# Exercises: Particle Detectors WS 2016/17

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## Problem Set No. 6

**Solutions have to be handed in by Wednesday 3pm, 30.11.2016 in letter box no. 3, in the ground floor of Gustav-Mie building!**

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1. **pn-junction**

   - Sketch the behaviour of capacitance C(U) as a function of the applied voltage U of a diode operated in reverse mode.
   - Calculated the diffusion voltage and the width of the depletion zone of a diode. It is assumed to be doped with $N_A = 10^{17} cm^{-3}$ and $N_D = 10^{16} cm^{-3}$ at T=300 K, assume $N_i = 15 \times 10^{10} cm^{-3}$ .
   - How much does the depletion zone penetrate in both doped areas of the diode at a applied bias voltage of 5 V? (In case you couldn't solve bullet two, use for the diffusion voltage 0.7 V.)

   **[3 points]**

2. **Silicon detector**
   A silicon detector with a surface area of $100\,\text{mm}^2$ and $300\,\mu$m thickness is used to detect and trigger on minimum ionizing particles (MIPs) crossing at a roughly perpendicular angle. The detector is asymmetrically doped with a thin p-layer and a doping level of $6.6\text{x}10^{12}\,\text{cm}^{-3}$ in the n-bulk. The signal is read out over a voltage amplifier, with a time constant sufficiently large that the detector current pulse is integrated on the detector capacitance and the resulting voltage pulse is sensed by the amplifier.

   - What is the required bias voltage to fully deplete the detector?
   - The detector is operated well beyond full depletion. What is the collection time and the 10-90% rise time of the voltage pulse? For simplicity assume saturation of drift velocities, using $9\times10^6$ cm/s for electrons and $5\times10^6$ cm/s for holes.
   - What is the peak voltage signal and 10-90% rise time for an otherwise identical detector operated the same way, but with a thickness of $100\,\mu$m?
   - A MIP loses ≈80 keV of energy in the $300\,\mu$m of silicon. Given that 3.6 eV are required to produce an electron/hole pair and the relative permittivity $\epsilon_{Si} = 11.9$, what is the peak voltage of the signal at the amplifier input?

   **[6 points]**

3. **Leakage current**
   In addition to the recombination lifetime an important parameter of semiconductor detector material is the charge generation lifetime $\tau_g$. As electrons and holes are created in pairs the equilibrium condition is $p = n = n_i$. The lifetime $\tau_g$ can be expressed as $\tau_g = n_i/G_{th}$, using the thermal generation rate $G_{th}$. The leakage current results as $I = e \times A \times W_D \times G_{th}$, with A being the detector area and $W_D$ the depletion width.

   - At room temperate $n_i \approx 10^{10}\,\text{cm}^{-3}$. What is the leakage current per $\text{cm}^3$ in a fully depleted silicon detector for $\tau_g = 1\,\text{ms}$?
   - What is the leakage current after an equivalent particle fluence $\phi_{eq} = 10^{14}\,\text{cm}^{-2}$, with the proportionality constant $\alpha$ being $2\times10^{-17}$ A/cm?

   **[3 points]**