ENEE 601 FINAL EXAM SPRING 2005

1. Bipolar Transistors a. Assume the transistor collector current is 10^{-3} Amps, estimate g_m, r_π and C_{diff}.

b. "Reach-through" occurs when the collector-base space charge extends fully through the neutral base. Assume the following: a 5V supply, $N_d(emitter) = 10^{19}/cm^3; N_a(base) = 10^{17}/cm^3; N_d(collector) = 10^{16}/cm^2$. What is the minimum separation between collector-base and emitter-base metallurgical junctions which would keep the component out of reach-through?

c. Noise is an important concern in any analog design. Due to random scattering in materials, there will be a distribution of path lengths to collection for any transported mobile carrier. The distribution is modeled as a "Poisson" distribution whose "width" is the square root of its mean. Thus, current fluctuations are usually expressed as:

$$< i^2 >= 2qI\Delta f \tag{1}$$

where q is the electron charge, I is the mean current and Δf is the system bandwidth. Using Shockley-Reed theory, calculate the "leakage" noise of the collector-base junction of the transistor described above. Assume the transistor described in this problem is in forward active. You may take the junction areas to be 10^{-7}cm^2. Compare this noise to the shot noise of the total forward current, which you may take to be 1.0mA. Assume "unity" bandwidth ($\Delta f = 1Hz$).

Throughout the exam, you may take: $\tau = 10^{-4} sec$, $L_n = L_p = 10^{-3} cm$. You may also take the saturation current of any of the bipolar diodes as being $10^{-14} - 10^-15$.

2. MOSCAPs

a. For a MOSCAP on p-material ($N_a = 10^{16}/cm^3$), with NO interface of bulk oxide charge, evaluate the metal-semiconductor work function difference, taking $\chi_{si} = 4.05$eV, and a metal work function of 4.5eV. Does the work function raise or lower the threshold?

b. For the capacitor in (a) above, assume an interface state density of 10^{11} states per cm^2 per eV. Furthermore, take the states to be donor-like. Calculate the flat-band shift resulting from this charge. Be clear to specify explicitly whether the turn-on is raised or lowered. The oxide thickness is 10nm.

3. MOSFETS

a. Consider an n-channel MOSFET. Take the mean bulk doping to be $N_a = 10^{16}$. Further, take W= .10μm and L = 0.03μm (a deeply scaled MOSFET!) The insulator thickness is 4nm. Assume doping is a "Poisson" process, as defined above. What would you anticipate the statistical uncertainty in threshold voltage would be due to doping fluctuations? Note: here, of course, "bandwidth" doesn't play a role. We just assume the fluctuation goes as the square root of the mean.

b. Describe, verbally, what is meant by saturation in a MOSFET.

c. Derive a formula to estimate the electric field in the high-field drain region of a MOSFET operating in saturation.