Problem set for the lecture

Particle Detectors, WS 2015/16

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Problem set 8

Deadline: Thursday December 17, 10am
(Please drop into mailbox number 1 on the ground floor of the Gustav-Mie building.)

1. **Active material and detector resolution**
   The energy lost by a particle can for example be measured by a liquid noble gas detector, silicon detector or scintillator. A key parameter is the energy required to create a pair of initial charge carriers. These values are $W = 26$ eV for liquid argon and $W = 3.6$ eV for silicon. For the scintillator, one photon is produced for 100 eV of energy loss, with a 10% chance to reach the photomultiplier which has a quantum efficiency of 25%.

   What are the relative precisions with which energy losses in the detectors can be measured, for an energy loss of either 100 keV or 20 MeV?

   (1 Point)

2. **Silicon detector**
   A silicon detector with a surface area of 100 mm^2 and 300 μm 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 $6.6{\cdot}10^{12}$ 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.

   (a) A MIP loses $\sim$80 keV of energy in the 300 μm 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?

   (b) What is the required bias voltage to fully deplete the detector?

   (c) 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 $9 \cdot 10^6$ cm/s for electrons and $5 \cdot 10^6$ cm/s for holes.

   (d) 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 μm?

   (4 Points)

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

   (a) At room temperate $n_i \approx 10^{10}$ cm^{-3}. What is the leakage current per cm^3 in a fully depleted silicon detector for $\tau_g = 1$ ms?

   (b) What is the leakage current after an equivalent particle fluence $\phi_{eq} = 10^{12}$ cm^{-2}, with the proportionality constant α being $2 \cdot 10^{-17}$ A/cm?

(2 Points)

4. **NUMERICAL SIMULATION - Strip and pixel occupancy**
Consider a small detector consisting of 10×10 equidistant strips/wires creating a rectangular grid. Simulate particles crossing the detector at random positions, for simplicity with just the closest strip/wire (in both coordinates) registering a signal. The distribution of incident particles is flat over the detector area.

   (a) Study the distribution of the number of hits (all crossing points of two strips/wires registering a signal) depending on the number of particles impacting simultaneously, as well as the means of the distribution.

   (b) At what point does "saturation" start to play a significant role, when comparing the number of hits to the simple expectation for an infinitely fine grid?

   (c) How does a grid of 100 pixels compare to the strip/wire grid?

(3 Points)