ECE 416/516 Simulation Assignment #2: Diodes (100 points) **Due 12/2/2016 5PM**

This assignment is intended to explore the behavior of p-n junctions and modeling tools through calculation of some basic diode parameters in Matlab and modeling in SPICE and ATLAS.

Doping profiles: (i) $N_A = 1\text{x}10^{17}$ and $N_D = 1\text{x}10^{15}$; (ii) $N_A = 1\text{x}10^{15}$ and $N_D = 1\text{x}10^{17}$; (iii) $N_A = 1\text{x}10^{16}\ cm^{-3}$ and $N_D = 1\text{x}10^{16}$; (iv) $N_A = 5\text{x}10^{14}\ cm^{-3}$ and $N_D = 5\text{x}10^{15}\ cm^{-3}$. Assume T = 300 K, minority carrier lifetime = 15 µs, a cross-sectional area of 2 µm × 1 µm, both regions are uniformly-doped Si (M=0.5), and ideal ohmic contacts. Use the equation below for mobility as needed.

$$\mu_n \approx 88 + {}^{1252}\!/_{(1 + 6.95 \times 10^{-18}\, N_D)}\ {}^{cm^2}\!/_{Vs} \qquad \mu_p \approx 54.3 + {}^{407}\!/_{(1 + 3.75 \times 10^{-18}\, N_A)}\ {}^{cm^2}\!/_{Vs}$$

1) <u>Matlab (30 points)</u>: ((Checkpoint: figures due 11/18/2016 11:59PM, 0.5 point per day late penalty)

a) Assuming ideal diode operation, calculate and tabulate (make a table of) the following values for each doping profile:

   I_0: Reverse saturation current
   C_{j0}: zero-bias junction capacitance
   $C_{j,-3V}$: junction capacitance at -3V bias (3V reverse bias)
   V_{bi}: built-in voltage

b) Using these values, create log(|I|)-V curves from -1.5 to 1.5 V for each doping profile. Present all four plots on one graph, labeling everything clearly and including positive and negative voltages. Again, assume ideal diode operation and note that the absolute value is needed for a log plot.

c) We assumed uniform doping profiles for section a) and b); in practice however, it is difficult to achieve highly abrupt junctions. So if we have a linearly graded junction, plot the doping concentrations, electric field, and voltage potential for dopant grading constant is $20^{20}/cm^4$.

d) Compute the I-V curve for doping profile iii with a minority carrier lifetime of 150µs (a reasonable value for relatively pure Si). Plot both I-V curves (15µs and 150µs) together on a graph. Explain what differences there are and why.

2) <u>SPICE (30 points)</u>: (Checkpoint: figures due 11/25/2016 11:59PM, 0.5 point per day late penalty)

Using the example netlist given and the values calculated for $N_A = 1\text{x}10^{16}\ cm^{-3}$ and $N_D=1\text{x}10^{16}\ cm^{-3}$, create a SPICE diode model and perform a DC sweep simulation to replicate the I-V curve produced in Matlab (-1.5 V to 1.5 V). Compare this result to part 1 b) and identify any non-ideal effects that SPICE considers.

516 STUDENTS ONLY	Using SPICE, plot the response of your diode model to a 0 V, 1. 5 V, 0 V, -1.5 V square-wave (transient analysis). Report rise and fall times (90% of max or min) for forward and reverse biases, and discuss the effect that using a higher purity material would have (and why).

3) <u>ATLAS (40 points)</u>:

a) Using the attached SILVACO ATLAS device simulation deck as a starting point, create an I-V curve for the same diode ($N_A = 1\text{x}10^{16}\ cm^{-3}$ and $N_D=1\text{x}10^{16}\ cm^{-3}$) from -1.5 to 1.5 V. Compare your results to those from SPICE and Matlab. Label all three conduction regimes and identify the ideality factor of each.

b) Apply 5V reverse bias to the model. Using TonyPlot, create four separate graphs of (i) mobile carrier concentration, (ii) energy bands, (iii) electric field, and (iv) electric potential along a cutline at x = 0.5 µm and y = 0 µm to 2 µm.

<u>Report</u>: Every table or graph should be followed by a brief but detailed explanation. This is what your grade will be based on. Describe the physical processes behind any trends you see; for example, don't just write "conductivity increases with doping," *explain* why doping affects conductivity from a physical standpoint. **There is a penalty of two points off per day for late submissions.**