Unit 2 Schottky TTL.

- The metal-semiconductor junction characteristic is determined by the difference of work functions and by the semiconductor doping concentrations.
- A Schottky diode has a knee voltage of about 0.3 V and has a very fast response since it operates by majority carrier conduction.
- A Schottky diode used with an npn or pnp transistor prevents minority carrier saturation of the transistor.
- STTL circuits use Schottky transistors and operate at higher speeds than TTL circuits.

When a metal to semiconductor (such as silicon) junction is formed, there are two critical parameters which determine the gross characteristics of the junction. These are:

- The difference between the work function of the metal, ϕ_m, and the work function of the semiconductor, ϕ_s.
- The doping concentration of the silicon semiconductor material which is denoted by n and p for moderate doping and by n^+ and p^+ for heavily doped silicon.

If a metal and an n-type semiconductor are in contact and if the work-functions are such tha $\phi_m < \phi_s$ it is found that a weakly rectifying junction is formed.

The I–V characteristics of such a Schottky diode are shown in Figure 2.1. The three diagrams shown above the characteristic give a representation of the electron flow in each direction through the junction for the three bias configurations.

The general operational characteristics are then that a Schottky diode has a knee voltage of about 0.3 V which is lower than the 0.7 V for a pn diode The reverse current in a Schottky diode is greater than the reverse current in a pn diode but there is no problem of minority carrier storage slowing

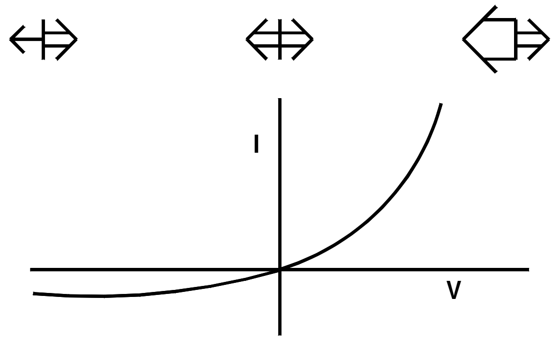

Figure 2.1: Schottky diode characteristic. Arrow thickness is proportional to majority carrier current in each direction.

down the device when it is switched from forward bias to reverse bias since the Schottky diode is a majority carrier type device. The fast recovery from forward bias and the low knee voltage of Schottky diodes are the two features which lead to these diodes being often used for fast rectification applications in radio circuits and in switch mode rectifiers.

Figure 2.2 shows how the devices are fabricated on a silicon wafer, with a pn diode shown for comparison. In both cases the cathode to n^+ connection form an Ohmic contact. Note the symbol used for a Schottky diode.

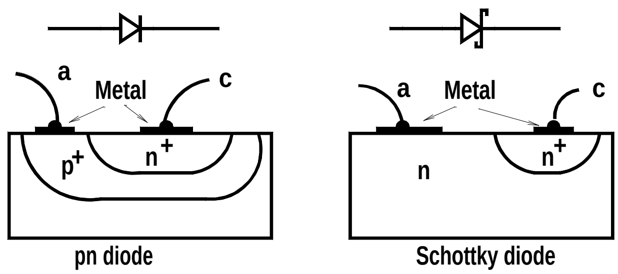

Figure 2.2: Schottky diode structure.

Schottky TTL logic. We have already discussed TTL circuits and their principle of operation in Unit 1. The TTL family was one of the earlier technologies and is still used extensively because of its speed of operation, straightforward manufacturing processes associated with using only npn transistors, low cost and proven reliability. The TTL family does, however, suffer the disadvantage that the current consumption per gate is about 10 mA and this implies that a circuit containing, say, 100 gates draws 1 A from a 5 V supply and therefore has a power dissipation of 5 W. The heat dissipated in large circuits is a significant problem requiring the use of fans or water cooling systems and also the power supplies for such a system are bulky and heavy.

The transistors in TTL type integrated circuits are driven into saturation so that the transistor is either fully conducting or fully non conducting. In the ON state the signals applied across the base-emitter junction not only forward bias the junction but also give a current which is in excess of that which can flow out of the collector due to the $\frac{V_+}{R_L}$ voltage drop in the collector resistor. This results in the base- collector junction becoming forward biased and the injection of a significant number of minority carriers into the collector region. Before the transistor can turn off all of the these excess minority carriers must be removed and this takes a finite time since the minority carriers are removed from within the collector region by a diffusion process. This slows down the switching off of the transistor. This mechanism is illustrated in Figure 2.3 where it can be seen that if the operating point moves along the load line to the point Q, the base-collector diode is forward biased and majority carriers are injected from the base into the collector region.

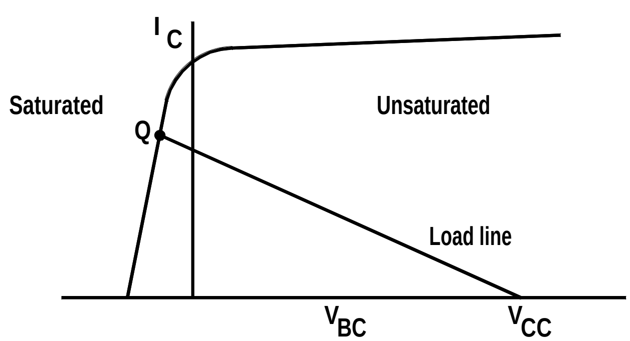

Figure 2.3: Saturation mechanism in npn transistor.

The solution to the problem is to prevent the base-collector junction from becoming forward biased as the transistor saturates by fabricating a Schottky diode in parallel with the base-collector junction of the transistor as shown in the circuit in Figure 2.4.

The fast recovery and low knee voltages of Schottky diodes prevent the transistors in TTL logic circuits from going into saturation. A Schottky diode is fabricated in parallel with the base-collector junction of the npn transistor. The transistor is prevented from going into saturation by the clamping action of the lower knee voltage of 0.3 V of the Schottky diode which prevents the operating point from moving to the point Q shown in Figure 2.3. This means that the npn transistor can be turned off more rapidly since there is less minority carrier storage within the transistor collector region and therefore less time required to stop conduction through the transistor.

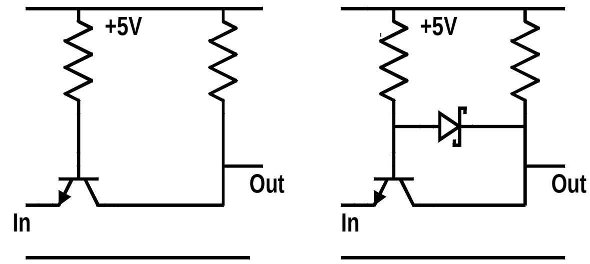

Figure 2.4: Schottky diode used to prevent saturation.

Another advantage of using Schottky diodes is that since the transistors are not driven into saturation, the current consumption is reduced as compared to TTL and this gives the Schottky STTL and low power Schottky LSTTL families of devices.

Fabrication of a Schottky diode in parallel with the base-collector junction of a transistor is not a difficult modification to the npn transistor fabrication process since it can be achieved by changing the masks which determine the base metalization so that the base metalization straddles the join of the base and collector regions as is shown in Figure 2.5. One half of this metalization forms the Schottky diode between the base region and the collector lead. The other half of the metalization forms the base connection. Note that a separate heavily doped n^+ well is used to make an Ohmic metal to semiconductor connection for the collector.

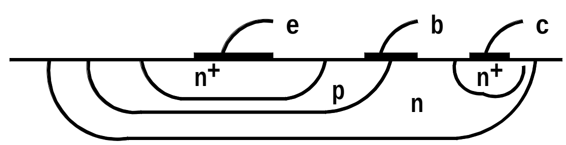

Figure 2.5: Fabrication structure of Schottky transistor.

One of the penalties associated with low power Sckottky devices is that there is a reduction in the number of inputs that can be fed or driven by a single output—the fan-out of the devices is reduced from 10 for TTL to about 2 for LSTTL. The LSTTL also suffer a slight speed reduction, typically from 20 ns for TTL to about 40 ns propagation time for LSTTL. However, in a large system the reduced power consumption and reduced cooling required can be a major advantage.

2.1 Problems

2.1 Give a physical explanation for each of the currents in the I-V Schottky junction characteristics shown in Figure 1.

2.2 Draw the energy level digram for a Schottky diode. (See References below).

2.3 Explain what is meant by the term "fan-out" of an electronic gate circuit.

2.2 References

Streetman, B.G., (1995), *Solid State Electronic Devices*, Prentice Hall

Milnes, A.G., (1980), *Semiconductor Devices and Integrated Electronics*, Van Nostrand Reinhold.

Rhoderick, E.H., Williams, R.H., (1988), *Metal–Semiconductor Contacts*, Oxford University Press.