

Project 1 Assignment – Diode Characterization (Solution Draft)

EE 5342 - Semiconductor Device Theory

Project 1 Test on March 24, 2005

Download this assignment at <http://www.uta.edu/ronc/5342/projects/5342Project1.pdf>

All project solutions should be submitted on 8.5" x 11" paper with a cover sheet attached when the Project 1 Test is taken. The project report should be limited to 20 pages and stapled only in the upper left-hand corner with no other cover or binder or folder. 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 5342 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.) Download a sample solution at <http://www.uta.edu/ronc/5340/project/40ProjectSolution03.pdf>.

I. Semiconductor Device Capacitance-Voltage Characteristics

A. The Capacitance-Voltage (C-V) characteristics of a semiconductor device are given in http://www.uta.edu/ronc/5342/projects/Project_1/CVdata.xls

Fit the SPICE model equation given in Equation 1 to the data in order to determine the values for C_{J0} , V_J and M .

$$C_j = C_{J0} \left[1 - \frac{V_a}{V_J} \right]^{-M} \quad \text{Equation 1}$$

A1. Develop extraction techniques on the data given in the Excel file for determining C_{J0} , V_J and M . You might want to do this along the lines of Lecture 10, page 9 and following.

According to the lecture referenced above, to fit a data set to Equation 1 a plot of the function formed from the data of $y \equiv \{d[\ln(CJ)]/dV\}^{-1}$ vs. V has slope of $-1/M$ and y -axis intercept of V_J/M for the range chosen for the fit.

A2. Include a table of the C-V data, including columns for $y \equiv \{d[\ln(CJ)]/dV\}^{-1}$, and dy/dV . Also include a graph of y vs. V . Refer to the table to form a hypothesis for the best range of data to use for the SPICE capacitance model equation.

The table is given in Appendix A, and includes V_{ext} , C_j , y (as defined above) and the apparent M -value, $m_{eff} = -dV_{ext}/dy$. The derivatives were taken using the central difference method, except at the end-points, where the forward derivatives were used. (Note that in the case where forward derivatives are calculated, the voltage is the

average of the two end-points of the derivative - values in **bold** on the tabulation.) The only range where m_{eff} is nearly constant is for $-0.1 \text{ V} < V_{ext} < 0.4 \text{ V}$.

A3. Use these extraction techniques on the data given to determine estimates for CJO, VJ and M. What forward voltage range actually fits the standard CV model? (Hint: You might want to try to prove that this will be for $V_a > V_{PT}$.)

The graph of y vs. $V_{ext} = V_a$ is shown in Figure A3.1 with a straight line least-squares fit for $V_a > 0.2 \text{ V}$. An even better ($R \sim 1$) would be obtained if only data for $V_a > 0.3 \text{ V}$ were used.

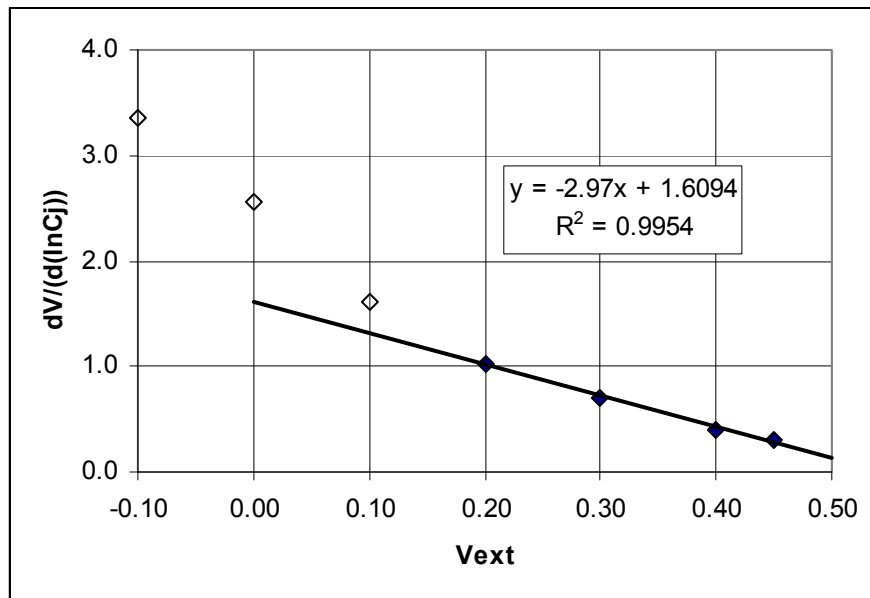


Figure A3.1: $dV/d(\ln C_j)$ vs V_{ext} for the data given. The intercept is 1.61 V. and the slope is 2.97 (giving $M_{eff} = 0.337$, and $V_{J_{eff}} = 0.542 \text{ V}$).

The effective M -value is 0.337 and the effective VJ value is 0.542. The former is not consistent with the profile that we observe later on (more like a step junction) and the latter is, consistent with a $P+n$ junction in that $VJ \sim E_g/2k$. For these values of M and VJ , we can solve for CJO in terms of $C_j(0.2)$ (which is the lowest V_{ext} value which fits the model).

$$CJO = C_j(0.2) * (1 - 0.2/VJ)^M = 2.03E-13 \text{ Fd}$$

A4. Using the pin/srd diode theory, determine the punch through voltage, V_{PT} , for this device.

The V_{pt} value will be determined later in part C1.

A5. Determine the thickness of the intrinsic region from the CV data.

This will also be determined later in part C1.

A6. What adjustments to the SPICE model can you suggest in order to create a better model? (Hint: What auxiliary circuit would you add in order to model the diode for operation at $V_a < V_{PT}$?)

Since $C_j = 0.189 \text{ pF}$ for $-4.0 \text{ V} < V_{ext} < -0.5 \text{ V}$, perhaps it would be better to let

$$C_j = C_i + C(\text{SPICE})$$

B. A7. Add a column to the table generated in part A2 which includes the values calculated with the extracted model parameters in Equation 1. Determine the least squares error (L.S.E.) between the data and the model equation and comment on the consequence of this error. Note that Equation 2 has been corrected. Student calculations may result in different numbers if the correction has not been made.

The column has been added to the table in Appendix A. The L.S.E. determined by Equation 2 (corrected) is $9.58\text{E-}15 \text{ Fd}$, which works out to be an average error of 5%.

$$\text{L.S.E.} = \sum \sqrt{(C_{\text{SPICE}}(v_i) - C_{\text{data}}(v_i))^2} / (\# \text{ data points}) \quad \text{Equation 2}$$

C. If the area of this junction is known to be 804 sq. microns, determine the doping concentration on the lightly doped side as a function of depletion width. The concentration is related to the C-V data by Equation 3.

$$N(x_n) = -\frac{2}{\epsilon q A^2} \frac{d(C^{-2})}{dV} = \frac{C^3}{\epsilon q A^2} \left(\frac{dC}{dV} \right) \quad \text{Equation 3}$$

Another column has been added to the table in Appendix A for calculations of $N(x)$, and a final column for calculations of x . Note that the second equality in Equation 3 is the more accurate to use for finite difference calculations, and has been used throughout.

C1. Plot $N(x)$ as a function x_n . Consider data for $-5.0 < v_a < 0.5 \text{ V}$. What doping function $N(x_n)$ best fits this plot (linear, square, exponential, etc.)?

The plot is shown as Figure C1.1.

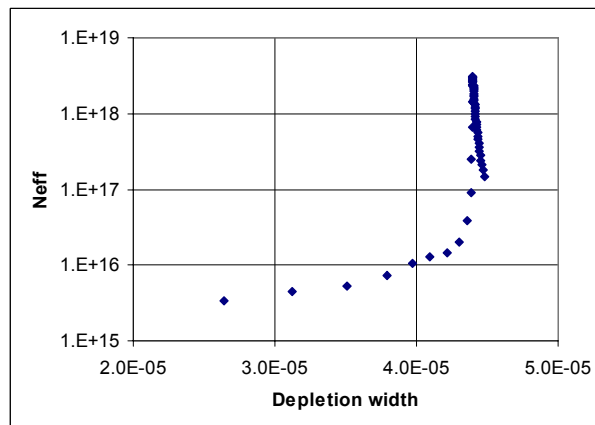


Figure C1.1: The effective doping concentration (Equation 3) versus depletion width.

This most nearly fits a step junction with $N^- \sim 1E16/cm^3$ for $W < 0.44 \mu m$. It appears that $P^+ \sim 1E18/cm^3$. The punch through voltage would be computed for such a P+n junction when the depletion width is 0.44 microns (i.e., the intrinsic region width).

$$W_i = \sqrt{\frac{2\epsilon(V_{bi} - V_{pt})}{qN^-}} = 0.44 \mu m, \quad V_{bi} = V_t * \ln(N^+ * N^- / n_i^2) \quad \text{Equation C1.1}$$

For the concentrations given, $V_{bi} = 814 \text{ mV}$, and $V_{pt} = -682 \text{ mV}$. The value used for V_t is 0.025843 V .

C2. Is the function determined in C1 consistent with the value of M determined in A2? Why, and should a different model be used in SPICE for this diode?

This was noted in A3. Using $C_j = C_i + C(\text{SPICE})$ would work better. Note that using 0.44 microns for the intrinsic region thickness gives $C_i = 0.189 \text{ pF}$.

II. Semiconductor Device Static Diode Characteristics

D. See http://www.uta.edu/ronc/5342/projects/Project_1/IVdata.xls for the IV data.

D1. Use these data to extract values for I_S , N , I_{SR} , N_R , and R_S . Document the procedures you use and why you choose these procedures.

Following the procedures developed in lectures, parameters $n_{eff} = \{dV_d/d[\ln(i_D)]\}/V_t$ and $I_{Seff} = \ln(i_D) - V_d/(n_{eff} * V_t)$ and $R_{Seff} = dV_d/di_D$, were calculated for each data point. The results of these calculations are in Appendix B and plotted in Figures D2.1 and D2.2.

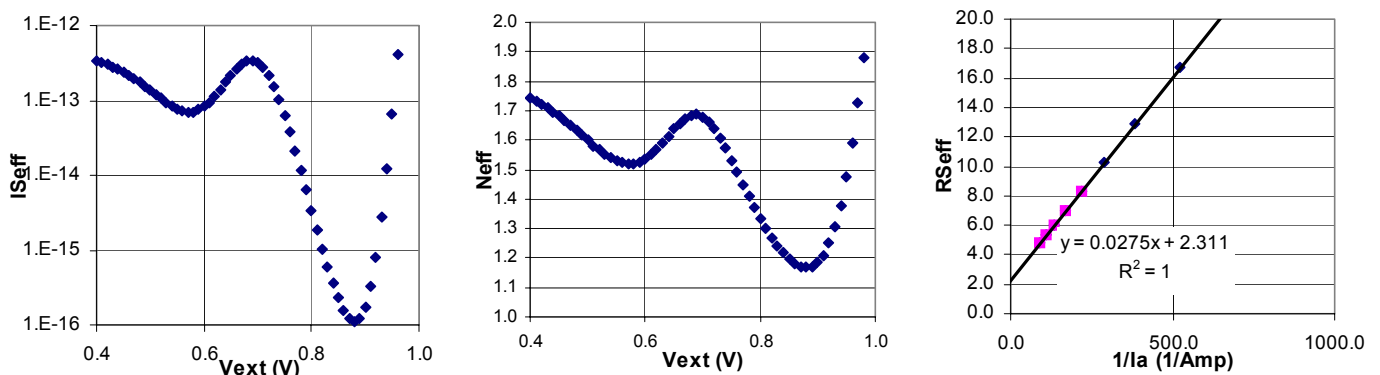


Figure D2.1: I_{Seff} and N_{eff} and R_{Seff} for the data given in Appendix B

The values chosen to fit the 700mV to 1000mV data range for I_S , N , I_{SR} , N_R and R_S are given in Table D3.1. These were chosen at 880mV for I_S and N , and 690mV for I_{SR} and N_R . The value of R_S was chosen from R_{Seff} extrapolated to infinite current.

The values chosen to fit the 300mV to 1000mV data range for IS, N, ISR, NR and RS are given in Table D1.1. These were chosen at 880mV for IS and N, and 690mV for ISR and NR. The value of RS was chosen from RSeff extrapolated to infinite current.

Table D1.1: Values chosen for SPICE parameters

lower lim	700 mV	300 mV
IS	1.12E-16	1.12E-16
N	1.17	1.17
ISR	3.44E-13	6.99E-14
NR	1.69	1.52
RS	2.311	2.311

The simulated data are shown in Appendix C. Note that the error for the 300 mV fit is as large as 106%, whereas, the 700 mV fit has a maximum value of 66%.

D2. Develop the best least squares static model values for IS, N, ISR, NR, and RS for operating the diode in the range $700\text{mV} < v_{\text{ext}} < 1000\text{mV}$. (i.e. minimize the least squares error – by trial and error). (Corrected again.)

$$\text{L.S.E.} = \sum \sqrt{(i_{\text{SPICE}}(v_i) - i_{\text{data}}(v_i))^2} / (\# \text{ data points}) \quad \text{Equation 4}$$

This can be done in iccap.

D3. Repeat D2 for the range 300mV to 1V.

This can be done in iccap.

D4. Comment on the differences in the parameter values obtained in D2 and D3.

The differences are largely due to selecting a lower voltage at which to estimate the ISR and NR values. Also, the values extracted are done assuming only one exponential fits the data. The ISR, NR values should be extracted with the IS, N model removed from the data. Lastly, if a reliable RS value is known, then the data can be interpreted in terms of the voltage across the depletion region, $V_a = V_{\text{ext}} - I_d \cdot R_S$. Note that the optimization with iccap (or any other package) gives RS values different than what is found in the y-parameter measurements (which are the most reliable).

III. Semiconductor Device Y-parameters

E. See http://www.uta.edu/ronc/5342/projects/Project_1/Ydata.xls for the Y-parameter data.

E1. Use the corner frequencies at each voltage to determine the TT parameter and the C(Va) function over the range of Va values given.

The y-parameters were converted to z-parameters, using the relations $\text{Re}\{z\} = \text{Re}\{Y\}/|Y|^2$, and $\text{Im}\{z\} = \text{Im}\{Y\}/|Y|^2$. These data should fit the model equation:

$$\text{Re}\{Z\} = \frac{r_d}{1 + 4\pi^2 f^2 r_d^2 C_d^2} + RS \quad \text{Equation E1.1}$$

Thus, the frequency at which $\text{Re}\{z, f\} - \text{Re}\{z\}_{\min} = (\text{Re}\{z\}_{\max} - \text{Re}\{z\}_{\min})/2$ gives the corner frequency, $f_c = 1/(2\pi r_d C_d)$. (Note RS is identified as $\text{Re}\{z\}_{\min}$. Furthermore $r_d = 1/g_d$ where $g_d = g_{d, \text{raw}} = g_{d, \text{inj}} + g_{d, \text{rec}}$, due to both the injection and recombination current.) The value of $r_{d, \text{rec}}$, ($r_{d, \text{rec}} C_d = TT$) is estimated by

$$r_{d, \text{rec}} = r_{d, \text{raw}} \left(1 + \frac{ISR \cdot N}{IS \cdot NR} \exp \left(\frac{(v - iR) \left(\frac{1}{NR} - \frac{1}{N} \right)}{Vt} \right) \right) \quad \text{Equation E1.2}$$

Table E2 shows the values of TT extracted at each voltage (current). The value at 300 mV cannot be extracted as the maximum for $\text{Re}\{Z\}$ is unknown. The value at 500 mV is essentially the same as $C_j(500 \text{ mV})$ from the C_j data, so at this potential, the diffusion charge is negligible. There is not a constant value of TT , but the TT_{adj} probably represents the true value that should be used in the SPICE model.

E2. Make a comparison of the various limiting values of the Y-parameter data to the values you observe from the static parameters obtained in part D. For instance, the low frequency limit of $\text{Re}(Z)$ should be

$$\lim_{f \rightarrow 0} \text{Re}\{Z\} = g_d^{-1} + RS \quad \text{Equation 5}$$

The high frequency limit should be RS .

The limiting values of $\text{Re}\{Z\}$, with other parameters and calculations are shown in Table E2. Note that $dv/di \sim \text{Re}\{Z\}$ at 10 kHz, which is what we should observe, the differential dc conductance should be $rd + rs$. Note further that RS seems to be voltage or current dependent. This is probably due to the conductance of the intrinsic region being first small and adding resistance and then modulated to higher values due to high level injection thus reducing resistance at higher applied bias.

Table E2: The limiting values of $\text{Re}\{Z\}$, with corner frequency, effective total capacitance and transit time (both raw and adjusted to include $r_{d, \text{inj}}$ only).

va	ia	dv/di	Re{Z}, 10k	Re{Z}, 10G	fcorner	Ctot	(Rlo-Rhi)*C	rdinj*C
0.30	2.79E-10	1.50E+08	n/a	4.83			= TTraw	= TTadj
0.50	2.45E-08	1.67E+06	1.68E+06	7.14	2.22E+05	4.26E-13	7.16E-07	8.07E-06
0.70	3.26E-06	1.32E+04	1.33E+04	4.76	1.09E+06	1.10E-11	1.46E-07	4.69E-07
0.80	4.18E-05	8.10E+02	8.24E+02	2.89	2.24E+06	8.67E-11	7.12E-08	1.44E-07
0.90	1.01E-03	2.98E+01	3.02E+01	2.45	7.36E+06	7.79E-10	2.16E-08	3.21E-08
1.00	1.34E-02	4.54E+00	4.35E+00	2.35	1.78E+07	4.46E-09	8.92E-09	1.14E-08

E3. Is the value of g_d obtained for each V_d in part E2 consistent with the IV data and the N value you obtained? Comment on any differences.

See comments in E2.

E4. Confirm your determination of I_S , N , I_{SR} , N_R and R_S based on these Y-parameters.

This can be done by using the above values to calculate $g_d = di/dV$ using the model equations.

E5. This data will not fit the ordinary diode model exactly. Is it possible to make a combination of diodes that will fit the data better? Describe.

Yes. In this case, we used a parallel combination of D_{inj} (with I_S , N , C_{j0} , M , V_J , F_C , T_T) and D_{rec} (with I_{SR} , N_R , $C_{j0} = 0$, $T_T = 0$) in series with R_S .

Note 1: The $\text{Re}\{Z\}$ IS NOT the same as $1/\text{Re}\{Y\}$. $\text{Re}\{Z\} = \text{Re}\{1/Y\} = \text{Re}\{1/(\text{Re}\{Y\} + j\text{Im}\{Y\})\}$

Appendix A.

Table AA.1: Data given for the C-V part of the project with data below -4 V truncated as it wasn't used.

Vext	Cj	y	Meff	Model	squared error	N(x)	x
-4.000	1.88E-13	167.6405	-0.006	9.94E-14	7.86E-27	5.525E+17	4.43E-05
-3.900	1.88E-13	184.2457	-0.006	1.00E-13	7.75E-27	6.079E+17	4.43E-05
-3.800	1.88E-13	201.8224	-0.006	1.01E-13	7.63E-27	6.666E+17	4.42E-05
-3.700	1.88E-13	219.93	-0.005	1.02E-13	7.50E-27	7.271E+17	4.42E-05
-3.600	1.88E-13	239.1102	-0.005	1.03E-13	7.38E-27	7.912E+17	4.42E-05
-3.500	1.88E-13	259.0304	-0.005	1.03E-13	7.25E-27	8.578E+17	4.42E-05
-3.400	1.89E-13	279.1786	-0.005	1.04E-13	7.11E-27	9.252E+17	4.42E-05
-3.300	1.89E-13	298.8427	-0.005	1.05E-13	6.97E-27	9.91E+17	4.42E-05
-3.200	1.89E-13	321.4616	-0.004	1.06E-13	6.82E-27	1.067E+18	4.41E-05
-3.100	1.89E-13	345.2029	-0.004	1.07E-13	6.67E-27	1.146E+18	4.41E-05
-3.000	1.89E-13	366.8812	-0.004	1.08E-13	6.52E-27	1.219E+18	4.41E-05
-2.900	1.89E-13	391.4433	-0.004	1.09E-13	6.36E-27	1.301E+18	4.41E-05
-2.800	1.89E-13	415.7956	-0.004	1.10E-13	6.19E-27	1.383E+18	4.41E-05
-2.700	1.89E-13	443.3566	-0.004	1.11E-13	6.02E-27	1.475E+18	4.41E-05
-2.600	1.89E-13	470.062	-0.004	1.13E-13	5.85E-27	1.565E+18	4.41E-05
-2.500	1.89E-13	494.9042	-0.004	1.14E-13	5.66E-27	1.648E+18	4.41E-05
-2.400	1.89E-13	522.5022	-0.003	1.15E-13	5.48E-27	1.741E+18	4.41E-05
-2.300	1.89E-13	553.34	-0.003	1.16E-13	5.29E-27	1.844E+18	4.4E-05
-2.200	1.89E-13	580.7691	-0.003	1.18E-13	5.09E-27	1.936E+18	4.4E-05
-2.100	1.89E-13	611.0403	-0.003	1.19E-13	4.88E-27	2.038E+18	4.4E-05
-2.000	1.89E-13	644.626	-0.003	1.21E-13	4.67E-27	2.15E+18	4.4E-05
-1.900	1.89E-13	672.3543	-0.003	1.22E-13	4.45E-27	2.244E+18	4.4E-05
-1.800	1.89E-13	702.5627	-0.003	1.24E-13	4.23E-27	2.345E+18	4.4E-05
-1.700	1.89E-13	735.5969	-0.003	1.26E-13	4.00E-27	2.456E+18	4.4E-05
-1.600	1.89E-13	771.877	-0.003	1.28E-13	3.76E-27	2.578E+18	4.4E-05
-1.500	1.89E-13	798.1441	-0.004	1.30E-13	3.51E-27	2.666E+18	4.4E-05
-1.400	1.89E-13	826.2509	-0.003	1.32E-13	3.25E-27	2.761E+18	4.4E-05
-1.300	1.89E-13	872.2556	-0.003	1.35E-13	2.99E-27	2.915E+18	4.4E-05
-1.200	1.89E-13	905.9077	-0.012	1.37E-13	2.72E-27	3.028E+18	4.4E-05
-1.100	1.89E-13	888.9151	0.004	1.40E-13	2.44E-27	2.972E+18	4.4E-05
-1.000	1.89E-13	856.6891	0.001	1.43E-13	2.16E-27	2.865E+18	4.4E-05
-0.900	1.89E-13	703.3507	0.000	1.46E-13	1.87E-27	2.353E+18	4.4E-05
-0.800	1.89E-13	428.4945	0.000	1.50E-13	1.57E-27	1.434E+18	4.4E-05
-0.700	1.9E-13	196.48	0.001	1.54E-13	1.28E-27	6.577E+17	4.39E-05
-0.600	1.9E-13	74.34468	0.001	1.58E-13	9.90E-28	2.491E+17	4.39E-05
-0.500	1.9E-13	27.22995	0.003	1.63E-13	7.23E-28	9.151E+16	4.38E-05
-0.400	1.91E-13	11.14207	0.009	1.69E-13	4.96E-28	3.778E+16	4.36E-05
-0.300	1.93E-13	5.834556	0.028	1.75E-13	3.31E-28	2.027E+16	4.3E-05
-0.200	1.98E-13	4.082356	0.081	1.83E-13	2.19E-28	1.483E+16	4.21E-05
-0.100	2.03E-13	3.362093	0.131	1.92E-13	1.24E-28	1.291E+16	4.1E-05
0.000	2.1E-13	2.550317	0.115	2.03E-13	4.25E-29	1.039E+16	3.97E-05
0.100	2.2E-13	1.619244	0.131	2.18E-13	3.96E-30	7.173E+15	3.79E-05
0.200	2.37E-13	1.028145	0.219	2.37E-13	0.00E+00	5.288E+15	3.51E-05
0.300	2.67E-13	0.704982	0.317	2.67E-13	3.84E-32	4.554E+15	3.12E-05
0.400	3.15E-13	0.39767	0.490	3.19E-13	1.55E-29	3.35E+15	2.64E-05
0.425			0.498				
0.450		0.297202					
0.500	4.41E-13			4.81E-13	1.60E-27		1.89E-05

Appendix B.

Table AB.1: The tabulation of data for the IV data.

va	ia	ia (700)	ia (300)	err700	err300	ISeff	Neff	1/ia	RSeff
3.00E-01	2.79E-10	3.38E-10	1.48E-10	21%	47%				
3.10E-01	3.45E-10	4.26E-10	1.91E-10	23%	45%	4.54E-13	1.81	2.90E+09	1.34E+08
3.20E-01	4.28E-10	5.36E-10	2.46E-10	25%	42%	4.48E-13	1.80	2.34E+09	1.08E+08
3.30E-01	5.30E-10	6.75E-10	3.18E-10	27%	40%	4.39E-13	1.80	1.89E+09	8.70E+07
3.40E-01	6.58E-10	8.51E-10	4.11E-10	29%	37%	4.30E-13	1.79	1.52E+09	6.99E+07
3.50E-01	8.16E-10	1.07E-09	5.31E-10	31%	35%	4.19E-13	1.79	1.23E+09	5.61E+07
3.60E-01	1.01E-09	1.35E-09	6.87E-10	33%	32%	4.07E-13	1.78	9.86E+08	4.50E+07
3.70E-01	1.26E-09	1.70E-09	8.88E-10	35%	30%	3.93E-13	1.77	7.93E+08	3.61E+07
3.80E-01	1.57E-09	2.14E-09	1.15E-09	36%	27%	3.78E-13	1.77	6.38E+08	2.88E+07
3.90E-01	1.95E-09	2.70E-09	1.48E-09	38%	24%	3.62E-13	1.76	5.12E+08	2.30E+07
4.00E-01	2.44E-09	3.40E-09	1.92E-09	39%	21%	3.44E-13	1.75	4.10E+08	1.83E+07
4.10E-01	3.04E-09	4.28E-09	2.48E-09	41%	18%	3.25E-13	1.73	3.28E+08	1.46E+07
4.20E-01	3.81E-09	5.40E-09	3.21E-09	42%	16%	3.04E-13	1.72	2.63E+08	1.16E+07
4.30E-01	4.77E-09	6.81E-09	4.16E-09	43%	13%	2.83E-13	1.71	2.10E+08	9.17E+06
4.40E-01	5.99E-09	8.59E-09	5.38E-09	43%	10%	2.61E-13	1.70	1.67E+08	7.25E+06
4.50E-01	7.53E-09	1.08E-08	6.96E-09	44%	8%	2.39E-13	1.68	1.33E+08	5.71E+06
4.60E-01	9.49E-09	1.37E-08	9.02E-09	44%	5%	2.16E-13	1.67	1.05E+08	4.49E+06
4.70E-01	1.20E-08	1.73E-08	1.17E-08	44%	3%	1.94E-13	1.65	8.34E+07	3.52E+06
4.80E-01	1.52E-08	2.18E-08	1.51E-08	44%	0%	1.73E-13	1.63	6.59E+07	2.75E+06
4.90E-01	1.93E-08	2.76E-08	1.96E-08	43%	2%	1.54E-13	1.62	5.19E+07	2.14E+06
5.00E-01	2.45E-08	3.49E-08	2.54E-08	42%	4%	1.36E-13	1.60	4.08E+07	1.67E+06
5.10E-01	3.12E-08	4.41E-08	3.30E-08	41%	6%	1.19E-13	1.58	3.20E+07	1.29E+06
5.20E-01	4.00E-08	5.58E-08	4.28E-08	40%	7%	1.05E-13	1.57	2.50E+07	1.00E+06
5.30E-01	5.12E-08	7.06E-08	5.56E-08	38%	9%	9.34E-14	1.55	1.95E+07	7.74E+05
5.40E-01	6.58E-08	8.95E-08	7.22E-08	36%	10%	8.39E-14	1.54	1.52E+07	5.98E+05
5.50E-01	8.47E-08	1.13E-07	9.39E-08	34%	11%	7.67E-14	1.53	1.18E+07	4.62E+05
5.60E-01	1.09E-07	1.44E-07	1.22E-07	32%	12%	7.20E-14	1.52	9.16E+06	3.57E+05
5.70E-01	1.41E-07	1.83E-07	1.59E-07	30%	13%	6.99E-14	1.52	7.10E+06	2.76E+05
5.80E-01	1.82E-07	2.33E-07	2.07E-07	28%	14%	7.06E-14	1.52	5.51E+06	2.14E+05
5.90E-01	2.34E-07	2.96E-07	2.69E-07	26%	15%	7.45E-14	1.53	4.27E+06	1.67E+05
6.00E-01	3.02E-07	3.77E-07	3.51E-07	25%	16%	8.23E-14	1.54	3.32E+06	1.30E+05
6.10E-01	3.88E-07	4.81E-07	4.58E-07	24%	18%	9.52E-14	1.55	2.58E+06	1.02E+05
6.20E-01	4.97E-07	6.14E-07	5.97E-07	24%	20%	1.14E-13	1.57	2.01E+06	8.10E+04
6.30E-01	6.35E-07	7.85E-07	7.80E-07	24%	23%	1.41E-13	1.59	1.58E+06	6.43E+04
6.40E-01	8.08E-07	1.01E-06	1.02E-06	24%	26%	1.75E-13	1.61	1.24E+06	5.12E+04
6.50E-01	1.02E-06	1.29E-06	1.34E-06	26%	30%	2.18E-13	1.64	9.76E+05	4.10E+04
6.60E-01	1.30E-06	1.66E-06	1.75E-06	28%	35%	2.64E-13	1.66	7.71E+05	3.28E+04
6.70E-01	1.63E-06	2.13E-06	2.29E-06	30%	40%	3.07E-13	1.67	6.12E+05	2.63E+04
6.80E-01	2.06E-06	2.75E-06	3.01E-06	34%	46%	3.38E-13	1.68	4.86E+05	2.10E+04
6.90E-01	2.59E-06	3.55E-06	3.95E-06	37%	53%	3.44E-13	1.69	3.86E+05	1.67E+04
7.00E-01	3.26E-06	4.60E-06	5.20E-06	41%	60%	3.22E-13	1.68	3.07E+05	1.32E+04
7.10E-01	4.10E-06	5.96E-06	6.84E-06	45%	67%	2.76E-13	1.66	2.44E+05	1.04E+04
7.20E-01	5.19E-06	7.75E-06	9.02E-06	49%	74%	2.16E-13	1.64	1.93E+05	8.08E+03
7.30E-01	6.58E-06	1.01E-05	1.19E-05	53%	81%	1.54E-13	1.61	1.52E+05	6.24E+03
7.40E-01	8.39E-06	1.32E-05	1.57E-05	57%	87%	1.02E-13	1.57	1.19E+05	4.78E+03
7.50E-01	1.08E-05	1.73E-05	2.08E-05	60%	93%	6.34E-14	1.53	9.29E+04	3.62E+03
7.60E-01	1.39E-05	2.27E-05	2.75E-05	63%	98%	3.72E-14	1.49	7.19E+04	2.73E+03
7.70E-01	1.81E-05	2.98E-05	3.65E-05	65%	102%	2.10E-14	1.45	5.52E+04	2.04E+03
7.80E-01	2.37E-05	3.94E-05	4.85E-05	66%	104%	1.15E-14	1.41	4.21E+04	1.51E+03
7.90E-01	3.14E-05	5.20E-05	6.45E-05	66%	106%	6.28E-15	1.37	3.19E+04	1.11E+03
8.00E-01	4.18E-05	6.90E-05	8.59E-05	65%	106%	3.41E-15	1.33	2.39E+04	8.10E+02
8.10E-01	5.61E-05	9.16E-05	1.14E-04	63%	104%	1.87E-15	1.30	1.78E+04	5.88E+02
8.20E-01	7.58E-05	1.22E-04	1.53E-04	61%	101%	1.04E-15	1.27	1.32E+04	4.24E+02
8.30E-01	1.03E-04	1.63E-04	2.04E-04	58%	98%	5.96E-16	1.24	9.69E+03	3.05E+02
8.40E-01	1.41E-04	2.18E-04	2.73E-04	54%	93%	3.57E-16	1.22	7.07E+03	2.18E+02
8.50E-01	1.95E-04	2.91E-04	3.64E-04	49%	87%	2.27E-16	1.20	5.13E+03	1.56E+02
8.60E-01	2.70E-04	3.90E-04	4.87E-04	44%	80%	1.58E-16	1.18	3.71E+03	1.11E+02
8.70E-01	3.75E-04	5.22E-04	6.51E-04	39%	73%	1.24E-16	1.17	2.67E+03	7.91E+01
8.80E-01	5.23E-04	6.99E-04	8.68E-04	34%	66%	1.12E-16	1.17	1.91E+03	5.67E+01
8.90E-01	7.28E-04	9.34E-04	1.16E-03	28%	59%	1.24E-16	1.17	1.37E+03	4.09E+01
9.00E-01	1.01E-03	1.24E-03	1.53E-03	23%	51%	1.75E-16	1.19	9.88E+02	2.98E+01
9.10E-01	1.40E-03	1.64E-03	2.02E-03	17%	44%	3.24E-16	1.21	7.15E+02	2.21E+01
9.20E-01	1.92E-03	2.16E-03	2.63E-03	12%	37%	8.14E-16	1.25	5.21E+02	1.67E+01
9.30E-01	2.60E-03	2.80E-03	3.40E-03	8%	31%	2.76E-15	1.31	3.85E+02	1.29E+01
9.40E-01	3.47E-03	3.59E-03	4.35E-03	4%	25%	1.22E-14	1.38	2.88E+02	1.02E+01
9.50E-01	4.55E-03	4.54E-03	5.47E-03	0%	20%	6.64E-14	1.47	2.20E+02	8.34E+00
9.60E-01	5.87E-03	5.66E-03	6.78E-03	4%	16%	4.08E-13	1.59	1.70E+02	7.00E+00
9.70E-01	7.41E-03	6.93E-03	8.26E-03	7%	11%	2.61E-12	1.72	1.35E+02	6.02E+00
9.80E-01	9.19E-03	8.34E-03	9.92E-03	9%	8%	1.62E-11	1.88	1.09E+02	5.30E+00
9.90E-01	1.12E-02	9.90E-03	1.17E-02	12%	5%	9.16E-11	2.06	8.94E+01	4.77E+00
1.00E+00	1.34E-02	1.16E-02	1.37E-02	14%	2%				

Appendix C

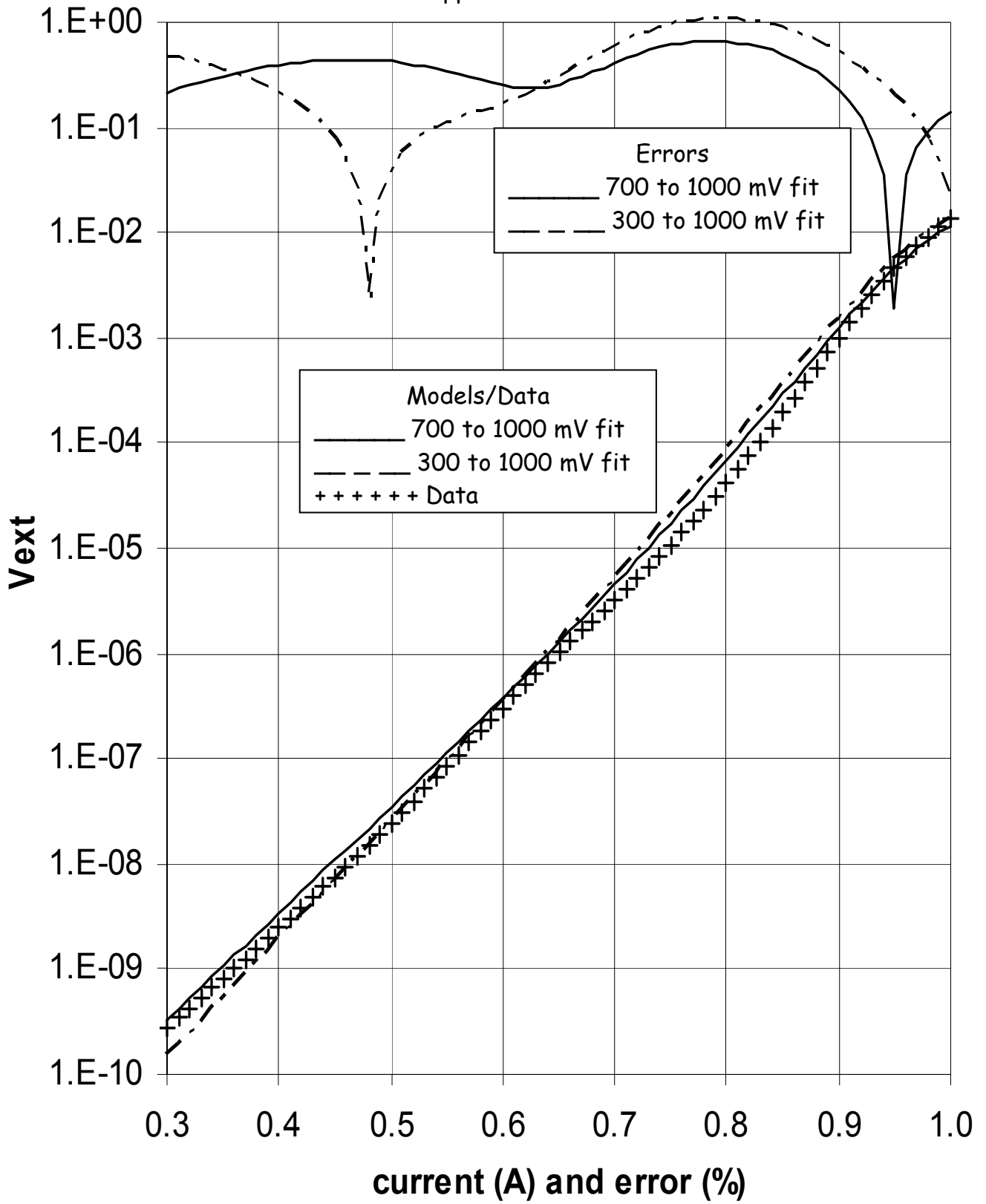


Figure A1: IV Data and model fits.

