Department of Electrical and Computer Engineering
UNIVERSITY OF BRITISH COLUMBIA
EECE 480 MICROELECTRONIC DEVICES

MID-TERM EXAM, October 25, 2007

Time: 1.25 hours
Full marks can be obtained by answering Questions 1, 2, 3, and 4 correctly.
No notes, books, data-storage- or telecommunication-devices allowed.
Simple calculators may be used.
This exam consists of **2** pages.
Some equations are given on a separate, double-sided sheet.

Information: $kT/q = 25.9\,\text{mV}$, $\epsilon_0 = 8.85 \times 10^{-12}\,\text{F/m}$.
For Si: $n_i = 10^{10}\,\text{cm}^{-3}$, $E_g = 1.12\,\text{eV}$, $\chi = 4.1\,\text{eV}$, $\epsilon_r = 11.9$, $N_C = 3.22 \times 10^{19}\,\text{cm}^{-3}$, $N_V = 1.83 \times 10^{19}\,\text{cm}^{-3}$.
For CMOS90: $V_T = 0.26\,\text{V}$, $t_{ox} = 2.3\,\text{nm}$, $\epsilon_{ox} = 3.9\epsilon_0$, $N_A = 8.3 \times 10^{17}\,\text{cm}^{-3}$, $\mu_{\text{eff}} = 230\,\text{cm}^2(\text{Vs})^{-1}$, $v_{sat} = 7 \times 10^6\,\text{cm/s}$.
For SiO_2: $\chi = 0.9\,\text{eV}$, $E_g = 8\,\text{eV}$.

1. [8 marks]
Consider a CMOS90 N-MOSFET with the usual heavily doped n-type polySi gate ($E_C - E_F = 0$), and other parameters as listed above.
(a) Calculate the flat-band voltage.
(b) Carefully construct an energy band diagram, in the y-direction (gate to body), under bias conditions of $V_{DS} = 0$, $V_{SB} = 0$ and $V_{GB} = -1.04\,\text{V}$. Show E_0, E_l, E_C, E_V throughout the device, and E_{Fn} in the gate, and E_{Fp} in the body.

2. [8 marks]
(a) Sketch the drift velocity-field ($v_d - \mathcal{E}_x$) relationship for electrons in silicon. Explain why the curve has its particular shape.
(b) How is this velocity-field relationship used in the LEVEL1 and LEVEL49 models for the MOSFET?
(c) Why does the LEVEL1 model overestimate V_{DSsat}?

3. [8 marks]
(a) Sketch typical transfer characteristics ($I_D - V_{GS}$, $I_C - V_{BE}$) for a MOSFET and a BJT.
(b) Comment on, and give reasons for, the similarities and differences of the two characteristics.

More questions are on the back of this page.

4. [8 marks]

An n-p-n BJT has a quasi-neutral basewidth that is much shorter than the minority-carrier diffusion length, but that is much greater than any changes in depletion-region widths that may occur on switching. The transistor is biased in the saturation regime, with V_{BE} slightly greater than V_{BC}.

(a) Sketch the electron concentration profile in the quasi-neutral base.

(b) On the same sketch, add a line showing the electron concentration profile at the instant the collector current would begin to decrease after V_{BE} had been reduced to zero.

(c) Let the base doping density be $N_A = 10^{17}\,\text{cm}^{-3}$, the quasi-neutral basewidth be 100 nm, and the cross-sectional area be $10\,\mu\text{m} \times 10\,\mu\text{m}$. Consider the transistor to be in the common-emitter configuration with $V_{BE} = 0.7\,V$. The conditions are such that the transistor is in the saturation regime with $V_{BC} = 0.6\,\text{V}$. On switching-OFF the transistor, electrons are removed from the quasi-neutral base at an average rate of 1.15×10^{14} electrons/second.

How long does it take before the collector current begins to change?

5. [Bonus Question]

The $E - k$ relationships for the conduction bands of two, one-dimensional semiconductor materials, A and B, can be expressed as

$E_A - E_C = \alpha k^2$ and $E_B - E_C = 2\alpha k^2$,

respectively, where α is a constant, and E_C is the energy of the bottom of the conduction band.

Consider each material to be moderately doped n-type, with the same concentration of donors, all of which can be taken to be ionized.

Giving reasons for your answers, which doped material would have:

(a) the greater conductivity?

(b) its Fermi energy closer to E_C?

(c) the greater average x-directed thermal velocity for electrons?