Department of Electrical and Computer Engineering
UNIVERSITY OF BRITISH COLUMBIA

EECE 480 MICROELECTRONIC DEVICES

FINAL EXAM, December 14, 2007

Time: 3 hours
ALL QUESTIONS MAY BE ATTEMPTED. A mark of greater than 50/50 is possible.
Simple calaculators are allowed. Notes or books are not allowed.
This exam consists of 2 pages.
Some equations and constants are given on additional pages.

1. [10 marks]
(a) Consider a simple 1-D semiconductor crystal comprising 6 primitive cells separated by a distance a. Each primitive cell contains a single atom; each atom has 4 valence electrons.
Make a rough sketch of the reduced-zone representation of the band structure. Identify the conduction band and the bandgap.
(b) What is the Parabolic Band Approximation?
Why is it reasonable to use this approximation when considering semiconductors in practical devices?
(c) Sketch the parabolic band structure for the top of the valence band in the general case. Show 5 momentum states, one of which is unoccupied. Indicate the movement of the electrons in the parabolic valence band when an electric field is applied that would increase the momentum positively of an electron near the bottom of the *conduction band* in the same material.
(d) Consider a 1-D crystal of length 1 cm. The effective mass for holes in this material is $0.5m_0$. What is the current density due to carriers in the valence band at the instant when the only unoccupied state has a wavenumber of $4.32 \times 10^8\,\mathrm{m}^{-1}$?

2. [10 marks]
(a) Explain why Si CMOS technology might be headed in the direction of metal gates and undoped, or unintentionally doped, substrates (bodies).
(b) Consider a Si MOSFET utilizing a metallic gate with a workfunction of 4.9 eV, and an unintentionally doped body, *e.g.*, acceptor impurity doping of the order of n_i. Carefully construct an energy band diagram, in the y-direction (gate to body), under equilibrium conditions. Show E_0, E_l, and E_F throughout the device, and E_C in the oxide and in the body.
(c) For the Si MOSFET of Question 2b, estimate the threshold voltage.

3. [10 marks] For a symmetrical, rectangular potential barrier of thickness t, the tunneling transmission probability can be approximated by

$$T(E) = \exp[-2k'(E)\,t]$$

where $ik' \equiv k$ is the electron wavenumber within the barrier, and the electron effective mass is assumed to be the same in all regions of the structure. Assume that this situation applies to tunneling through the oxide in a silicon-gate Si MOSFET.

In Si CMOS technology the gate oxide has been silica ($\epsilon_r = 3.9$, and electron affinity $\chi = 0.9\,\text{eV}$) but the change is being made to hafnia ($\epsilon_r \approx 4 \times 3.9$, and $\chi = 2.9\,\text{eV}$).

(a) What thickness of hafnia is needed for $T(E = 0.2\,eV)$ to be equal to that for silica of thickness 2 nm?

(b) Discuss, without doing a numerical calculation, how the drain saturation current in a MOSFET will change if the oxide is changed from 2 nm of silica to the thickness of hafnia computed in the previous question.

4. [10 marks]

(a) Consider an HBT utilizing the materials InGaP(n)-GaAs(p^+)-GaAs(n^-) for the emitter, base, and collector, respectively. Sketch the energy band diagram (E_C and E_V are sufficient) for the HBT operating in the active mode.

(b) The above question indicates that the base doping density is made higher than the emitter doping density:

(i) why is this done in low-noise HBTs?

(ii) why is it not done in homojunction BJTs?

(c) By considering breakdown voltage, collector-base junction capacitance, and base-emitter transit capacitance, show that a conflict arises when trying to choose a desirable value for the collector doping density in an HBT intended for high-power, high-frequency applications.

5. [10 marks]

(a) Sketch the cross-section of a MESFET, showing the body, substrate, gate, source, drain, and some approximate depletion layer for the case of $V_{DS} > 0$.

(b) Why is the MESFET often used in very high-frequency amplifiers?

(c) Consider a GaAs MESFET with a body thickness of 500 nm, a doping density of $N_D = 10^{16}\,\text{cm}^{-3}$ and a Schottky barrier height ($\Phi_G - \chi_S$) of 0.8 eV.

(i) Is this a depletion-mode- or an enhancement-mode-FET?

(ii) Calculate the threshold voltage.

6. [5 marks]

The Si body of a DRAM cell has a doping density of $N_A = 10^{17}\,\text{cm}^{-3}$. The plate MOS capacitor has $V_{fb} = 0$. On writing a ONE, the region under the plate goes into deep depletion; the depletion region width reaches a maximum of 144.8 nm.

If the current due to field-separated, thermally generated electron-hole-pairs is constant at $6.4\,\mu\text{A/cm}^2$ while the depletion region width is changing, how long does it take for the ONE to become a stable ZERO?