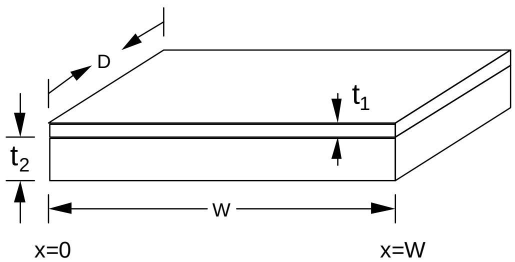
ECE 340 Homework XIII Spring 2003

Due: Monday, April 21, 2003

1. A bipolar junction transistor uses a current variation in the base region to modulate the emitter-base voltage and hence a modulation on the injected current leading to a variation in the collector output current. So it is a current control mechanism. Field-effect transistors employ a different mechanism to control the output current by changing the charge density in the active region. The following problem is designed to illustrate the effect of changing charge density on the output current. Assume that a rectangular bar of silicon shown below consists of two layers, each of thickness t_1 and t_2, respectively. The dimensions are D=100μ m, W=5μ m, t_2= 1μ m and t_1=200Å. The t_1 layer is uniformly doped with N_{d1}/cm^3 donors and $N_{d2}=10^{11}$/cm^3 donors are also uniformly doped in the t_2 layer. A bias of 1 V is applied between x=0 and x=W. Determine and plot the output current for different carrier densities in the t_1 layer. Specify the current for N_{d1}= 3×10^{13}/cm^3, 3×10^{15}/cm^3, 3×10^{17}/cm^3, and 3×10^{19}/cm^3. For simplicity, use an average electron mobility of 1000 cm^2/V-s for both layers and various carrier densities to estimate the conductivity. In real field-effect transistors, the variation in carrier density in the t_1 layer is accomplished by charges induced by a vertical electric filed.



Solution:

Since both doping concentration is much larger than n_i, $n \approx N_d$

$$\mathcal{E} = \frac{V}{W}, \qquad I = JA = s\,\mathcal{E}A = qm_n nA\frac{V}{W}$$

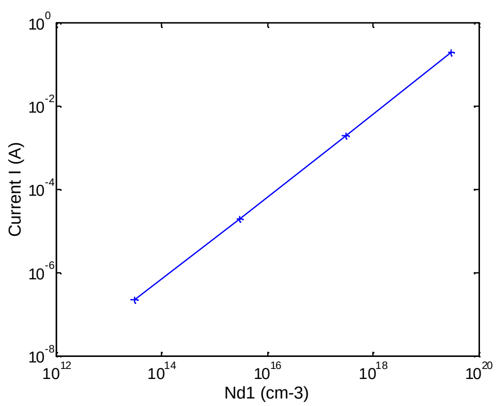
Current flowing through region 1 and 2 are:

$$I_1 = 1.6\times10^{-19}\times1000\times100\times10^{-4}\times200\times10^{-8}\times\frac{1}{5\times10^{-4}}\times N_{d1} = 6.4\times10^{-21}\times N_{d1}(Amp)$$

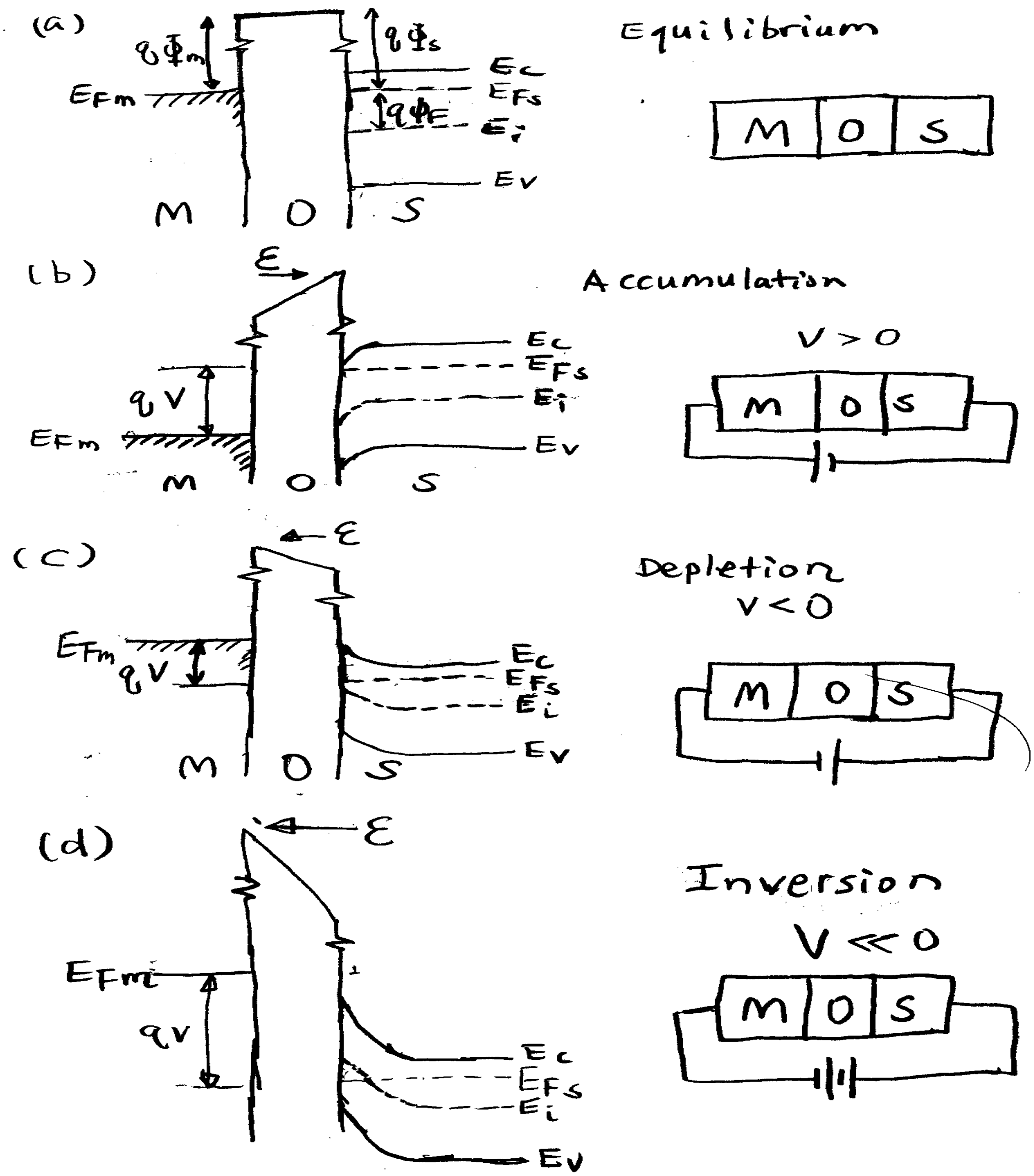
$$I_2 = 1.6\times10^{-19}\times1000\times100\times10^{-4}\times1\times10^{-4}\times\frac{1}{5\times10^{-4}}\times10^{11} = 3.2\times10^{-8}(Amp)$$

$$I_{total} = I_1 + I_2 = 6.4\times10^{-21}\times N_{d1} + 3.2\times10^{-8}(Amp)$$

N_d (cm-3)	3E13	3E15	3E17	3E19
I (A)	2.25×10^{-7}	1.92×10^{-5}	1.92×10^{-3}	1.92×10^{-1}



2. Redraw Figure 6-12 of band diagrams for the ideal MOS structure in an n-type silicon at (a) thermal equilibrium (b) electron accumulation (c) electron depletion and (d) strong inversion. Also, in the drawing show a simple circuit illustrating how the biasing is applied in each case.



3. For an ideal MOS structure, the SiO_2 thickness is 200 Å, and the substrate is doped with $5x10^{16}/cm^3$ acceptors. Determine the threshold voltage, V_T, required to achieve strong inversion and find the electric field in the oxide when the applied bias $V=V_T$. Repeat for a different MOS where the SiO_2 thickness is 40 Å but the substrate doping is the same.

(a), For ideal MOS, we assume $\Phi_{ms} = 0V$,

$$f_F = \frac{kT}{q}\ln\frac{N_a}{n_i} = 0.389V$$

$$W_m = \sqrt{\frac{2e_s f_s}{qN_a}} = 2\sqrt{\frac{e_s f_F}{qN_a}} = 0.1425mm$$

$$C_i = \frac{e_i}{d} = \frac{3.9\times 8.85\times 10^{-14}}{200\times 10^{-8}} = 1.73\times 10^{-7}\,F/cm^2$$

$$Q_d = -qN_aW_m = -q\times 5\times 10^{16}\times 0.1425\times 10^{-4} = -1.14\times 10^{-7}\,C/cm^2$$

$$V_T = -\frac{Q_d}{C_i} + 2f_F = \frac{1.14\times 10^{-7}}{1.73\times 10^{-7}} + 2\times 0.389 = 1.437V$$

At V_t, strong inversion, by the third equation of the Maxwell eqns

$$|\mathcal{E}| = \frac{|Q_d|}{e} = \frac{1.14\times 10^{-7}}{3.9\times 8.85\times 10^{-14}} = 3.3\times 10^5 V/cm$$

The electrical field points from the gate to the substrate.

(b), The value for f_F ,W_m and Q_d stay the same.

$$C_i = \frac{e_i}{d} = \frac{3.9\times 8.85\times 10^{-14}}{40\times 10^{-8}} = 8.63\times 10^{-7}\,F/cm^2$$

$$V_T = -\frac{Q_d}{C_i} + 2f_F = \frac{1.14\times 10^{-7}}{8.63\times 10^{-7}} + 2\times 0.347 = 0.91V$$

Electrical field across the oxide is same as part a:

$$|\mathcal{E}| = \frac{|Q_d|}{e} = \frac{1.14\times 10^{-8}}{3.9\times 8.85\times 10^{-14}} = 3.3\times 10^5 V/cm$$

pointing from the gate to the substrate.

Comment: the electrical field is independent of oxide thickness.