EE128 Homework Set 3

Question 1:

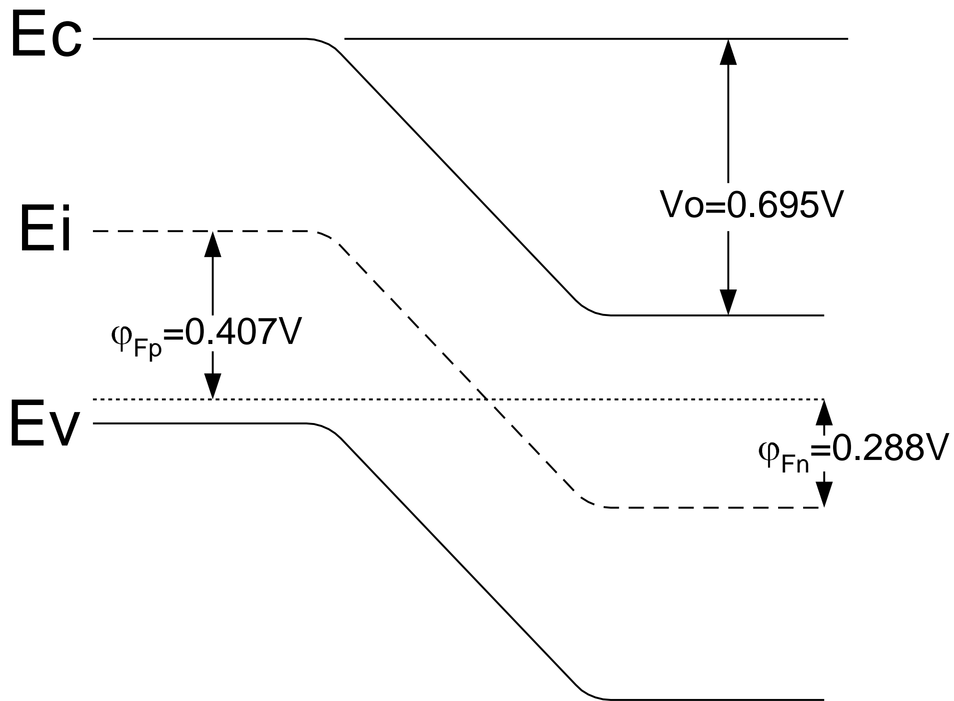
An abrupt Si p-n junction has the following properties at 300K:

p side	n side
$N_a=10^{17}cm^{-3}$	$N_d=10^{15}cm^{-3}$
$\tau_n=.1x10^{-6}s$	$\tau_p=10x10^{-6}s$
$\mu_p=400\ cm^2/Vs$	$\mu_n=1200cm^2/Vs$
$\mu_n=650\ cm^2/Vs$	$\mu_p=400\ cm^2/Vs$
$A=2x10^{-4}cm^2$	$A=2x10^{-4}cm^2$

a) Calculate the Fermi level positions at 300K in the n and p regions.

b) Draw the equilibrium band diagram for the junction and determine the contact potential Vo from the diagram.

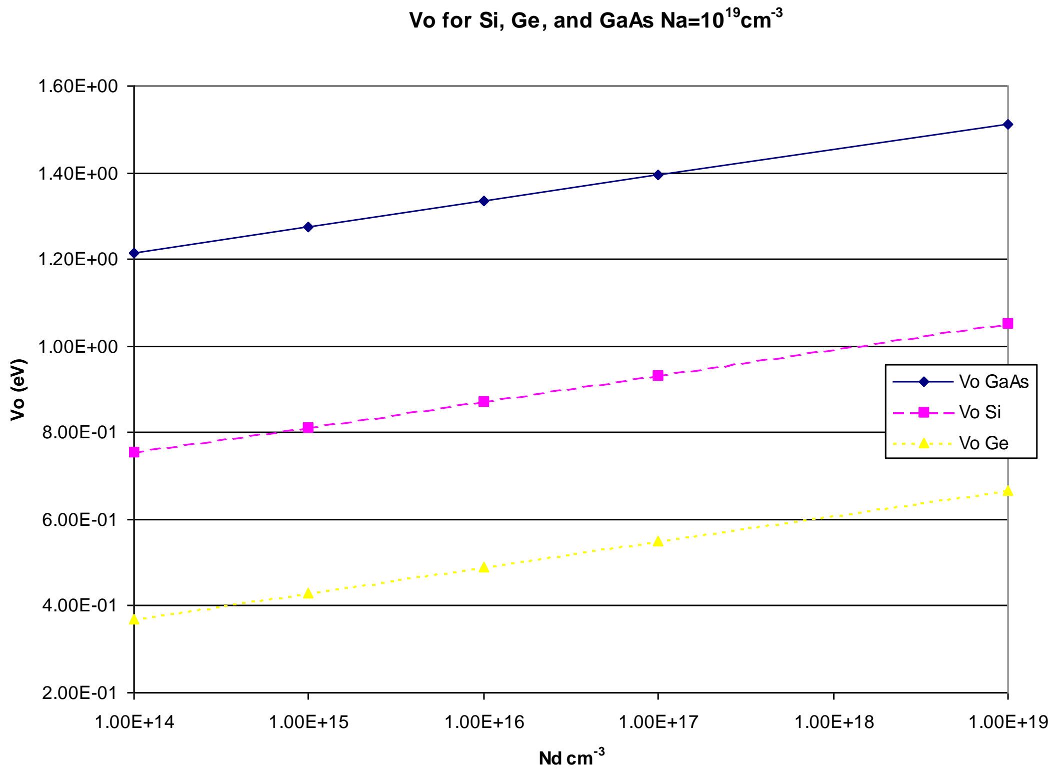
c) Calculate Vo according to the equation Vo=kT/qln(NaNd/ni2). Compare Vo to the value determined from your diagram.



$\varphi_{Fn} = \frac{kT}{q} ln\left(\frac{N_D}{ni}\right), \varphi_{Fp} = \frac{kT}{q} ln\left(\frac{N_A}{ni}\right) \quad Vo = \varphi_{Fp} + \varphi_{Fn}$

Question 2:

On one set of axis, plot Vo versus Nd for three p-n junctions made of GaAs ($n_i=2x10^6 cm^{-3}$), Si ($n_i=1.5x10^{10} cm^{-3}$) and Ge ($n_i=2.5x10^{13} cm^{-3}$), at 300K where $Na=10^{18} cm^{-3}$. Use a log axis for Nd from 10^{14}-$10^{19} cm^{-3}$. Shown below is a sample plot.



Question 3:

a) For the diode of question 1, calculate I for -8 volts, 0 volts (TE), and .5 volts.

Question 4:

a) For the diode of question 1, calculate xn and xp for -8V, 0V(TE), and .5V.

kT/q (V)	Si n_i (cm^{-3})	N_D (cm^{-3})	N_A (cm^{-3})	Vo(V)	ε_r Si	ε_o F/cm^2	V Applied (V)	T	x_p (cm)	x_n (cm)
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	-8.0	300	3.37E-06	3.37E-04
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	0.0	300	9.51E-07	9.51E-05
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	0.5	300	5.03E-07	5.03E-05

b) Calculate the depletion capacitance for the diode in question 1 for -8V, 0V(TE), and .5V.

V Applied (V)	T	x_p (cm)	x_n (cm)	W	Area cm^2	Cj (F)
-8.0	300	3.37E-06	3.37E-04	3.40E-04	2.00E-04	6.20E-13
0.0	300	9.51E-07	9.51E-05	9.61E-05	2.00E-04	2.19E-12
0.5	300	5.03E-07	5.03E-05	5.08E-05	2.00E-04	4.15E-12

c) For the diode of question 1, calculate the diffusion capacitance for 1 for -8V, 0V(TE), and .5V.

kT/q (V)	Si n_i (cm^{-3})	N_D (cm^{-3})	N_A (cm^{-3})	Vo(V)	ε_r Si	ε_o F/cm^2	V Applied (V)	Area cm^2
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	-8.0	2.00E-04
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	0.0	2.00E-04
0.026	1.5E+10	1.0E+15	1.0E+17	0.694	11.9	8.85E-14	0.5	2.00E-04

μ_n (cm^2/Vs)	μ_p (cm^2/Vs)	τ_n (s)	τ_p (s)	Dn (cm^2/s)	Dp (cm^2/s)	Ln (cm)	Lp (cm)	Igen (A)	I (A)	$Cs=q/kT*I*\tau_p$ (F)
650	400	1.0E-07	1.0E-05	16.82	10.35	1.30E-03	1.02E-02	8.26E-15	-8.26E-15	0.00E+00
650	400	1.0E-07	1.0E-05	16.82	10.35	1.30E-03	1.02E-02	8.26E-15	0.00E+00	0.00E+00
650	400	1.0E-07	1.0E-05	16.82	10.35	1.30E-03	1.02E-02	8.26E-15	2.04E-06	7.87E-10

There is no stored charge in reverse bias or TE so Cs=0.

Question 5:

a) For the diode in question 1, find the breakdown voltage.

From Fig 5-22 page 201 Vbr=300V.

b) What is the breakdown mechanism?

Avalanche

c) Why?

Given that W is ~16 microns at 200V, it takes 300V to reach to breakdown strength of Si (10^6V/cm)

Question 6:

Using the data from Figure 1, extract the built in voltage ad the substrate doping concentration N_A.

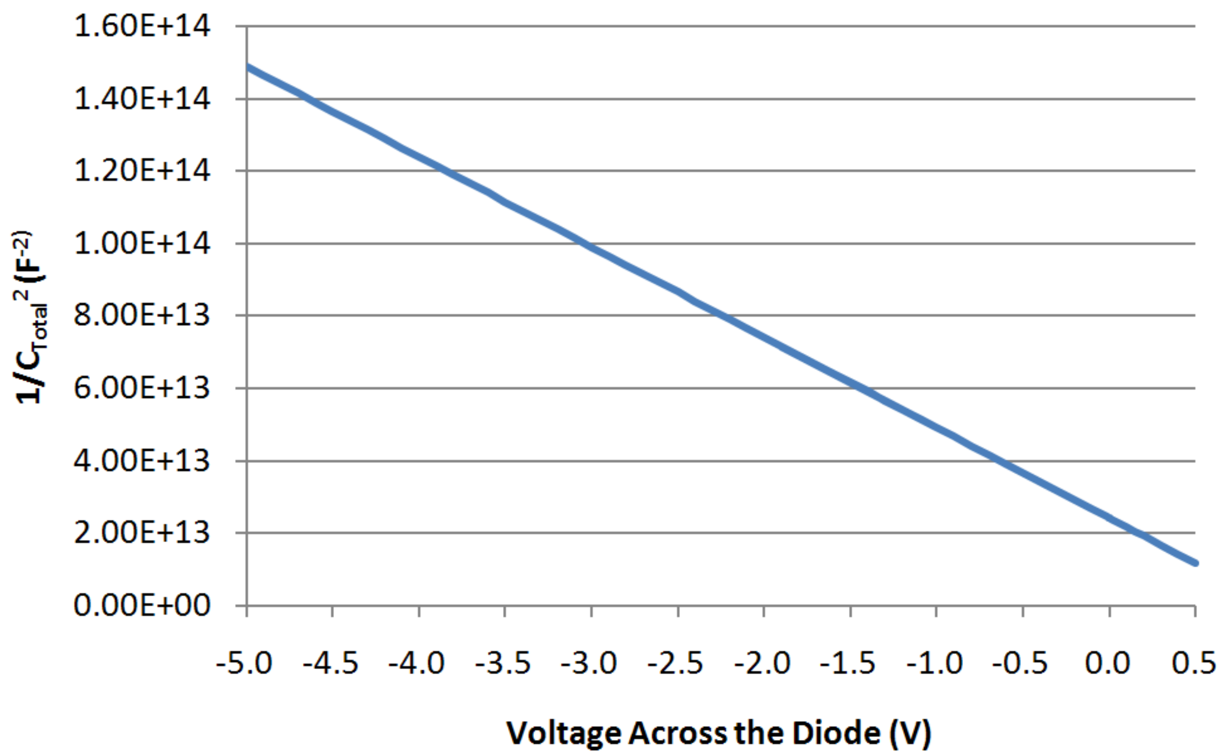
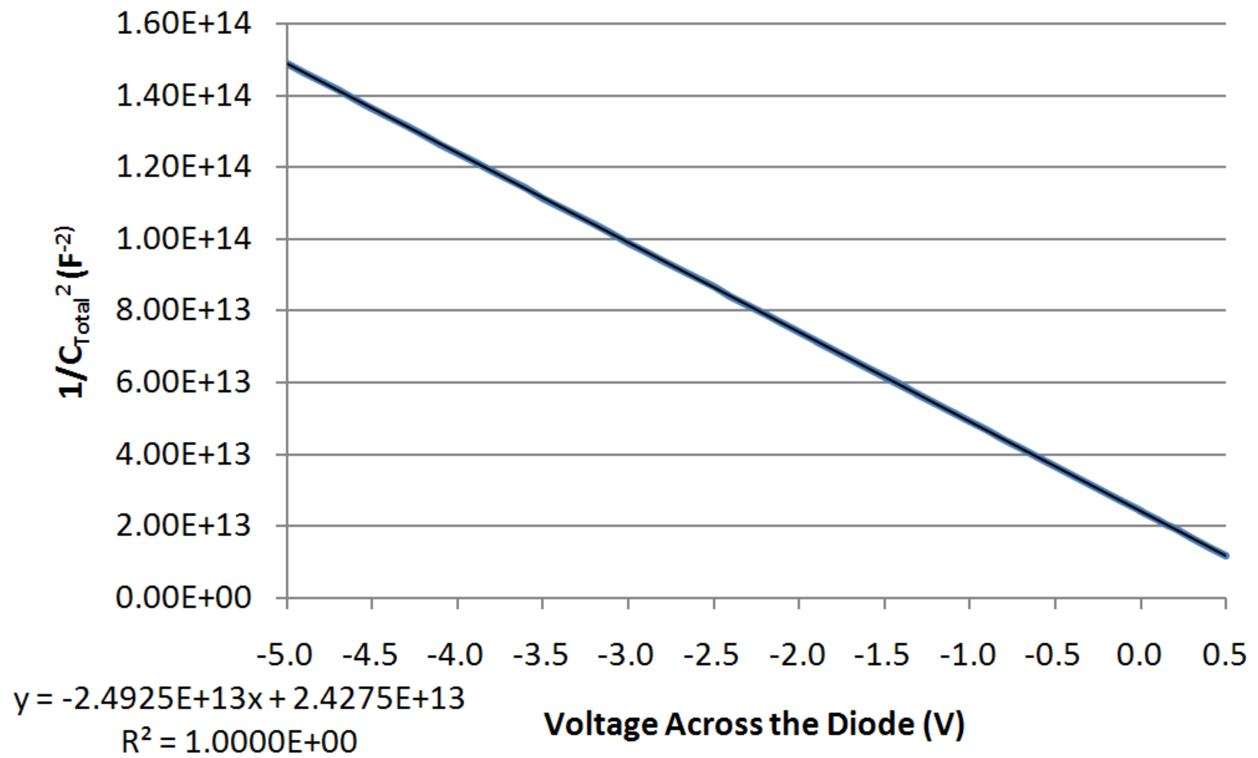


Figure 1: Data from a n+/p diode measured at 300K, with an Area of 1cm^2.



$$C_j = \frac{A}{2}\left[\frac{2q\varepsilon}{Vo - V} N_{substrate}\right]^{\frac{1}{2}}$$

$$\frac{1}{{C_j}^2} = \frac{4}{A^2\, 2q\varepsilon N_{substrate}}(Vo - V)$$

$$y = \frac{1}{{C_j}^2} = \frac{-2V}{A^2\, q\varepsilon N_{substrate}} + \frac{Vo}{A^2\, q\varepsilon N_{substrate}}$$

$$y = mx + b$$

$$m = \frac{-2}{A^2\, q\varepsilon N_{substrate}}$$

$$b = \frac{2Vo}{A^2\, q\varepsilon N_{substrate}}$$

$$N_{substrate} = \frac{-2}{A^2\, q\varepsilon m} = 4.76 \times 10^{17} cm^{-3}$$

$$\frac{Vo = bA^2\, q\varepsilon N_{substrate}}{2}$$

$$Vo = \frac{-b}{m} = \frac{-2.4275\times10^{13}}{-2.4925\times10^{13}} \quad = .973V$$

Question 7:

Using the data from Figure 2, extract the built Igen and the ideality factor.

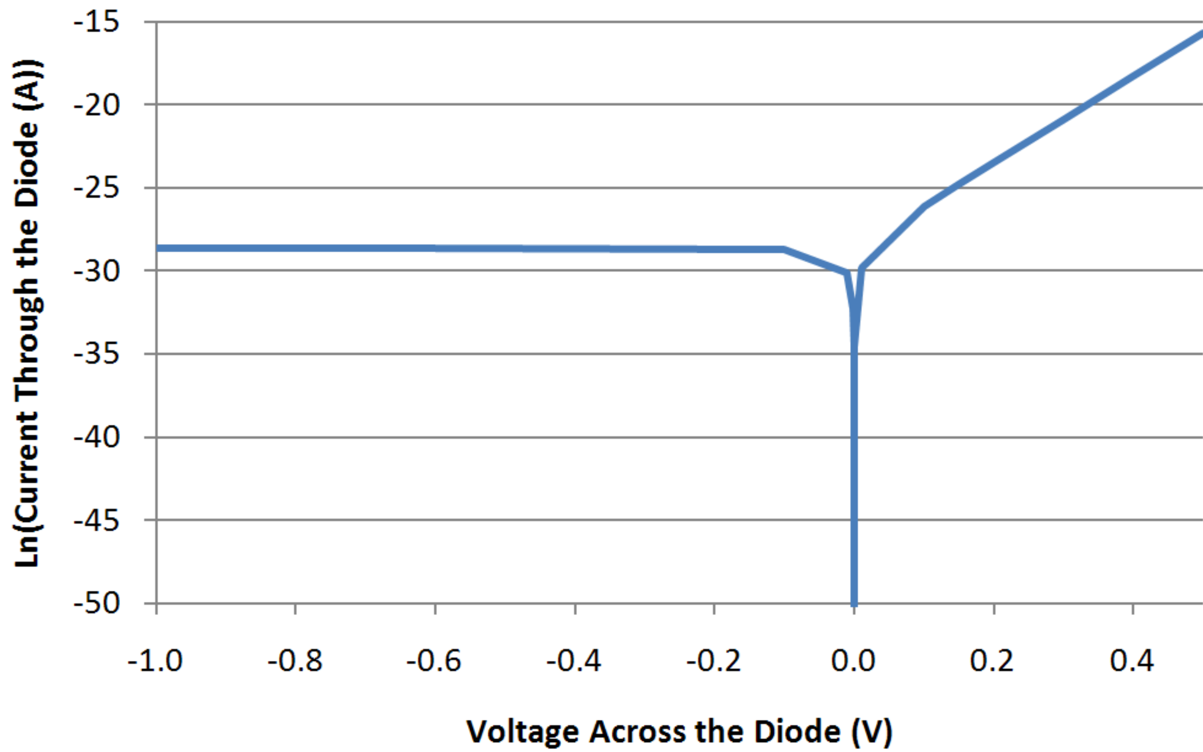
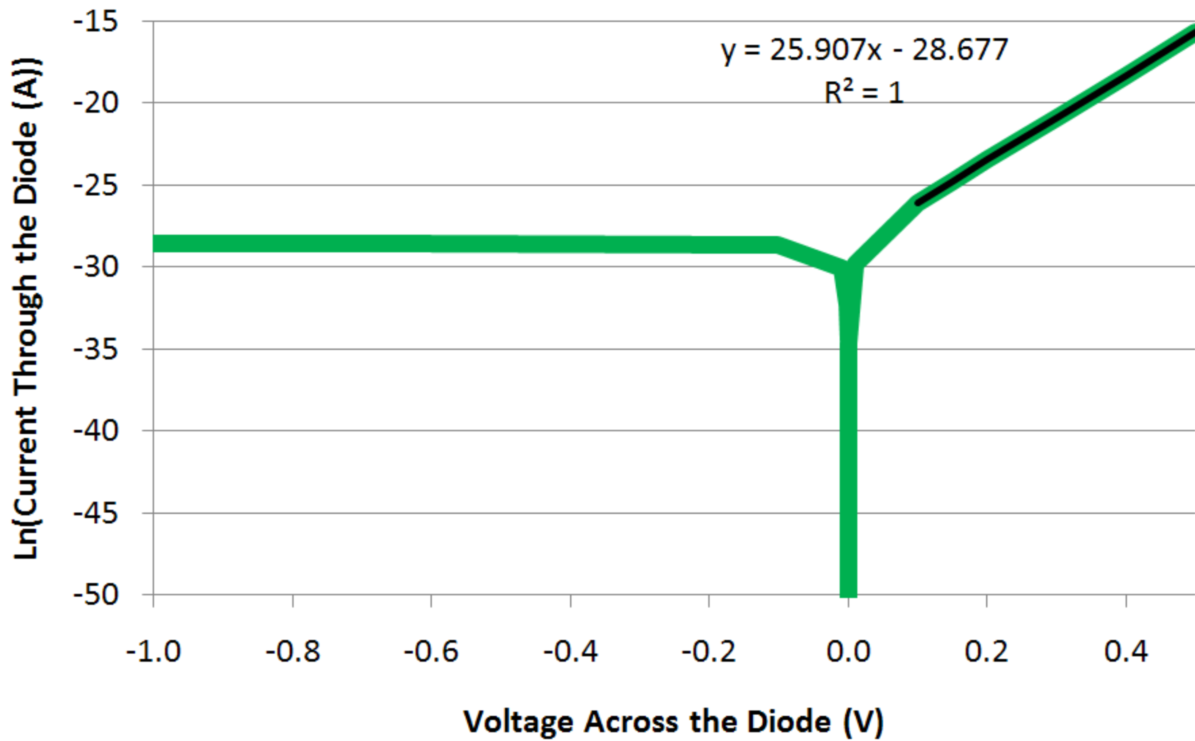


Figure 2: Data from an n+/p diode measured at 300K with an Area of 1cm^2.



$$I = Igen\left(e^{\frac{Vq}{nkT}} - 1\right)$$

In forward bias where: $e^{\frac{Vq}{nkT}} \gg 1$

$$I = Igen \times e^{\frac{Vq}{nkT}}$$

$$ln(I) = \frac{Vq}{nkT} + ln(Igen)$$

$$y = mx + b$$

$$m = \frac{q}{nkT}$$

$$n = \frac{q}{mkT} = \frac{1}{.026 \times 25.907} = 1.48$$

$$Igen = e^{b} = 3.51 \times 10^{-13} A$$

Question 8:

You are in charge of verifying that the break down voltage of your power rectifier diodes (n+/p , silicon, 300K) is greater than 100V. You notice that on the latest batch of wafers the breakdown voltages range from 10 to 15V. What do you think the problem is? What do you think the solution is?

If the breakdown voltage is a lot lower than it should be, the first thing I would check would be the substrate doping. To go from a Vbr of 300V to 10-15, would make me think that the substrate doping went from $10^{15}cm^{-3}$ to $10^{17}cm^{-3}$. Maybe the company uses different substrate dopings in various products, and someone used the wrong wafers. Also the wrong wafers could have been sent from the manufacturer. I would recommend using the resistivity probe more often to verify the substrate doping.