Chapter 13

Creation of Space-Charge Regions in Solids

The basic relations of the creation of space-charge regions caused by inhomogeneous doping can best be studied in a semiconductor with an abrupt step in the density of shallow donors (an \(nn^+\)-junction). The interrelations to electric fields and currents are transparent and present the foundation for more complex space-charge effects.

Space-charge regions, which were arbitrarily introduced in Section 12.2, occur normally in solids as a consequence of inhomogeneous doping or of the boundary conditions at the contact between adjacent solids. Here carriers can leak out from a region of higher carrier density into a region of lower carrier density. Since the average electron density in thermal equilibrium is equal to the density of ionized uncompensated donors in a homogeneous \(n\)-type solid, the leaking out of mobile electrons into an adjacent region of a lesser donor density must create a positive space charge

\[
\varrho = e(N_{d2} - n)
\]

(13.1)

in the more highly doped region where some of the charge-compensating electrons are now missing and a negative space charge

\[
\varrho = e(N_{d1} - n),
\]

(13.2)

in the adjacent, lower doped region, caused by the excess electrons, with an abrupt flip of sign of the space charge at the doping boundary between the two regions,* as shown in Figs. 13.1A and 13.1B.

* The left-hand region is identified with a parameter index 1, the right-hand region with an index 2.
The space-charge distribution, and hence the field and potential distributions (see Fig. 13.1C and D), looks somewhat similar to the abrupt space-charge distributions shown in Fig. 12.3. The shape of these distributions, however, is influenced by the distribution of the mobile carriers which is caused by carrier diffusion out of the highly doped region \((x > 0)\). In equilibrium such diffusion is counterbalanced by carrier drift in the opposite direction, due to the field induced by the space charge, which was created by the initial carrier diffusion. Hence, in addition to the Poisson equation discussed in the previous section, one must now consider the carrier transport equation* including drift and diffusion currents, here for electrons:

\[
j_n = e\mu_n n F + \mu_n kT \frac{dn}{dx}, \tag{13.3}
\]

where \(n\) is the electron density and \(\mu_n\), the electron mobility. Equations (12.17), (12.18) and (13.3) are now the governing set of differential equations that determine the space-charge distribution

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* For an extensive discussion of the transport equation and its derivation see Volume 1.