CHAPTER 11 HOMEWORK

11.3) CALCULATE MEAN VALUE AND VARIANCE IN NUMBER ELECTRON-HOLE PAIRS CREATED BY LOSS OF 100 keV PARTICLE ENERGY IN SILICON:

FROM TABLE (11.1) THE ENERGY/PAIR = 3.62 eV AT 77 K

NUMBER OF PAIRS $N = \frac{100\,000\ eV}{3.76\ eV} = 26595$

$\sigma = \sqrt{N} = 163$

26595 ± 163 ELECTRON-HOLE PAIRS

should include Fano factor $\sigma^2 = FN$

11.11) A TOTALLY DEPLETED SILICON DETECTOR, 0.1 mm THICK, OPERATED WITH LARGE OVER-BIAS SO CARRIER VELOCITIES ARE SATURATED; COLLECTION TIMES OF ELECTRONS & OF HOLES:

FROM FIGURE (11.2 A & B) AT SATURATION $\begin{cases} v_e \cong 9\cdot 10^6\ cm/s \\ v_h \cong 8\cdot 10^6\ cm/s \end{cases}$

$t_c = \frac{\text{THICKNESS}}{\text{VELOCITY}} \Rightarrow \begin{cases} t_e = \frac{.01\ cm}{9\cdot 10^6\ cm/s} = 1.11\ ns \\ t_h = \frac{.01\ cm}{8\cdot 10^6\ cm/s} = 1.25\ ns \end{cases}$ ✓

11.12) PARTIALLY DEPLETED SILICON SURFACE BARRIER DETECTOR OPERATED WITH BIG ENOUGH BIAS VOLTAGE THAT DEPLETION DEPTH EXCEEDS RANGE OF INCIDENT 5 MeV α. IF USED w/ VOLTAGE-SENSITIVE PREAMP, FIND CHANGE IN PULSE AMPLITUDE IF BIAS CHANGES BY 5%:

SINCE APPLIED VOLTAGE V_A CONTROLS DEPLETION DEPTH, IT AFFECTS HOW MUCH ENERGY α DEPOSITS AND THUS THE NUMBER OF ELECTRONS AS WELL AS THE CAPACITANCE

PULSE HEIGHT $V = \frac{Q}{C} \Rightarrow \sigma_V^2 = \left(\frac{\partial V}{\partial Q}\right)^2 \sigma_Q^2 + \left(\frac{\partial V}{\partial C}\right)^2 \sigma_C^2$

EQUATION (11.15) $C \cong \sqrt{\frac{e\epsilon N}{2V_A}}$ SO $V = Q\sqrt{\frac{2V_A}{e\epsilon N}}$ AND $\frac{\partial V}{\partial V_A} = Q\sqrt{\frac{2}{e\epsilon N}}\frac{1}{2\sqrt{V_A}} = \frac{1}{2}\frac{V}{V_A}$

SO $\sigma_V^2 = \left(\frac{V}{Q}\right)^2 \sigma_Q^2 + \left(\frac{1}{2}\frac{V}{V_A}\right)^2 \sigma_{V_A}^2$ WE NEED TO FIND Q & σ_Q

$Q = N_e q_e = \left(\frac{\text{ENERGY } \alpha \text{ DEPOSITS}}{\text{ENERGY/PAIR}}\right) q_e = \frac{5\ MeV}{3.62\ eV}\ 1.6\cdot 10^{-19}\ C = 2.213\cdot 10^{-13}\ C$

ESTIMATE $d \cong \alpha$ RANGE $\cong 20\ \mu m$ THE VALUE TAKEN FROM FIGURE (2.7)

DEPLETION DEPTH CHANGE: EQUATION (11.13) $d \cong \sqrt{\frac{2\epsilon V_A}{eN}} \Rightarrow \sigma_d = \frac{1}{2}\frac{d}{V_A}\sigma_{V_A} \Rightarrow \frac{\sigma_d}{d} = \frac{\sigma_{V_A}}{2V} = 2.5\%$

ROUGH CHANGE IN ENERGY DEPOSITED $\Delta E \simeq -\frac{dE}{dx} d' = \left(100\ \frac{keV}{\mu m}\right)(19.5\ \mu m) = 1.950\ MeV$

SO $\sigma_Q = \frac{\partial Q}{\partial E}\sigma_E = \frac{e}{\epsilon}\sigma_E = \frac{(1.6\cdot 10^{-19}\ C)(1.950\ MeV)}{3.62\ eV} = 8.630\cdot 10^{-14}\ C$

FINALLY $\frac{\sigma_V}{V} \cong \sqrt{\left(\frac{\sigma_Q}{Q}\right)^2 + \left(\frac{\sigma_{V_A}}{V_A}\right)^2} = \sqrt{(.39)^2 + (.05)^2} = 39.3\%$

good – this case for $d \simeq$ Range ; if $d > R$ then only second part contributes

11.13) AN ALPHA SOURCE WITH ACTIVITY 18 MBq IS PLACED 10 cm AWAY FROM SILICON SURFACE BARRIER; EXPOSURE TIME BEFORE SIGNIFICANT RADIATION DAMAGE:

$$10\ MBq = 10^7 \text{ DISINTEGRATIONS/SECOND}$$

SO AT 10 cm $R = \frac{10^7\ \alpha/s}{4\pi (10\ cm)^2} = 7957\ \frac{\alpha}{cm^2 s}$ ✓

WHEN RADIATION EXCEEDS $\sim 10^{11}\ \alpha/cm^2$, THE SILICON IS DAMAGED:

$$\Delta t = \frac{10^{11}\ \alpha/cm^2}{7957\ \frac{\alpha}{cm^2 s}} = 1.257 \cdot 10^7 \text{ SECONDS} = 145.4 \text{ DAYS}$$ ✓

11.16) A PLANAR GERMANIUM DETECTOR OPERATED AT T=77K

$\mathcal{E} = 1000\ V/cm$ THROUGHOUT VOLUME

CHARGES CREATED AT POINT IN DETECTOR BY INTERACTION WITH LOW ENERGY X-RAY PHOTON

ESTIMATE SPATIAL BROADENING OF ELECTRON CLOUD AS IT DRIFTS OVER 1 cm.

FROM TABLE (11.1) $\mu_e = 3.6 \times 10^4\ \frac{cm^2}{V \cdot s}$ $\Rightarrow$ $D = \mu_e \frac{k_B T}{e}$

$$= 3.6\ \frac{m^2}{V \cdot s} \frac{1.38 \cdot 10^{-23}\ J/K \cdot 300\,K}{1.6 \times 10^{-19}\ C} = .0931\ \frac{m^2}{s}$$

$$V = \mu_e \mathcal{E} = 3.6 \cdot 10^4\ \frac{cm^2}{V s}\ 10^3\ \frac{V}{cm} = 3.6 \times 10^7\ cm/s$$

EQUATION (11.6) $\sigma = \sqrt{\frac{2 k_B T x}{e \mathcal{E}}}$ IS SPREAD OF ELECTRON CLOUD WHICH HAS MOVED A DISTANCE x

$$= \sqrt{\frac{2 \times 1.38 \times 10^{-23}\ J/K \cdot 77K \cdot 1\,cm}{1.6 \cdot 10^{-19}\ C \cdot 1000\ V/cm}}$$

$$= \sqrt{1.327 \cdot 10^{-5}\ cm^2}$$

$$= 36.4\ \mu m$$ ✓

* I USE THE FIRST EDITION. CERTAIN NUMERICAL VALUES DIFFER BETWEEN EDITIONS, AND THE EQUATION & FIGURE NUMBERS USED MAY NOT CORRESPOND TO THOSE IN THE THIRD EDITION.