Department of Electrical and Computer Engineering
UNIVERSITY OF BRITISH COLUMBIA

EECE 480—SEMICONDUCTOR DEVICES

FINAL EXAM (December 17, 2004)

Time: 2.5 hours
ANSWER ALL FIVE QUESTIONS.
This exam has 4 pages.
No notes, calculators, or books allowed.

1. **(10 marks) General:**

   (a) Sketch the density of states in three dimensions. Be sure to label your axes appropriately. Specific numbers are not required.

   (b) Sketch the density of states in two dimensions. Be sure to label your axes appropriately. Specific numbers are not required.

   (c) For a potential energy of the form

   $$U(x) = \begin{cases} \alpha & , \quad x < 0 \\ \beta & , \quad x > 0 \end{cases} ,$$

   specify the appropriate matching condition(s) for the wavefunction at $x = 0$ if $\alpha \neq \beta$, where α and β are finite constants.

   (d) Specify at least five boundary/matching conditions required when invoking the depletion approximation in order to solve Poisson's equation for a *pn*-diode.

   (e) Sketch

      i. the charge density,
      ii. the electric field, and
      iii. the potential,

   as functions of position, in the depletion region of a *pn*-junction under the depletion approximation.

2. **(9 marks) BJT:**

   (a) Draw the circuit diagram for an ECL inverter, and explain why this device is so fast. Also, indicate at least one drawback to this logic family.

   (b) Describe, in principle, how one could compute f_{max} from the small-signal, hybrid-π model. Do not actually compute it.

3. **(18 marks) MOSFET:**

   (a) Explain, in words, equations, and/or pictures, how the propagation delay, the stand-by power, and the dynamic power depend on V_T and V_{DD} in a CMOS inverter.

   (b) Describe the short-channel effect in MOSFETs, and how it can be reduced. Indicate the negative side-effects, if any, of attempting to reduce the short-channel effect.

   (c) What is meant by SOI and STI, and why might these be utilized in MOSFET design?

4. **(10 marks) HBT:**

   Referring to Fig. 1, consider building an HBT on an InP substrate, using InAlAs and InGaAs epi-layers.

   (a) Which of the two epi-layers should be used as the emitter, and why?

   (b) Choose, giving reasons for your choice, suitable mole fractions of In for

      i. the emitter, and

      ii. the base.

   (c) Sketch an equilibrium energy band diagram, showing E_{vac}, E_C, E_V and E_F roughly to scale, for an *npn* version of your HBT. The electron affinity can be assumed to be the same for all the materials used.

5. **(10 marks) HFET:**

   (a) Sketch the physical structure of a GaAs MESFET, and explain why this device would outperform a Si MOSFET in terms of frequency and speed.

   (b) Sketch the physical structure of a MODFET, and describe its key features and performance advantages.

   (c) How does a pHEMT differ from a HEMT, and what performance advantage(s) does the pHEMT have over the HEMT?

Some basic equations:

$$
\begin{aligned}
\nabla^2\psi &= -\frac{\rho}{\epsilon} \\
\vec{J}_h &= -qp\mu_h\nabla\phi_p \\
\vec{J}_e &= -qn\mu_e\nabla\phi_n \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot\vec{J}_h - U \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot\vec{J}_e - U \\
n_0 &= \int_{E_C}^{\infty} g(E)f(E)\mathrm{d}E \\
n_0 &= N_C\exp\left(\frac{E_F-E_C}{k_BT}\right) \\
n_ip_i &= n_i^2 \;=\; N_CN_V\exp\left(-\frac{E_G}{k_BT}\right) \\
J &= J_0\left[\exp\left(\frac{qV_{\mathrm{appl}}}{k_BT}\right)-1\right] \\
I_E &= -a_{11}\left[\exp\left(\frac{V_{BE}}{V_{\mathrm{th}}}\right)-1\right]+a_{12}\left[\exp\left(\frac{V_{BC}}{V_{\mathrm{th}}}\right)-1\right] \\
I_C &= a_{21}\left[\exp\left(\frac{V_{BE}}{V_{\mathrm{th}}}\right)-1\right]-a_{22}\left[\exp\left(\frac{V_{BC}}{V_{\mathrm{th}}}\right)-1\right] \\
J &= -\frac{qn_{0B}\exp\left(\frac{V_{BE}}{V_{\mathrm{th}}}\right)}{\frac{W_B}{D}+\frac{1}{v^*}+\frac{1}{v_{\mathrm{sat}}}} \\
|C_{ij}| &= \left|\frac{\partial Q_i}{\partial V_j}\right| \\
\phi_B &= \frac{k_BT}{q}\ln\left(\frac{N_A}{n_i}\right) \\
V_T &= V_{FB}+2\phi_B+\frac{1}{C_{\mathrm{ox}}}\sqrt{2\epsilon_s qN_A\left(2\phi_B+V_{SB}\right)} \\
V_{FB} &= -\frac{Q_f}{C_{\mathrm{ox}}}-\frac{Q_{it}}{C_{\mathrm{ox}}}-\dots \\
m &= 1+\frac{C_B}{C_{\mathrm{ox}}} \\
I_D &= \frac{Z}{L}\mu C_{\mathrm{ox}}\left[\frac{\left(V_{GS}-V_T\right)V_{DS}-\frac{mV_{DS}^2}{2}}{1+\frac{V_{DS}}{\mathcal{E}_{\mathrm{crit}}L}}\right] \\
\Delta V_T &\simeq 8(m-1)\sqrt{V_{bi}\left(V_{bi}+V_{DS}\right)}\exp\left(-\frac{\pi L}{2mW}\right) \\
I_{D,\mathrm{subt}} &= I_{D,\mathrm{thresh}}\exp\left(\frac{V_{GS}-V_T}{mV_{\mathrm{th}}}\right)
\end{aligned}
$$

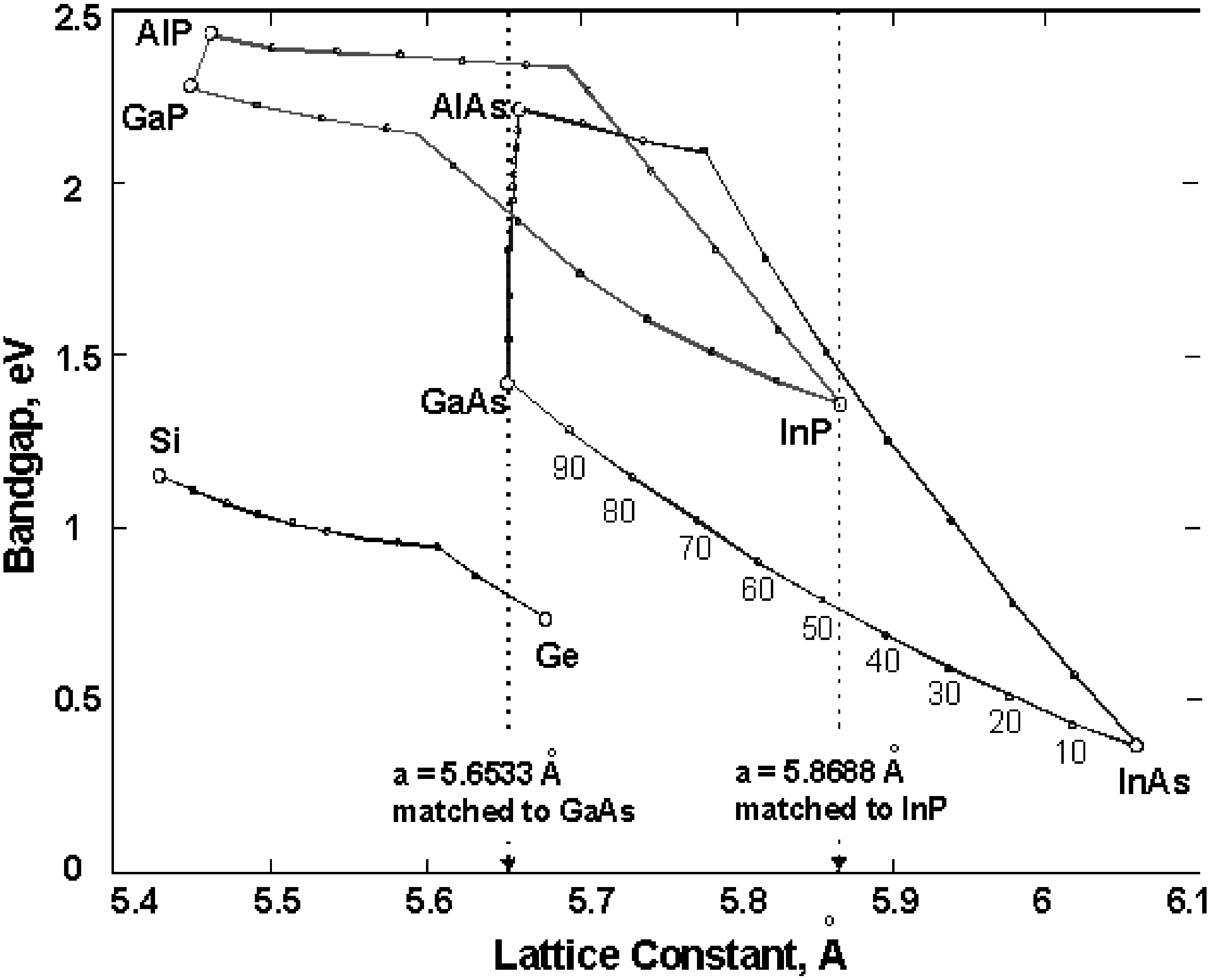

Figure 1: Bandgap and lattice constant for various materials.