Department of Electrical and Computer Engineering
UNIVERSITY OF BRITISH COLUMBIA

EECE 480 MICROELECTRONIC DEVICES

FINAL EXAM, December, 2005

Time: 2.5 hours
ANSWER ALL QUESTIONS.
All questions carry equal weight.
No notes, programmable calculators or books allowed.
This exam consists of 2 pages.

1.
(a) List the 3 main noise mechanisms that occur in transistors, and:
(i) describe their physical origin;
(ii) sketch the frequency dependence of their spectral noise-power density.
(b)
(i) Sketch the energy band diagram (conduction-band edge, Fermi level in the gate metal and in the semiconductor body) of a HEMT operating in the ON condition.
(ii) Explain why the HEMT has a very low noise figure.

2.
(a) Si MOSFETs dominate in digital, VLSI circuitry. State, and elaborate upon, the 3 main reasons why this is so.
(b) There are indications that Si MOSFETs may be reaching their "limit" as regards the continued increase in their ON/OFF-current ratio via simply reducing the channel length L. Discuss why this is so.
(c)
(i) List, and discuss, 4 factors that significantly affect the drift velocity in the longitudinal (source-drain) direction of electrons in the channel of a Si NMOSFET.
(ii) Identify, and discuss, 2 innovations that attempt to improve carrier mobility in the channel of Si MOSFETs.

3. Consider a *npn* HBT in which both the emitter and collector are made from semiconductor material A, and in which the base is made from semiconductor material B. For material A the bandgap and electron affinity are 2.0 eV and 0.5 eV, respectively. The corresponding values for material B are 1.5 eV and 1.0 eV.
(a) Sketch the equilibrium energy band diagram (vacuum level, conduction-band edge, Fermi level, valence-band edge) for the device.
(b) The Fermi level on your sketch indicates the doping densities assigned to the emitter, base, and collector regions of the device. Explain your reasons for choosing the relative doping densities.
(c) By employing a wide-bandgap material for the collector, what particular property of the device is likely to be improved, and why?

4.

(a) Explain why two subscripts are needed to properly identify the intrinsic capacitors that appear in AC equivalent circuits of transistors.

(b) Show that f_T for a MOSFET can be written as

$$2\pi f_T = \frac{g_m}{C_{SG} + C_{DG}} . \tag{1}$$

(c) Consider using Eq. (1) to compute f_T for a MOSFET biased in the saturation regime. Explain whether it would make any difference to the result if C_{GD} were used instead of C_{DG}.

(d)

(i) Describe the physical process associated with the "base-storage" component of C_{EB} in a BJT operating in the normal, active mode.

(ii) Explain why the above process also leads to a quasi-neutral region within the base.

5.

(a) The gradual-channel approximation leads to the following expression for the position-dependence of the charge in the channel of a Si NMOSFET

$$Q_n(y) = -C_{ox}(V_{GS} - V_T - mV_{CS}(y)) . \tag{2}$$

(i) Taking the electron velocity in the channel to be given by

$$v_y(y) = \mu_0|\mathcal{E}_y(y)| , \tag{3}$$

derive the expression (the so-called "LEVEL 1 improved" formula) for the drain current.

(ii) Sketch this current as a function of V_{DS}, and indicate the region of its validity.

(iii) The point of failure of the I_D-V_{DS} expression corresponds to the appearance of a non-physical feature in $Q_n(y)$. What is this feature?

(b)

(i) Sketch on a semilog plot the forms of I_D-V_{GS} for a MOSFET and I_C-V_{BE} for a BJT. In each case let the voltage range extend from zero to well into the ON condition.

(ii) What are the physical mechanisms that lead to the similarities and differences of these curves?