Depletion

Advanced

- This is the case where an electrical field of arbitrary origin repulses the majority carriers and a space charge region develops.
  - Starting with the Poisson equation for doped semiconductors and all dopants ionized, we have

$$\frac{d^2(\Delta E_C)}{dx^2} = -\frac{e^2 \cdot N}{\epsilon\epsilon_0}\left(1 - \exp - \frac{\Delta E_C}{kT}\right)$$

  - In contrast to the case of quasi-neutrality , we now have $+\Delta E_C >> kT$ and *the sign is important*!
- This leads to a simple approximation:

$$\exp - \frac{\Delta E_C}{kT} \approx 0$$

  - The Poisson equation for the part of the semiconductor that contains this carrier density reduces to

$$\frac{d^2(\Delta E_C)}{dx^2} = -\frac{e^2 \cdot N_D}{\epsilon\epsilon_0}$$

- We have treated this case already in the more basic considerations. The result was

$$U(x) = \frac{e \cdot N_D}{2\epsilon\epsilon_0} \cdot x^2 - 2d_{SCR} \cdot x + d_{SCR}^2$$

$$d_{SCR} = \frac{1}{e} \cdot \left(\frac{2\Delta E_C(x = 0) \cdot \epsilon\epsilon_0}{N_D}\right)^{1/2}$$

  - With $\Delta E_C(x = 0) = \Delta E$ for brevity, we can rewrite the expression for the width of the space charge layer in terms of the Debye length L_{Db}

$$L_{Db} = \left(\frac{\epsilon\epsilon_0 \cdot kT}{e^2 \cdot N_D}\right)^{1/2}$$

  - and obtain

$$d_{SCR} = L_{Db} \cdot \left(\frac{2\Delta E}{kT}\right)^{1/2}$$

  - If we express ΔE in terms of the the voltage U between the ends of the sample by $e \cdot U = \Delta E$, we have the final result

$$d_{SCR} = L_{Db} \cdot \left(\frac{2 \cdot e \cdot U}{kT} \right)^{1/2}$$

Remember that L_{Db} is a purely material related quality and thus a *constant* for a given semiconductor. The width of the space charge region can be expressed very simply in terms of L_{Db} , it is always larger by the factor $\{2eU/kT\}^{1/2}$

- Since kT at room temperature ≈ **1/40 eV**, while applied voltages may be up to **1000 V**, d_{SCR} may exceed L_{Dn} by several orders of magnitude. This is shown in the illustration below (the numbers are basically correct, but not in detail).
- The breakdown limit indicates that the **SCR**, being an dielectric insulator, will eventually experience electrical breakdown if the field strength exceeds an upper limit.