Exam #1—EE531

due 6:30pm, Sunday 5/7 either via email or under door of EE 218

This is a take-home exam. Please limit your time working on exam to 8 hours. Do not talk to anyone else about exam until after due date. Any questions should utilize GoPost.

1. Consider a material with 6 equivalent conduction band minima located along the $\pm k_x$, $\pm k_y$ and $\pm k_z$ axes (like silicon). Each of these minima is ellipsoidal, elongated along the axis on which it lies. For example, the minima along positive k_x axis is given by:

$$E = \frac{\hbar^2}{2}\left(\frac{(k_x - k_0)^2}{m_l} + \frac{k_y^2 + k_z^2}{m_t}\right).$$

A thin film of this material forms a 2D system confined to a thickness b in the z-direction. Assume the result is a 1D infinite potential well. Take b = 2nm, $m_l = m_0$ and $m_t = m_0/4$.

(a) Calculate the minimum energy for the three lowest sub-bands. Note that the effective mass in confinement direction determines the minimum energy level.

(b) Calculate and sketch the resulting density of states for these three sub-bands. Note that the effective masses within the plane of confinement determine the 2D density of states ($g_{2D}(E) = m^*/(\pi\hbar)$).

(c) If $T = 300K$, determine the overall effective mass tensor, averaged over the lowest three sub-bands. Would the mobility in the plane of film be enhanced or retarded due to the confinement (ignore changes in scattering).

2. Consider an MOS capacitor with n-type substrate doped with $N_d = 5 \times 10^{18}\text{cm}^{-3}$, a 1.5nm oxynitride gate dielectric ($\kappa = 6$), and an p^+ poly gate ($E_f = E_v$, $N_a = 10^{20}\ \text{cm}^{-3}$), and an p^+ channel contact biased at -1 V relative to the substrate. The structure is biased such that $Q_s = 8 \times 10^{-7}\ \text{C/cm}^2$.

(a) What is the gate to substrate voltage? Include voltage drop across inversion or accumulation layer and poly depletion if appropriate.

(b) Calculate the gate capacitance that would be measured.

(c) What fraction of this capacitance would be coupled to the channel contact (reservoir for electrons)?

3. The doping in a nMOS transistor with an n^+ poly gate ($E_f = E_c$) and t_{ox} = 1.2nm varies linearly with depth from a very small surface concentration to N_0 at depth a and then is constant. The body is tied to the source.

(a) What should be the values of N_0 and a such that transistor has a long-channel threshold voltage of −0.3V and subthreshold slope of 75mV/decade.

(b) What is the minimum channel length such that $dV_T/dL < 0.005$V/nm. Use the expression for short channel effects on threshold voltage given in Taur and Ning. What is the associated threshold voltage at this channel length?

(c) What is the minimum channel length such that $I_{\text{off}}/W < 10^{-4}A/\mu$m with V_{GS} = 0V and V_{DS} = 1.0V.

(d) Would the minimum channel lengths calculated in (b) and (c) be larger or smaller for uniformly doped channel with same long channel threshold voltage? Explain.