9 Metal–Semiconductor Contacts

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Metal–semiconductor contacts display a range of electrical characteristics from strongly rectifying to ohmic, each having its own applications. The rectifying properties of metal points on metallic sulphides were used extensively as detectors in early radio experiments, while during the second world war the rectifying point contact diode became important as a frequency detector and low level microwave radar detector [1]. Since 1945 the development of metal semiconductor contacts has been stimulated by the intense activity in the field of semiconductor physics and has remained vital in the ohmic connection of semiconductor devices with the outside world. The developments in surface science and the increased use of Schottky barriers in microelectronics has lead to much research with the aim of obtaining a full understanding of the physics of barrier formation and of current transport across the metal-semiconductor interface. Large gain spin electronic devices are possible with appropriate designs by incorporating ferromagnetic layers with semiconductors such as silicon [2]. This inevitably leads to metal-semiconductor contacts, and the impact of such junctions on the device must be considered. In this section we aim to look simply at the physical models that can be used to understand the electrical properties that can arise from these contacts, and then briefly discuss how deviations of these models can occur in practical junctions.

The simplified energy band diagrams for a metal and \( n \)-type semiconductor are shown in Fig. 9.1 Assuming the metal work function \( \phi_m \) is much greater than the semiconductor work function \( \phi_s \), then when brought into intimate contact under conditions of thermal equilibrium, electrons pass from the conduction band of the semiconductor into the metal until the Fermi levels equalise. This leaves behind a depletion region in the semiconductor causing band bending and a barrier \( \phi_{bn} \).

The diffusion potential \( V_i \), or amount by which the bands are bent upwards, is given by

\[
V_i = \phi_m - \phi_s \tag{9.1}
\]

The bending upwards of the bands in an \( n \)-type semiconductor produces a barrier to electrons from semiconductor to metal. The barrier height \( \phi_{bn} \) as viewed from the metal is usually quoted:

\[
\phi_{bn} = V_i + (E_c + E_F) = \phi_m - \chi_s \tag{9.2}
\]

Where \( \chi_s \{= \phi_s - (E_c - E_F) \} \) is called the electron affinity of the semiconductor. Equation (9.2) is known as the Schottky limit, and was developed independently by Schottky and Mott in 1938 [3]. The drift and diffusion of majority
Fig. 9.1. Simplified band diagram of a metal and a n-type semiconductor, $\phi_m \gg \phi_s$ before (left) and after (right) contact.

Carriers govern the actual current voltage characteristics of the contact across the depletion region and emission over the barrier. These two processes are essentially in series and the resulting characteristics are governed by which ever causes the most impediment to majority carrier flow [4]. At thermal equilibrium, the rate at which the electrons diffuse across the barrier from the semiconductor to the metal is balanced by the rate at which electrons drift across the barrier in the opposite direction due to the junction electric field; there is no net current (Fig. 9.2a). Applying a forward bias voltage $V_F$ across the contact reduces the depletion region width as the depletion voltage reduces from $V_i$ to $(V_i - V_F)$. The electrons in the semiconductor see a reduced barrier and flow to the metal increases. Negligible voltage appears across the low resistance metal, and so $\phi_m$ and electron flow into the semiconductor remains unchanged. As a result there is a net flow of electrons from the semiconductor to the metal (Fig. 9.2b).

Applying a negative bias $-V_R$ across the contact increases the potential drop across the region by $(V_i + V_R)$ and increases the barrier seen from the semiconductor, while the flow from the metal to the semiconductor remains unchanged. The net effect is a small current flow from the semiconductor to the metal and rectification has occurred (Fig. 9.2c). The resulting contact is known as a Schottky barrier and is firmly established as a diode device in microelectronic technology. It allows devices with higher conductances than is possible with p-n structures, has a lower turn on voltage (0.2 V for Al/n-Si) and is also a majority carrier device enabling faster recovery times and higher frequency applications [5].

The case for an n-type semiconductor with $\phi_m \ll \phi_s$ is shown in Fig. 9.3. After contact electrons flow from the metal into the conduction band of the semiconductor, causing a small surface accumulation of electrons on the semiconductor side of the boundary. There is no potential barrier to electrons flowing in either direction. The region of the contact is of low resistance, the highest resistivity region being the bulk semiconductor and any applied voltage appears across this region and does not affect the contact band diagram. The bulk semiconductor resistance determines current flow, and the contact is known as ohmic. These are an important group of metal-semiconductor contacts and are central...