

Project Assignment

[4/10/11 ver.]

EE 5340 - Semiconductor Device Theory

Due April 26, 2011

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All project solutions should be submitted on 8.5" x 11" paper with a cover sheet attached. The project report should be stapled only in the upper left-hand corner and no other cover or binder or folder should be used. The cover sheet should include (1) your name, (2) the project title, (3) the course name and number, and (4) your e-mail address. The report should include clearly marked sections on (a) purpose of the project and the theoretical background, (b) a narrative explaining how you did the project, (c) answers to all questions asked in the project assignment, and (d) a list of references used in the order cited in the report (the reference number should appear in the report each time the reference is used). All figures and tables should be clearly marked with a figure or table number and caption. The caption and labels on the figures should make the information in the figure comprehensible without reading further in the text of the report. Auxiliary information (such as SPICE data outputs, etc.) should be included in appropriate Appendices at the end of the report. Be sure to describe exactly how all results were obtained, giving enough information for anyone who understands EE 5340 to repeat your work. All work submitted must be original. If derived from another source, a full bibliographical citation must be given. (See all of Notes 5 and 6 in the syllabus.) Click [solution.pdf](#) to download a pdf file copy. Use the IEEE style sheet to write project report (plus cover sheet and auxiliary information). For further information, see <http://ieee.org/documents/TRANS-JOUR.doc> and http://ieee.org/publications_standards/publications/authors/authors_journals.html.

Using SPICE to Verify a Thermometer Design Using a Diode

Introduction: A p-n junction diode can be used to generate a voltage which can be converted to temperature. The SPICE parameter values for IS, XTI, N, IKF, RS, ISR, NR and TNOM provide a sufficiently complete model to verify this concept and design the circuit to obtain the requisite temperature dependent voltage.

- A. For a diode model with SPICE parameters identified above, with applied voltage v_A and forward current i_D , it can be shown that the junction temperature, T_j is (approximately) given by the function defined in (1) as T_{jA} .

$$T_j = \text{TEMP} \approx T_{jA} \equiv \frac{q}{k} \frac{1}{N} \left[\frac{dv_A}{d(\ln(i_D))} \right]_{\min} - 273.15 \quad (1)$$

The constant k is Boltzmann's constant, and q is the magnitude of the electron charge. The "min" subscript notation is taken to mean the minimum value observed for the derivative of v_A as a function of $\ln(i_D)$. By definition, TEMP is the SPICE global simulation parameter for the junction temperature of the diode modeled with the parameters above. TNOM is the temperature at which the parameters have been determined. At the condition thus described, the diode state is specified as $i_{D,\min}$, $v_{A,\min}$.

- Using the SPICE diode equations, derive the above approximation. For simplicity, assume that the parameters IS, IKF and ISR are temperature independent. In all cases, assume $300 \text{ mV} < v_A < 1 \text{ V}$.
 - Do the derivation for $v_{A,\min}$ in terms of the SPICE parameter values, finding the value of $v_{A,\min}$ for which T_{jA} , as defined in (1), best approximates $\text{TEMP} = T_j$. In other words, derive the equation for $v_{A,\min}$ in terms of IS and ISR, etc., which gives the minimum for the logarithmic derivative expressed in (1).
 - Find the value $v_{A,\min}$ in the limit of $RS > 0$, and $IKF \rightarrow \infty$. (Note that setting $IKF = 0$ in a SPICE simulation has the effect $IKF \rightarrow \infty$.)
 - Or** find the value $v_{A,\min}$ in the limit of $RS = 0$, and $IKF < i_D(v_A=1V)$
 - Express your conclusion in the form of a plot of $(T_{jA} - T_j)$ vs. IS/ISR , in terms of values of IKF/IS or $i_D(v_A=1V) \times RS/(1V)$.

- B. Derive theoretical calculations for IS, IKF, RS and ISR as a function of process parameters (N_d , N_a , etc.) for a diode which will minimize the error function ($T_{jA} - T_j$). Assume that $N=1$, $NR=2$ and $XTI=3$. Further, assume the diode is made with either a p+ diffusion into an n-type (phosphorous doped) wafer, or an n+ diffusion into a p-type (boron doped) wafer, and that the thickness of the wafer is 700 μm . For simplicity, assume the diode chip will be 100 μm by 100 μm , and that the one-dimensional diffusion current theory applies at the depletion regions boundaries. Assume the diffusion is 1 μm deep. For minority carrier mobility, assume the same value that Muller and Kamins give for majority carrier mobility. For minority carrier recombination rates, apply the results given in M. E. Law, E. Solley, M. Liang, and D. E. Burk, "Self-Consistent Model of Minority-Carrier Lifetime, Diffusion Length, and Mobility," IEEE Electron Device Lett., vol. 12, pp. 401-403, 1991.
1. You may assume that all that you need do is to choose the doping concentration and doping type of the lightly doped wafer. You should give a justification for making this assumption.
 2. Report the values of IS, IKF, RS, ISR you calculate for the best diode.
 3. Using SPICE simulation, calculate the values of ($T_{jA} - T_j$) using the values reported in B.2. Report these values for the simulation temperature range for T_j of $-40\text{ C} < \text{TEMP} < 100\text{ C}$.
 4. Report this result in a graph of ($T_{jA} - T_j$) vs. $T_j = \text{TEMP}$.
 5. Identify the SPICE parameter most responsible for error parts B.4 and B.5.
 6. Verify the correctness of the theoretical values of v_A derived in A.1.a. Discuss reasons why the values of v_A you observed in the simulations of B.3 are different than the theoretical values you predicted.
- C. A simple thermometer circuit can be made by using a 9 V source, V , in series with a resistor and a diode.
1. Using the diode parameters you derived in B.2, determine the values of the resistor, R , that at $T=300\text{ K}$ will give

$$V - i_{D,\text{min},300} \times R = v_{A,\text{min},300} \quad (2)$$

2. Using the value of R from (2) in the circuit thus defined, plot the value of v_A as a function of TEMP for the range $-40\text{ C} < \text{TEMP} < 100\text{ C}$.
3. Will this function serve as a voltage to temperature conversion? Report the computation that will be required to convert these voltage values to a Celsius temperature scale?