal is connected to the *n*-type material and the negative terminal is connected to the *p*-type material as shown in Figure below, the number of uncovered positive ions in the depletion region of the *n*-type material will increase due to the large number of free electrons drawn to the positive potential of the applied voltage. For similar reasons, the number of uncovered negative ions will increase in the *p*-type material.

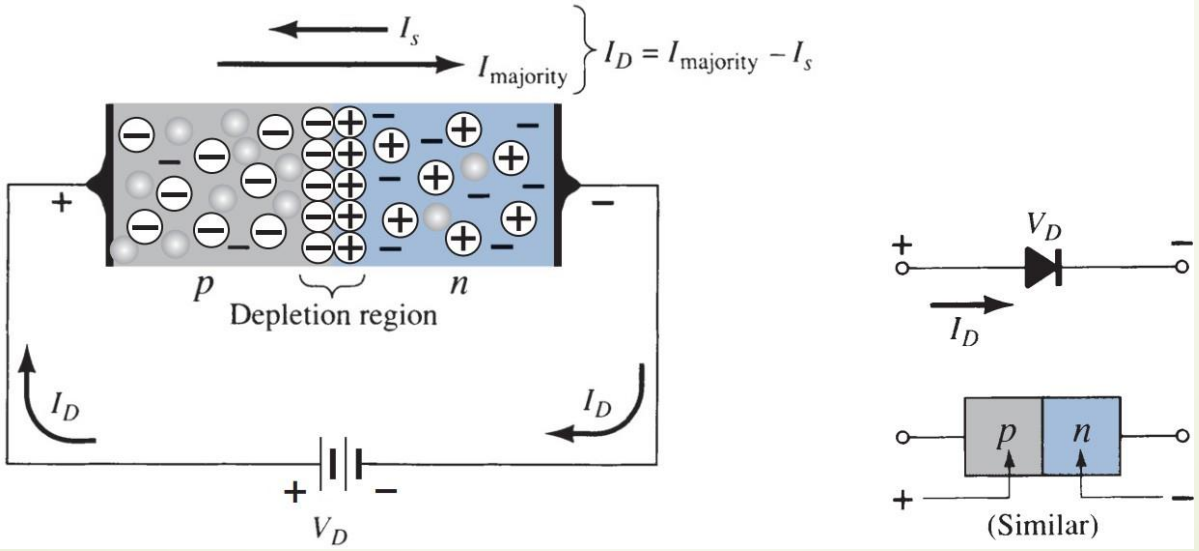


- This widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero.
- The number of minority carriers, however, entering the depletion region will not change, resulting in minority-carrier flow vectors of the same magnitude indicated with no applied voltage.
- The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is.

- The reverse saturation current is seldom more than a few microamperes and typically in nA, except for high-power devices.
- The term saturation comes from the fact that it reaches its maximum level quickly and does not change significantly with increases in the reverse-bias potential.
- Note, in particular, that the direction of Is is against the arrow of the symbol. Note also that the negative side of the applied voltage is connected to the p-type material and the positive side to the n-type material, the difference in underlined letters for each region revealing a reverse-bias condition.

Forward-bias Condition

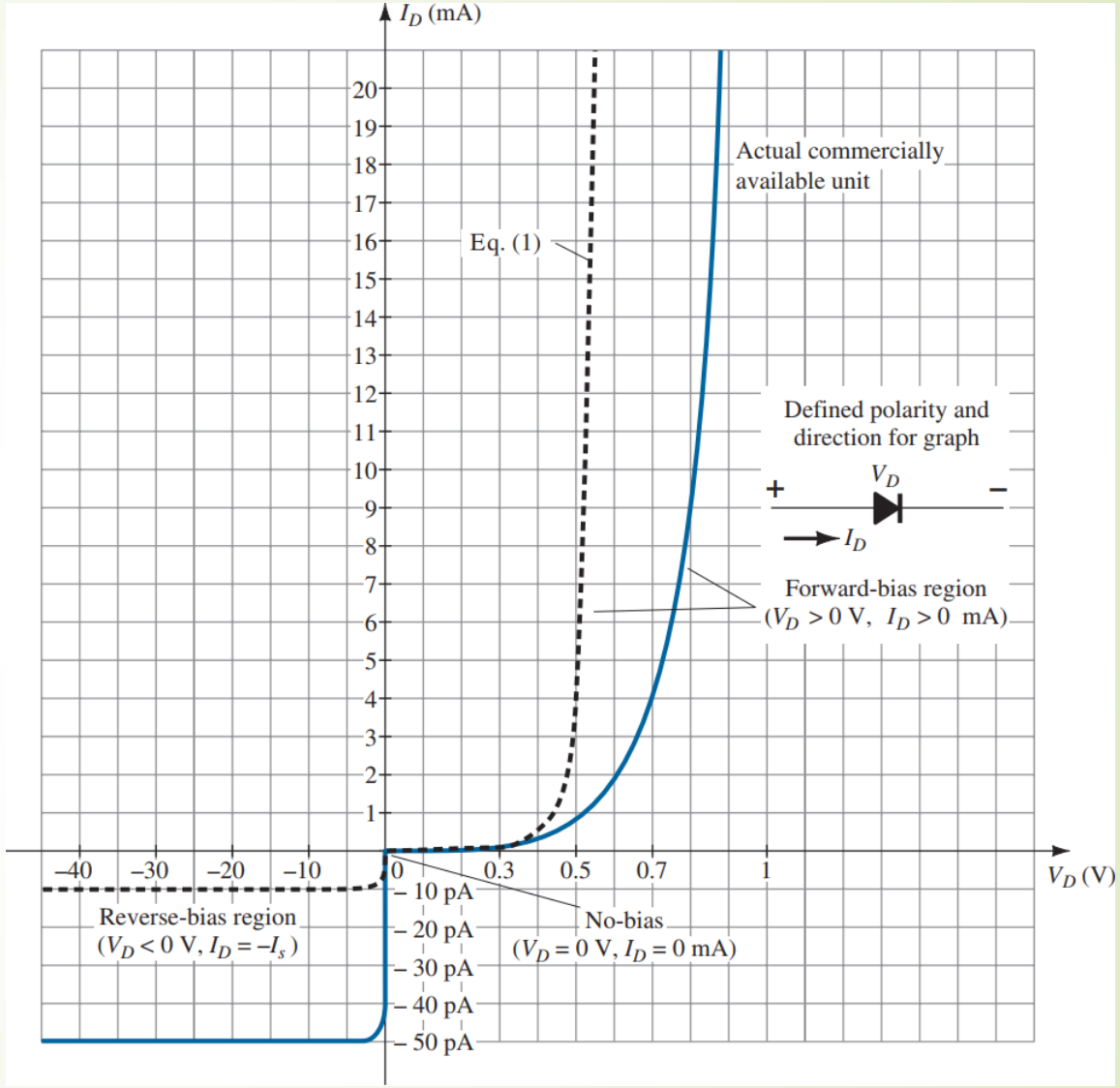
- A forward-bias or “on” condition is established by applying the positive potential to the p-type material and the negative potential to the n-type material as shown in figure below



- The application of a forward-bias potential VD will “pressure” electrons in the n-type material and holes in the p-type material to recombine with the ions near the boundary and reduce the width of the depletion region.
- The resulting minority-carrier flow of electrons from the p-type material to the n-type material (and of holes from the n-type Semiconductor diode material to the p-type material) has not changed in magnitude (since the conduction level is controlled primarily by the limited number of impurities in the material), but the reduction in the width of the depletion region has resulted in a heavy majority flow across the junction.

- An electron of the *n*-type material now “sees” a reduced barrier at the junction due to the reduced depletion region and a strong attraction for the positive potential applied to the *p*-type material.
- As the applied bias increases in magnitude, the depletion region will continue to decrease in width until a flood of electrons can pass through the junction, resulting in an exponential rise in current.

- The sharp change in direction of the curve at $V_D = 0$ V is simply due to the change in current scales from above the axis to below the axis.
- Note that above the axis the scale is in milliamperes (mA), whereas below the axis it is in picoamperes (pA).
- For the voltage VD there is also a measurable change in scale between the right-hand region of the graph and the left-hand region.
- For positive values of VD the scale is in tenths of volts, and for the negative region it is in tens of volts



Silicon semiconductor diode characteristics

Diode Current

- The diode current I_D can be expressed using Shockley's equation:

$$I_D = I_s(e^{\frac{V_D}{n V_T}} - 1)$$

I_S, is the reverse saturation current

V_D, is the applied forward-bias voltage across the diode

n, is an ideality factor (n=1 will be assumed throughout this text unless otherwise noted).

V_T, is the thermal voltage

- The thermal voltage can be determined using the following equation:

$$V_T = \frac{k\,T_k}{q}$$

- K, is Boltzmann's constant = 1.38×10^{-23}
- T_K, is the absolute temperature in kelvins = 273 + the temperature in °C
- q, is the magnitude of electronic charge 1.602×10^{-19}

- If we expand the equation of diode current, we will get:

$$I_D = I_s e^{V_D/nV_T} - I_s$$

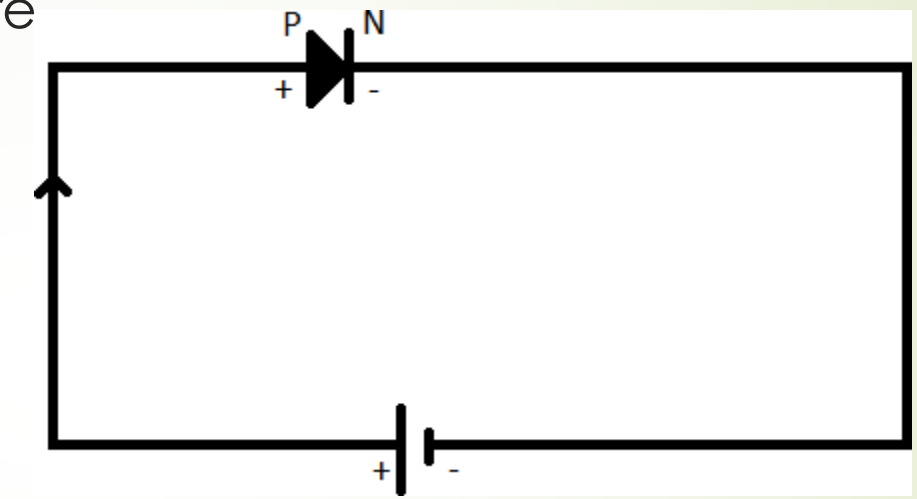
- For positive values of V_D, the first term of the above equation will grow very quickly and totally overpower the effect of the second term. The result is the following equation, which only has positive values and takes on the exponential format

$$I_D \cong I_s e^{V_D/nV_T}$$

- For negative values of V_D, the exponential term drops very quickly below the level of I, Semiconductor diode and the resulting equation for I_D is simply:

$$I_D \cong -I_s$$

Example: Find diode current if the applied voltage is 5v and the saturation current is 10 pA at room temperature



Solution:

$$I_D = I_s(e^{\frac{V_D}{n\,V_T}} - 1)$$

$$V_T = \frac{k\,T_k}{q}$$

$T_k = 273 + 27 = 300$ kelvin

$$V_T = \frac{1.38 \times 10^{-23} \times 300}{1.602 \times 10^{-19}} = 25.875\ mV$$

$$I_D = 10 \times 10^{-12}\left(e^{\left(\frac{5\ V}{25.875\ mV}\right)} - 1\right)$$

$$I_D =$$

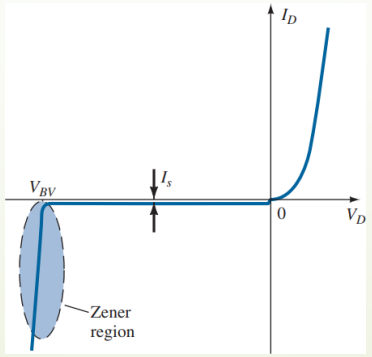
Example: Find diode current if the applied voltage is -5v and the saturation current is 10 pA at room temperature.

Solution:

$$I_D = -I_s$$

BREAKDOWN REGION

- In revers biasing, there is a point where the application large voltage with the reverse polarity will result in a sharp change in the characteristics, as shown in figure below.
- The current increases at a very rapid rate in a direction opposite to that of the positive voltage region.
- The reverse-bias potential that results in this dramatic change in characteristics is called the *breakdown potential* and is given the label V_{BV}.
- This sharp change in the characteristic at any level is called *the Zener region.*



THANK YOU FOR YOUR ATTENTION