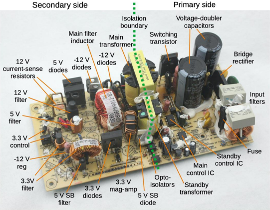

Characteristics of Junction Diodes

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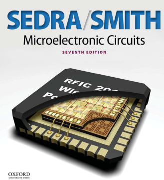
Readings

- Section 4.2 on pages 184-190
- Example 4.3 on page 187



[1] Readings are based on Sedra & Smith (2014), Microelectronic Circuits 7th edition.

[2] Bold reading section are mandatory. Other sections are suggested but not required readings

Background

- Diodes are commonly based on pn junction technology[1]
- As shown in Fig. 1, the characteristic curve consists of three distinct regions:
  - The forward-bias region when $v > 0$
  - The reverse-bias region when $v < 0$
  - The breakdown region $v < V_{ZK}$ (i.e., $v \ll 0$)

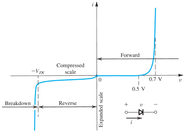


FIG 1. A detailed $i - v$ characteristic of a silicon junction diode.

[1] In-depth knowledge on the structure and operation of the pn junction—which is a basic semiconductor structure that implements the diode and plays a dominant role in transistors—has been covered in your previous courses and is covered in details in chapter 3 of the textbook.

The forward bias region

The forward bias region

- The i–v relationship is closely approximated by Equation (1)

$$i = I_s\left(e^{v/V_T} - 1\right) \quad (1)$$

where:

- I_s is the saturation current (also called the scale current), $I_s \approx 10^{-15}A$[1]
- V_T is the thermal voltage, $V_T = k \cdot T/q = 0.0862T \approx 25mV$ at $T = 25\,°C$
- k is the Boltzmann's constant, $k = 8.62 \times 10^{-5} eV/K = 1.38 \times 10^{-23} joules/kelvin$
- T is the absolute temperature in Kelvins
- q is the magnitude of electronic charge, $q = 1.6 \times 10^{-19}$ coulomb

- In the forward region, since $i \gg I_S$, Equation (1) can be simplified as

$$i \approx I_s \cdot e^{v/V_T} \quad (2)$$

The forward bias region

- I_s is not a constant and varies with temperature. As a rule of thumb, I_s doubles in value for every 5 °C rise in temperature.
- Since both I_s and V_T are functions of temperature, the forward i–v characteristic varies (as shown in Fig. 2)
- At a given constant diode current, the voltage drop across the diode decreases by approximately 2 mV for every 1 °C increase in temperature.
- The change in diode voltage with

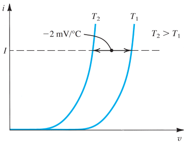


FIG 2. Diode temperature dependence
At a constant current, the voltage drop decreases by approximately 2mV for every 1 °C increase in temperature.

Effect of current flow

The current i has a very small effect on the forward biasing voltage, v

- Consider two currents I_1 and I_2 shown in

$$I_1 = I_s \cdot e^{V_1/V_T} \quad (4)$$

$$I_2 = I_s \cdot e^{V_2/V_T} \quad (5)$$

- Dividing Equation (5) with Equation (4) gives

$$\frac{I_2}{I_1} = \frac{I_s \cdot e^{V_2/V_T}}{I_s \cdot e^{V_1/V_T}} = e^{(V_2 - V_1)/V_T} \quad (6)$$

- Equation (6) can be re-written as

$$V_2 - V_1 = V_T \cdot ln\left(I_2/I_1\right) \quad (7)$$

- Equation (7) can be written in term of base 10 logarithms as

$$V_2 - V_1 = 2.3V_T log_{10} I_2/I_1 \quad (8)$$

Effect of current flow

From equation Equation (8), one can conclude that:

- If $I_2 = 10I_1$, the diode voltage drop changes by only $V_D = 2.3V_T \approx 60mV$
- If $I_2 = 100I_1$, the diode voltage drop changes by only $V_D = 2.3V_T \approx 115mV$
- In short, the change in current has a very small impact on the voltage v
- The *i*-*v* relationship is best plotted on a semilog graph, with a vertical linear axis for v and a horizontal logarithmic axis for i. The resulting graph would be a straight line with a slope of 60mv per decade of current
- An *i*–*v* characteristic in the forward region (Fig. 1) shows that the current is negligibly small for $v < 0.5V$. This value is called the cut-in voltage.
- Cut-in voltage is voltage, below which, minimal current flows, and is approximately equal to 0.5V

The Reverse-bias region

The Reverse-bias region

- The reverse-bias region of operation is entered when $v < 0$.
- The *i-v* relationship, for negative voltages with |v| > VT (25mV), is approximated by Equation (9)

$$\begin{aligned} i &= -I_s \cdot e^{-|v|/V_T} \\ &= -I_s \left(\frac{1}{e^{|v|/V_T}} \right) \end{aligned} \tag{9}$$

- When $v \gg V_T$, the exponential term becomes negligibly small compared to unity, and the diode current becomes

$$i \approx -I_s \tag{10}$$

- Real diodes have reverse currents that, though quite small, are much larger than I_s. For instance, a small-signal diode whose I_s is on the order of $10^{-14}A$ to $10^{-15}A$ could show a reverse current on the order of $10^{-9}A$.
- A large part of this reverse current is attributed to leakage

The Breakdown Region

The Breakdown Region

- The breakdown region of operation is entered when $v < V_{ZK}$
- The constant V_{ZK} is called Zener-Knee voltage, where the subscript Z stands for zener and K denotes knee.
- In the breakdown region, the reverse current increases rapidly while the associated increase in voltage drop being very small
- Diode breakdown is not destructive, provided the power dissipated in the diode is limited by external circuitry to a "safe" level.

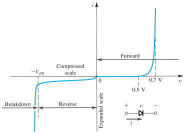


FIG 3. A detailed $i - v$ characteristic of a silicon junction diode.

Summary

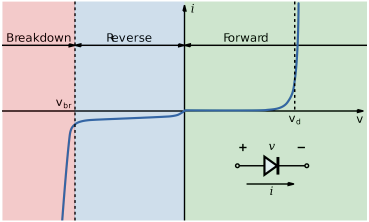


FIG 4. I–V characteristics of a p–n junction diode

The end