Forward Currents from the Space Charge Region

Advanced

- Again, we start from the equation for the net recombination U_{DL} via deep levels

$$U_{DL} = \frac{v \cdot \sigma^e \cdot N_{DL} \cdot (n^e \cdot n^h - n_i^2)}{n^e + n^h + 2n_i \cdot \cosh \dfrac{E_{DL} - E_{MB}}{kT}} = \frac{1/\tau \cdot (n^e \cdot n^h - n_i^2)}{n^e + n^h + 2n_i \cdot \cosh \dfrac{E_{DL} - E_{MB}}{kT}}$$

  - with $1/\tau = v \cdot \sigma^e \cdot N_{DL}$ as we know by now.

- The carrier densities n^e and n^h may be expressed via their Quasi-Fermi energies as E_F^e and E_F^h, respectively. For their product we get

$$n^e \cdot n^h = n_i^2 \cdot \exp - \frac{E_F^e - E_F^h}{kT}$$

- For the forward direction we have $E_F^e - E_F^h < 1$ and thus

$$n^e, n^h \gg n_i$$

  - This leaves us with

$$U_{DL} = \frac{1}{\tau} \cdot \frac{n^e \cdot n^h}{n^e + n^h}$$

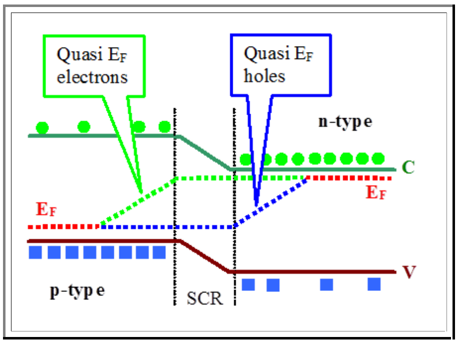
The *maximum* value for U_{DL} gives the upper limit for the net recombination rate and thus the *maximum current due to recombination in the* ***SRC***, too. The maximum is defined by

$$\frac{\partial\{(n^e \cdot n^h)/(n^e + n^h)\}}{\partial n^e} = \frac{\partial\{(n^e \cdot n^h)/(n^e + n^h)\}}{\partial n^h} = 0$$

  - which gives us $n^e = n^h$ for maximum current. With $n^e \cdot n^h = n_i^2 \cdot \exp - [(E_F^e - E_F^h)/kT]$ from above, we have

$$n^e = n^h = n_i \cdot \exp - \frac{E_F^e - E_F^h}{2kT}$$

- What we need now is an equation for the difference of the Quasi-Fermi energies. Lets look at the situation in a band-diagram



- Whatever the exact positions of the Quasi-Fermi energies, their difference $E_F{}^e - E_F{}^h$ is *about equal* to the difference in the bulk Fermi energy and thus

$$E_F{}^e - E_F{}^h \approx e \cdot U$$

- (The "*about equal*" contains roughly the same approximation as the "average barrier height" from the simple derivation!)

This gives us the final result

$$U_{DL}\,(\max) \approx \frac{1}{2\tau} \cdot n_i \cdot \exp - \frac{e \cdot U}{2kT}$$

Again , this is the *net* recombination rate at any point in the space charge region. To obtain the current density, we have to multiply with the width ***d*** of the **SCR** (and the elementary charge) and obtain for the maximum current from the **SCR** in forward direction:

$$j_F(\text{SRC}) = \frac{e \cdot n_i \cdot d_{SCR}}{2\tau} \cdot \exp - \frac{e \cdot U}{2kT}$$

Considering that we needed the whole formalism of Shockley-Read-Hall recombination theory, Quasi-Fermi energies, some junction theory, and lots of assumptions and approximations to get the same result as before, this does not appear to be a much better way of getting an idea about the influence of the **SCR** on the diode characteristic than the "quick and dirty" way.

- But don't deceive yourself! The treatment given here is not only physically sound, but transparent at every step. If you want to do more precise calculations, you would know - at least in principle - what to do.