Unit 25 Characteristics of real diodes

- Real diodes are modelled by an ideal junction diode in series with a bulk resistance, R_B.

Figure 25.1: Model for a real diode.

- The characteristic curve of I versus V has a knee voltage.

Material	Approximate knee voltage
Ge	0.3
Si	0.7
GaAs	2.0
SiC	2.7

- Below the knee voltage, the ideal diode equation:

$$I = I_0 \exp\left(\frac{eV}{kT}\right) = I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)$$

  dominates the characteristic of a real diode.

- Above the knee voltage, the bulk resistance, R_B, dominates the characteristic of a real diode.

- R_B is typically of the order of $1\,\Omega$. The bulk resistance prevents the large currents which are predicted by the junction equation for large forward bias voltages from flowing in real diodes.

The measured characteristic of a silicon diode is shown in Figure 25.2.

The distinguishing feature of this actual diode characteristic is that for voltages less than 0.7 V the current is so small that it hardly shows on the graph and above 0.7 V the current-voltage relationship is linear.

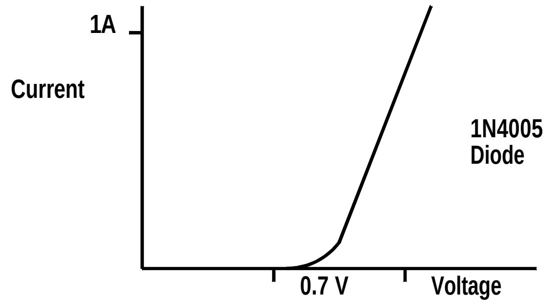

Figure 25.2: I–V characteristic for a 1N4005 diode.

For voltages below about 0.7 V the current is controlled by the diode junction and is related to the voltage by:

$$I = I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)$$

This is called the small signal region of operation.

For voltages above 0.7 V, the exponential junction relationship no longer governs the current through the diode. The current is now limited by the bulk resistance, R_B, of the diode which is due to the series resistances of the p-type and n-type material, the ohmic contacts and the connecting leads.

We can therefore model this real diode by a pn junction with the exponential characteristic and a series bulk resistance as shown in Figure 25.1.

The transition voltage between the two types of behaviour is called the knee voltage and the values of the knee voltages for different types of semiconductor material are shown in the table in the summary.

The bulk resistance depends on the design application for the diode. A rectifier diode designed to pass currents of the order of 5 A will have a bulk resistance of the order of $R_B = 0.1\,\Omega$. A small point contact diode, which is optimized for high operating frequency but which will only pass small currents, will have a bulk resistance of the order of $R_B = 5\,\Omega$.

The bulk resistance is determined by measuring the change of current for a change of voltage in the straight section of the characteristic above the knee voltage. This is called a dynamic resistance. For an ordinary resistor the dynamic resistance and the resistance are the same but this is not the case for a diode (or any other nonlinear device).

25.1 Example

25.1 A 1N4005 type silicon diode passes 1.0 A for a forward voltage of 1.1 V. Sketch the diode characteristic and calculate the diode bulk resistance.

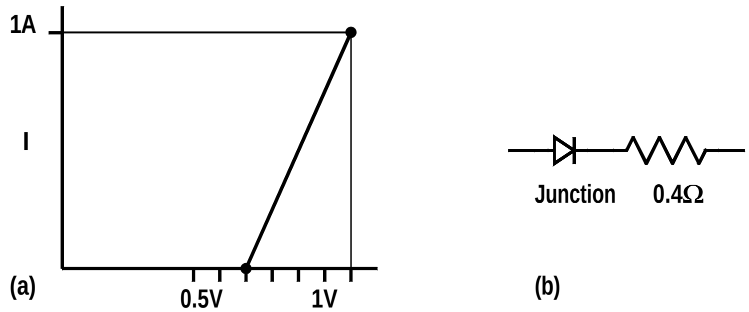

Figure 25.3: Approximation of diode characteristic.

Draw the I–V axes as shown in Figure 25.3 (a). Mark the point (1.1 V, 1.0 A). Mark the point (0.7 V, 0.0 A). Join these points as shown. This is an approximation to the diode characteristic. The real diode characteristic would be rounded off at the corner at the knee voltage.

$$\text{Bulk resistance} \qquad R_B = \frac{1}{\text{slope}} = \frac{1.1\,\mathrm{V} - 0.7\,\mathrm{V}}{1.0\,\mathrm{A} - 0.0\,\mathrm{A}} = 0.4\,\Omega$$

The equivalent circuit for this diode is shown in Figure 25.3 (b).

25.2 Problems

25.1 A variable current source drives a current through a diode for which $I_0 = 10^{-10}$ and using the circuit shown in Figure 25.4. Calculate the voltages across the diode for currents of 0.1 mA and 5 mA through the diode. Assume that the diode bulk resistance is 0.5 Ω.

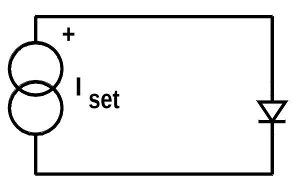

Figure 25.4: Problem 25.1.

25.2 What is the power rating for a small electronic soldering iron? Is the tip hot to touch after the iron has been switched on for five minutes?

25.3 What is the power rating for a typical torch bulb? How hot is the glass of the bulb when the bulb is lighting?

25.4 A current of 0.8 A flows through a 1N4005 diode. Calculate the power dissipation in the diode. (See Example 25.1 for data on this diode.)

25.5 The voltage across a 1N4005 diode is measured to be 0.85 V. Calculate the power dissipation in the diode. If you put your finger on the diode, should it feel hot?

25.6 The table gives spot measurements of V and I for seven different diodes. Sketch the characteristic curves for these diodes and obtain and fill in estimates for the knee voltages and for the bulk resistances of each diode type. Identify the semiconductor material used in the diode.

Diode type	Voltage	Current	Knee voltage	Bulk resistance
1N4148	1.0 V	80 mA		
	0.8 V	30 mA		
	0.5 V	50 μA		
1N4005	1 V	200 mA		
	0.8 V	100 mA		
	0.6 V	2 mA		
	0.4 V	20 μA		
OA91	0.7 V	1 mA		
	0.5 V	100 μA		
	0.4 V	2 μA		
OA47	0.6 V	50 mA		
	0.3 V	2 mA		
	0.25 V	200 μA		
	0.2 V	50 μA		
	−5.0 V	−0.1 μA		
Red led	3.0 V	60 mA		
	2.5 V	40 mA		
	2.0 V	10 mA		
	1.8 V	0 mA		
Green led	3.0 V	90 mA		
	2.5 V	45 mA		
	2.0 V	10 mA		
	1.8 V	0 mA		
Blue led LB5410	4.0 V	40 mA		
	3.0 V	10 mA		
	2.5 V	0 mA		