Solution 11. Tutorial on Optical Sources and Detectors

July 17th 2012

Problem 1: Dynamic of a pin-diode

a) How does absorption in the contact region and diffusion zone affect the bandwidth of a photodiode?

➔ Contact region: Only very small E-field, therefore the generated electron hole pairs are not separated and recombine again. Absorption in this region therefore does not contribute to the photocurrent and therefore does also not affect the bandwidth.
Diffusion zone: The minority carriers in this region diffuse. This is a random process where the carriers travel in a time τ the mean distance $\Delta x = \sqrt{D\tau}$, where D is the diffusion constant. Carriers that arrive by random diffusion the space charge zone then contribute to the photocurrent. Since this is a rather slow process it might limit the bandwidth of a photodiode.

b) Why is it preferable for a fast photodiode to be operated with a reverse bias?

➔ Widening of the depletion layer (space charge zone), which reduces the depletion layer capacity. This results in a larger cutoff frequency $f_c = 1/(2\pi RC)$.
The E-field in the depletion layer is large enough for the carriers to move with their saturation drift velocity. This increases the reaction time.
Linear operation over a larger range.

c) How can unwanted absorption in the respective areas of a pin-diode be avoided?

➔ Keep these regions as short as possible.
Use of heterojunctions, where a higher bandgap material can be used.
Orthogonal coupling of the light.

Problem 2: Operation principle of an avalanche photodiode (APD)

Figure 1 shows the basic structure of an APD, which consists of four layers, a highly n-doped (width d_n), the intrinsic absorption zone (width w_{ab}), another lesser n-doped layer (width w_{av}) and a highly p-doped layer (width d_p).

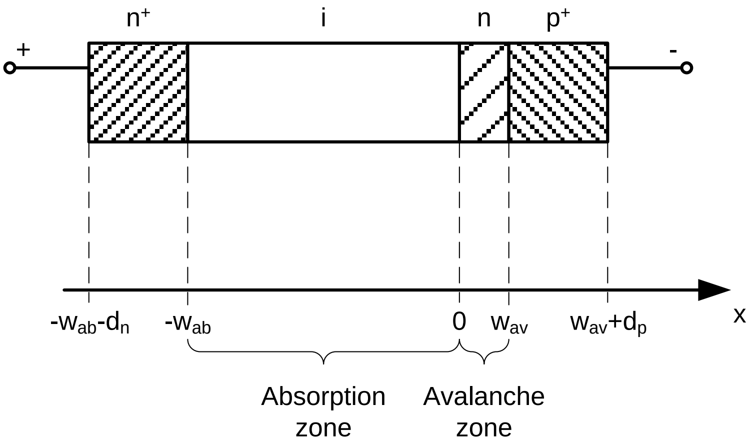

Figure 1 Schematic of an APD

a) Sketch the space charge density and the E-field profile as a function of x for partially and fully depleted avalanche zone. Assume that all donor/acceptor impurities are ionized ("Störstellenerschöpfung") and that there are no space charges within the absorption zone. Further assume that the depletion approximation holds and the dielectric constant ε_r is the same for all layers .

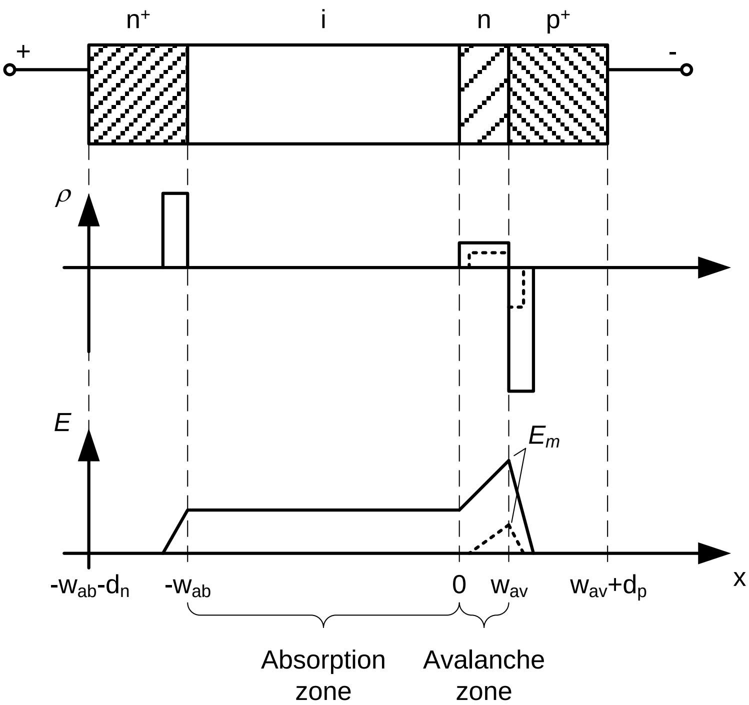

Figure 1 Schematic of an APD with charge density and E-field profile.

b) Using the sketch of part a) explain the operation principle of an APD.
   ➔ As in a pin-diode light that is absorbed in the i-layer generates electron hole pairs which get separated by the electric field. One carrier type, in this example the holes, enters the avalanche zone where the electric field is so strong that the hole accumulates enough energy to generate a new electron hole pair by impact ionization. These secondary carriers can then in turn generate even more carriers.

c) What is an ionization coefficient? What is the qualitative dependence of the ionization coefficients on the electric field?
   ➔ The ionization coefficient of a carrier type (α_n for the electrons and α_p for the holes) quantifies the mean number of newly generated electron hole pairs per unit distance. They increase exponentially with the electric field strength and for high electric fields α_n and α_p approach each other.

d) What can you tell about the relation between the change Δu of the bias voltage and the change ΔE_m of the maximum E-field strength? Regard two cases as in part a).
   ➔ For small bias voltages the depletion layer is very small and therefore the maximum E-field strength which is given by the upper tip of the triangle changes strongly with the bias voltage. Once the avalanche zone is fully depleted the depletion layer extends over the whole absorption zone. Therefore the maximum E-field, which remains at the same location changes less strong with the bias voltage.

e) What is the meaning of the avalanche multiplication factor M_0? Explain the kink in Figure 2, which shows M_0 for different operation temperatures as a function of applied voltage.
   ➔ The avalanche multiplication factor gives the mean amount of secondary carrier pairs per primary carrier that is measured in the outer circuit. It depends on the ionization coefficient of the electron and holes and therefore also on the electric field and on the bias voltage. The kink therefore stems from the kink in the function $E_m(u)$.

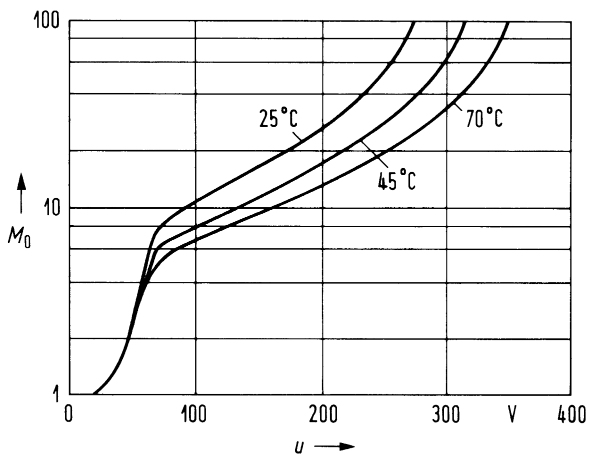

Figure 2 Avalanche multiplication factor as a function of the bias voltage, for different operation temperatures.

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