Transient and AC conditions

- Time variation of stored charge.
  - – Time dependant continuity equation
  - – p+/n diode (figure 5-20 page 168)

$$\mathrm{x_n}(0) \rightarrow \text{all hole current}$$

$$\mathrm{x_n}(\infty) \rightarrow \text{no hole current}$$

$$\mathrm{i(t)} = \frac{Q_p(t)}{\tau_p} + \frac{dQ_p(t)}{dt}$$

$$Q_p(t) = I\tau_p e^{-t/\tau_p}$$

Transient and AC conditions

- Time variation of stored charge.
  - Quasi-steady state approximation

$$v(t) = \frac{kT}{q} \ln\left(\frac{I\tau_p}{qAL_p p_n} e^{-t/\tau_p} + 1 \right)$$

- To decrease switching time
  - decrease n-type region to less than L_p or decrease τ_p (Au or Pt doping)

Transient and AC conditions

- . Reverse recovery transient
  - This is a switching characteristic or large signal analysis (large deviations from a reference point).
  - Assume a p+/n diode biased with resistor R, driven by a square wave (+E to -E with period T)
    - Forward bias: For large E most of the voltage drops across the resistor and the current is given by I_f=E/R.

Transient and AC conditions

- Reverse recovery transient
  - Sudden application of reverse bias:
    - Current initially becomes $i=I_r=-E/R$ because the stored charge in the junction can not be removed instantly, therefore the voltage can not be changed instantly.
    - Once all the minority charge is gone the junction will become reversed biased and thus act like a large resistance because only the I_{gen} current is flowing.

Transient and AC conditions

- Reverse recovery transient
  - Sudden application of reverse bias:
    - The time it takes for the junction voltage to become zero is t_{sd}. (figure 5-21 page 171)

$$t_{sd} = \tau_p \left[erf^{-1}\left(\frac{I_f}{I_f + I_r} \right) \right]^2$$

with the quasi-steady state approximation:

$$\mathrm{t_{sd}} = \tau_p \ln\left(1 + \frac{I_f}{I_r} \right)$$

Transient and AC conditions

- Capacitance of p-n junctions
  - This is for small signal analysis. Assume a bias point and that the applied time varying voltage or current does not perturb the diode’s G and C very far from their bias values.

Transient and AC conditions

- Junction capacitance:
  - Dominant under reverse bias, due to separation of positive and negative charges.

$$W=\left[\frac{2\varepsilon\left(V_o-V\right)}{q}\left(\frac{N_a+N_d}{N_aN_d}\right)\right]^{\frac{1}{2}}$$

$$\left|Q\right|=qA\frac{N_aN_d}{N_a+N_d}W$$

$$C_j=\left|\frac{dQ}{d(V_o-V)}\right|=\frac{A}{2}\left[\frac{2q\varepsilon}{(V_o-V)}\frac{N_aN_d}{N_a+N_d}\right]^{\frac{1}{2}}=\frac{A\varepsilon}{W}$$

Transient and AC conditions

- Storage capacitance:
  - Dominant under forward bias, due to the voltage lagging behind the current.

$$G_s = \frac{dI}{dV} = \frac{q}{kT} I$$

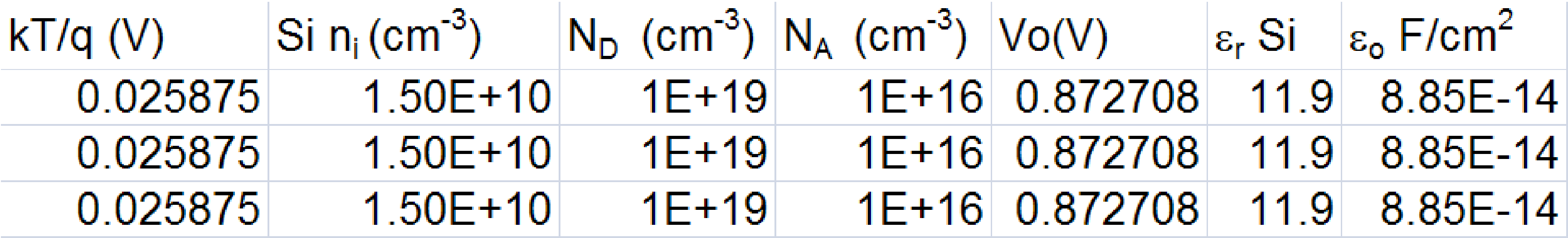
$$C_s = \frac{dQ_p}{dV} = \frac{q}{kT} I \tau_p$$

$$i(ac) = G_s v(ac) + C_s \frac{dv(ac)}{dt}$$

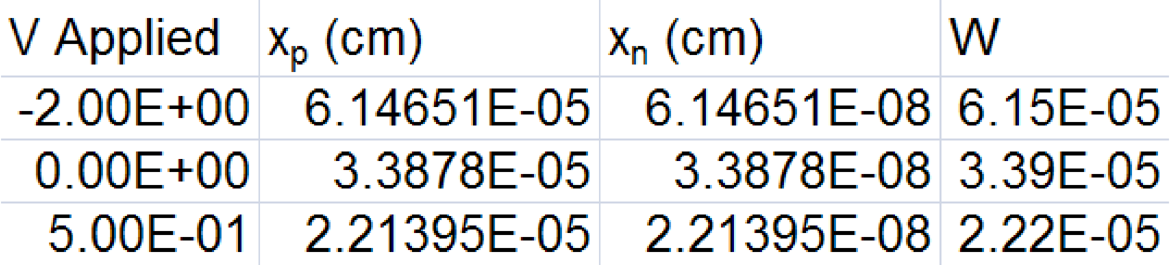
Example Cj, Cs

- For the Si example calculate Cj at –2, 0, and 0.5 volts.
- For the Si example calculate Cs at –2, 0, and 0.5 volts.
- Minority lifetimes are 1μs.

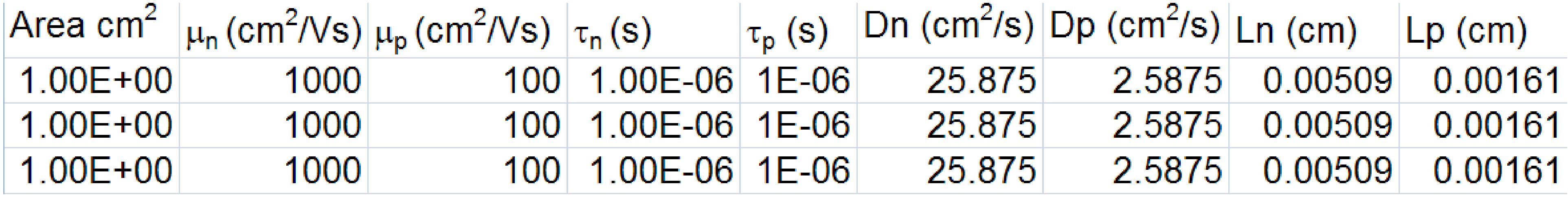
Example Cj, Cs



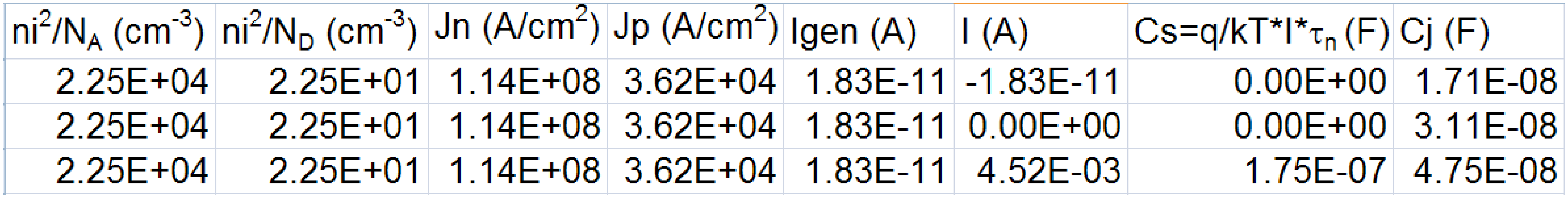
kT/q (V)	Si n_i (cm^{-3})	N_D (cm^{-3})	N_A (cm^{-3})	Vo(V)	ε_r Si	ε_o F/cm^2
0.025875	1.50E+10	1E+19	1E+16	0.872708	11.9	8.85E-14
0.025875	1.50E+10	1E+19	1E+16	0.872708	11.9	8.85E-14
0.025875	1.50E+10	1E+19	1E+16	0.872708	11.9	8.85E-14



V Applied	x_p (cm)	x_n (cm)	W
-2.00E+00	6.14651E-05	6.14651E-08	6.15E-05
0.00E+00	3.3878E-05	3.3878E-08	3.39E-05
5.00E-01	2.21395E-05	2.21395E-08	2.22E-05

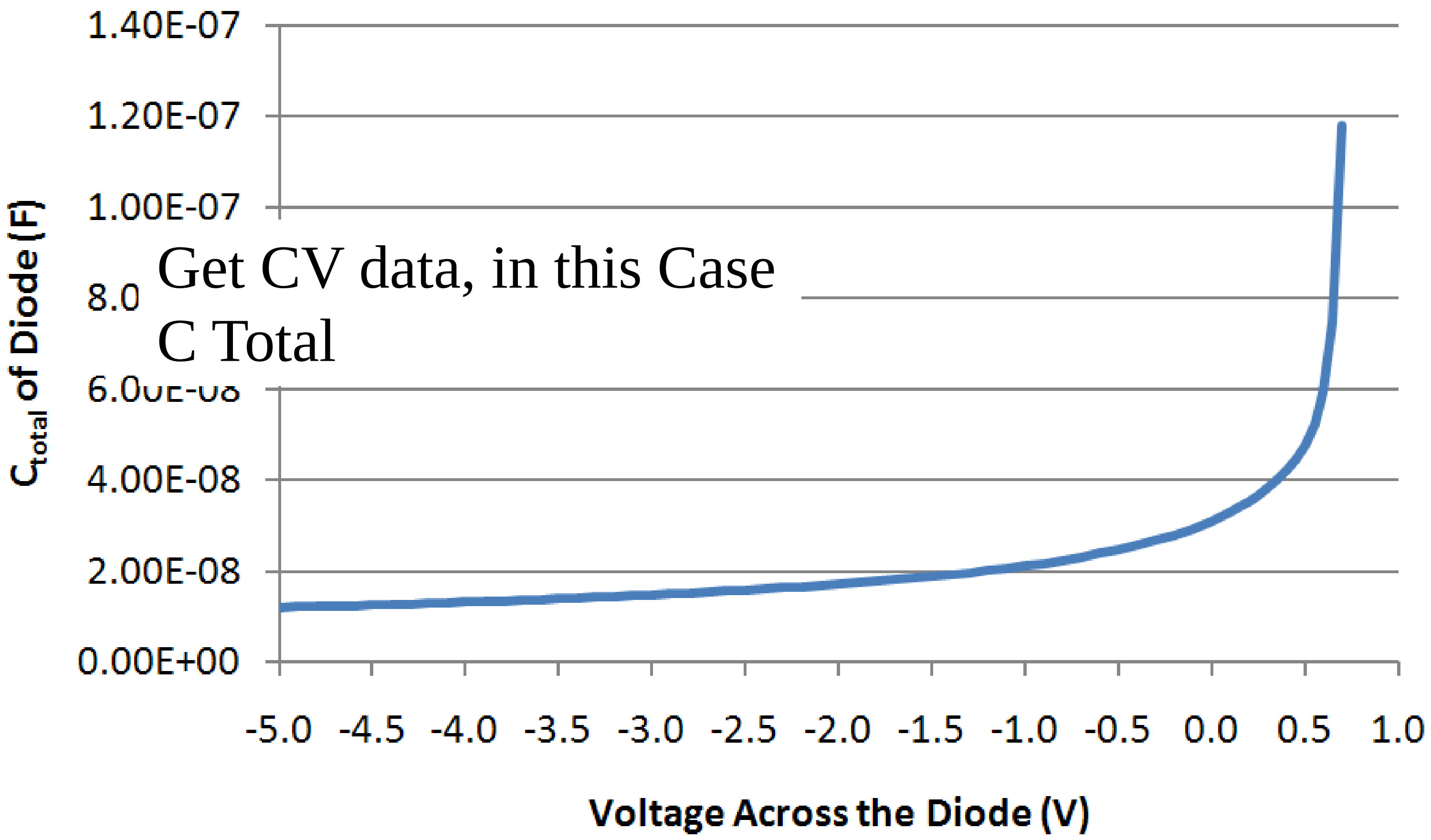


Area cm^2	μ_n (cm^2/Vs)	μ_p (cm^2/Vs)	τ_n (s)	τ_p (s)	Dn (cm^2/s)	Dp (cm^2/s)	Ln (cm)	Lp (cm)
1.00E+00	1000	100	1.00E-06	1E-06	25.875	2.5875	0.00509	0.00161
1.00E+00	1000	100	1.00E-06	1E-06	25.875	2.5875	0.00509	0.00161
1.00E+00	1000	100	1.00E-06	1E-06	25.875	2.5875	0.00509	0.00161



ni^2/N_A (cm^{-3})	ni^2/N_D (cm^{-3})	Jn (A/cm^2)	Jp (A/cm^2)	Igen (A)	I (A)	Cs=q/kT*I*τ_n (F)	Cj (F)
2.25E+04	2.25E+01	1.14E+08	3.62E+04	1.83E-11	-1.83E-11	0.00E+00	1.71E-08
2.25E+04	2.25E+01	1.14E+08	3.62E+04	1.83E-11	0.00E+00	0.00E+00	3.11E-08
2.25E+04	2.25E+01	1.14E+08	3.62E+04	1.83E-11	4.52E-03	1.75E-07	4.75E-08

Get CV data, in this case C_{Total}



Get CV data, in this Case
C Total

Plot $1/C^2$ vs. Voltage

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

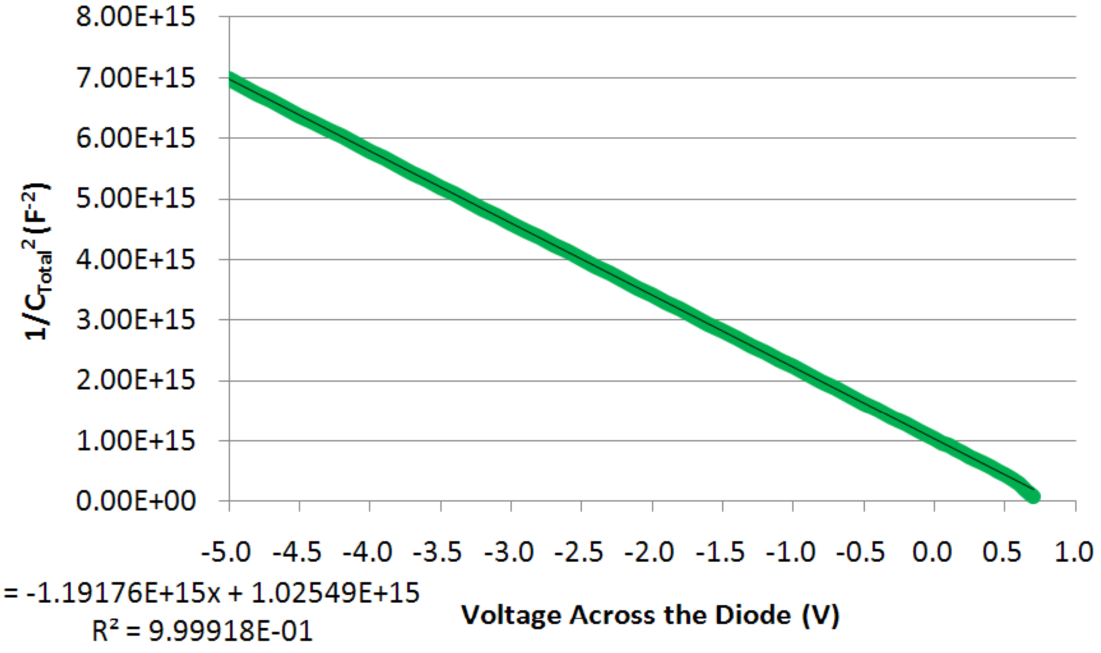
$$\frac{1}{C_j{}^2} = \frac{4}{A^2\, 2q\varepsilon N_{substrate}}(Vo - V)$$

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

$$y = mx + b$$

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

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



$$N_{substrate} = \frac{-2}{A^2\, q\varepsilon m} = 9.96 \times 10^{15}\, cm^{-3}$$

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

$$Vo = \frac{-b}{m} = \frac{-1.02549\times10^{15}}{-1.19176\times10^{15}} = .86V$$