Dij Results

Band Structure (E_c, E_v, E_g)

D.O.S.

$\Rightarrow n, p, E_F$

Conduction $\Rightarrow$ Drift - Diffusion Eqn.

G-R Events $\begin{cases} \text{traps} \rightarrow \text{SRH} \\ \text{a little bit radiative} \\ \text{a little Auger/Impact Ionization} \end{cases}$

$\rightarrow$ LLI, neutral $\Rightarrow$ minority carrier dominate dynamics

Continuity Relations / Equations

$n_p = \boxed{n_{p0}} + \Delta n_p$

$$\boxed{\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} - R + G}$$

$$\boxed{\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} - R + G}$$

special case of neutral material $\mathcal{E} = 0$, minority uniform doping

$$J_n = \cancel{q\mu_n n \mathcal{E}} + qD_n\frac{\partial n}{\partial x}$$

generation by light

$$\frac{\partial \Delta n_p}{\partial t} = \frac{\partial n}{\partial t} = D_n\frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

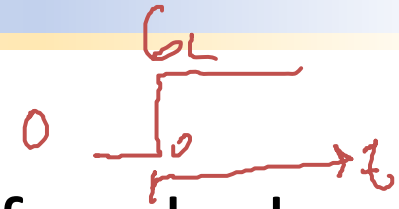
thermal/traps

Diffusion Equation Examples

EECS 320

Introduction to Semiconductor Devices

Example 1: Uniform Generation

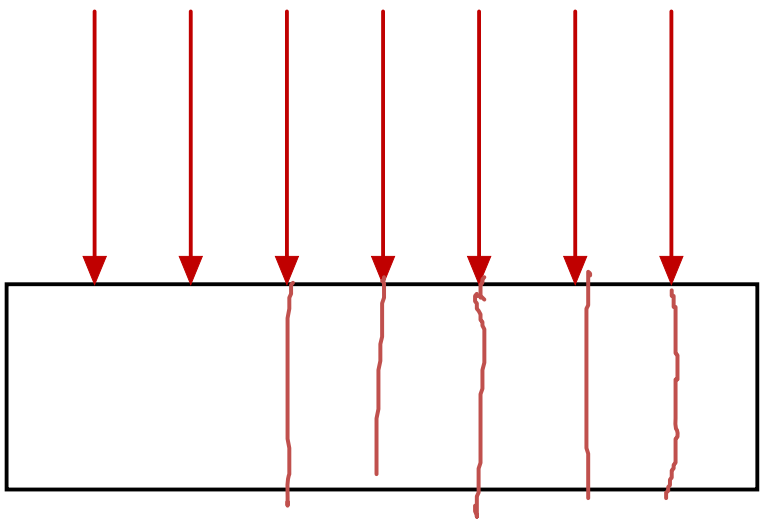


- A nondegenerate uniformly doped p-type region uniformly illuminated at t=0 with generation rate G_L pairs/cm^3/s

$(G_L \tau_n) = 10^{14}\ cm^{-3}$

10^{-6} s

- Si 300K $N_A=10^{16}cm^{-3}$ $\tau_n=1\mu s$ $G_L=10^{20}cm^{-3}s^{-1}$



$$\frac{\partial \Delta n_p}{\partial t} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

0

spatial uniformity

$$\frac{\partial \Delta n_p}{\partial t} = D_n \cancel{\frac{\partial^2 \Delta n_p}{\partial x^2}} - \frac{\Delta n_p}{\tau_n} + G_L$$

$$(\Delta n_p)_{nat} = A e^{-t/\tau_n}$$

$$(\Delta n_p)_{forced} = G_L \tau_n$$

$$\frac{\partial \Delta n_p}{\partial t} + \frac{\Delta n_p}{\tau_n} = G_L$$

$t < 0 \quad \Delta n_p = 0$

$$\Delta n_p(0) = 0 = A + G_L \tau_n$$

$$\Delta n_p(t) = (G_L \tau_n)(1 - e^{-t/\tau_n})$$

$G_L = cm^{-3} \cdot s^{-1} \quad \tau_n = s \quad cm^{-3}$

$N_A \simeq p_{p0} = 10^{16}\ cm^{-3}$

$t \to \infty \quad \Delta n_p \to 10^{14}\ cm^{-3} \quad \Delta n_p \ll p_{p0}$

$\Rightarrow$ LLI Applies

Quasi-Fermi Level Concept

$p_{p0} = 10^{16}\ cm^{-3}$

$t \to \infty$ $\quad \Delta n_p = 10^{14}\ cm^{-3} \quad \Delta p_p = 10^{14}\ cm^{-3}$

- Use equilibrium idea to describe non-equilibrium case

$n_{p0} = n_i^2/p_{p0} \simeq 1.145 \times 10^4\ cm^{-3}$

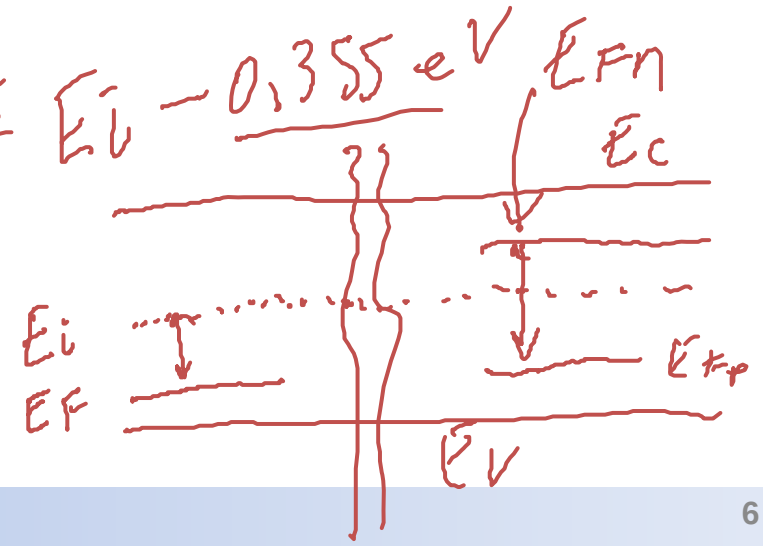
$\Delta n_p + n_{p0}$

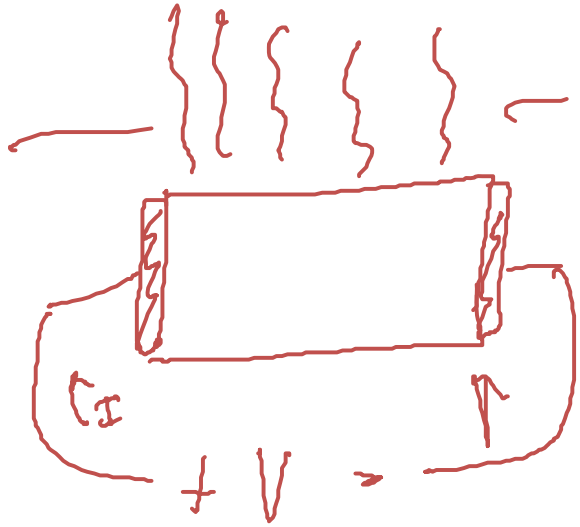
$$n = n_i \exp\left(\frac{E_{fn} - E_i}{kT}\right) \Rightarrow E_{Fn} \simeq E_i + 0.236\,eV$$

$p_{p0} + \Delta p_p$

$$p = n_i \exp\left(\frac{E_i - E_{fp}}{kT}\right) \Rightarrow E_{Fp} \simeq E_i - 0.356\,eV$$

In Eq. $E_{Fn} = E_{Fp} = E_F \simeq E_i - 0.355\,eV$



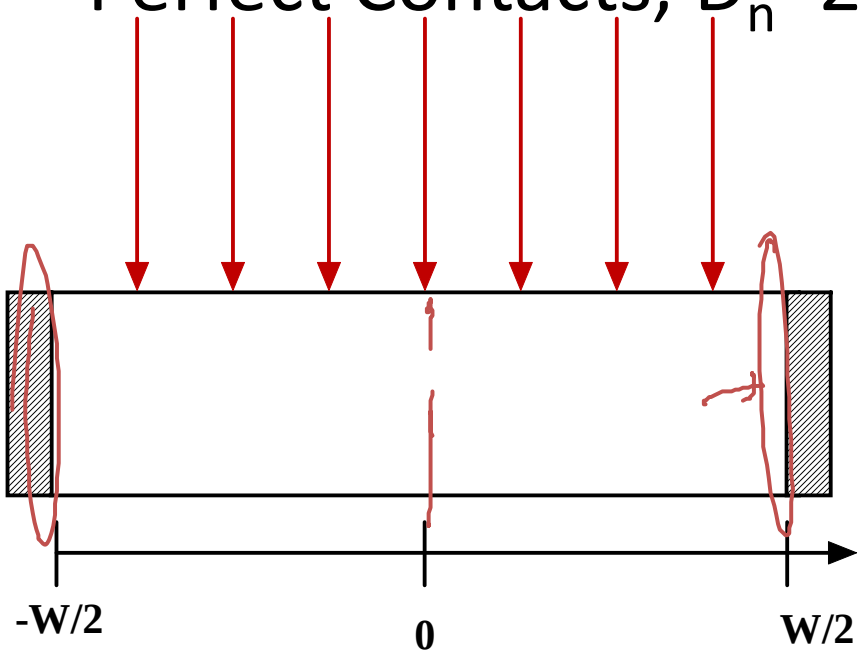

I
+ V -

Example 2: Uniform Generation

- A nondegenerate uniformly doped p-type region uniformly illuminated with generation rate G_L pairs/cm^3/s in steady state
- Perfect Contacts, D_n=25cm^2/s

Ohmic

0



$$\frac{\partial \Delta n_p}{\partial t} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

At Contacts
$\Delta n = \Delta p = 0$

$$0 = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

$$\frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{D_n \tau_n} = -G_L / D_n$$

Ngt. $\frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{D_n \tau_n} = 0 \Rightarrow \frac{\partial^2 \Delta n_p}{\partial x^2} = \frac{\Delta n_p}{D_n \tau_n}$

$$\frac{1}{\Delta n_p} \frac{\partial^2 \Delta n_p}{\partial x^2} = \left(\frac{1}{D_n \tau_n}\right)$$

$$= \frac{1}{L_n^2}$$

$(D_n \tau_n) \rightarrow \frac{cm^2}{s} \cdot s$

$L_n \equiv [D_n \tau_n]^{1/2}$ minority carrier Diffusion Length

$$\Rightarrow \frac{1}{\Delta n_p}\frac{\partial^2 \Delta n_p}{\partial x^2} = \frac{1}{L_n^2}$$ not part

$$\Delta n_{p,hom} = A_1 e^{+x/L_n} + A_2 e^{-x/L_n}$$

$$L_n \equiv [D_n \tau_n]^{1/2}$$

$$\Delta n_{p,f} = G_L \tau_n$$

$$\boxed{\Delta n_p = A_1 e^{+x/L_n} + A_2 e^{-x/L_n} + G_L \tau_n}$$

$$\Delta n_p(-W/2) = A_1 e^{-W/2L_n} + A_2 e^{+W/2L_n} + G_L \tau_n = 0$$

$$\Delta n_p(+W/2) = A_1 e^{+W/2L_n} + A_2 e^{-W/2L_n} + G_L \tau_n = 0$$

2 eqn's 2 unknowns A_1, A_2

$$A_1 = -\left(\frac{G_L \tau_n e^{+W/2L_n}}{1+e^{+W/L_n}}\right) \qquad A_2 = A_1$$

$G_L = 10^{20}\ cm^{-3}\ s^{-1}$

$G_L \tau_n = 10^{14}\ cm^{-3}$

$$\Delta n_p(x) = A_1 e^{x/L_n} + A_2 e^{-x/L_n} + G_L \tau_n$$

$$= A_1 \underbrace{\left(e^{x/L_n} + e^{-x/L_n}\right)} + G_L \tau_n$$

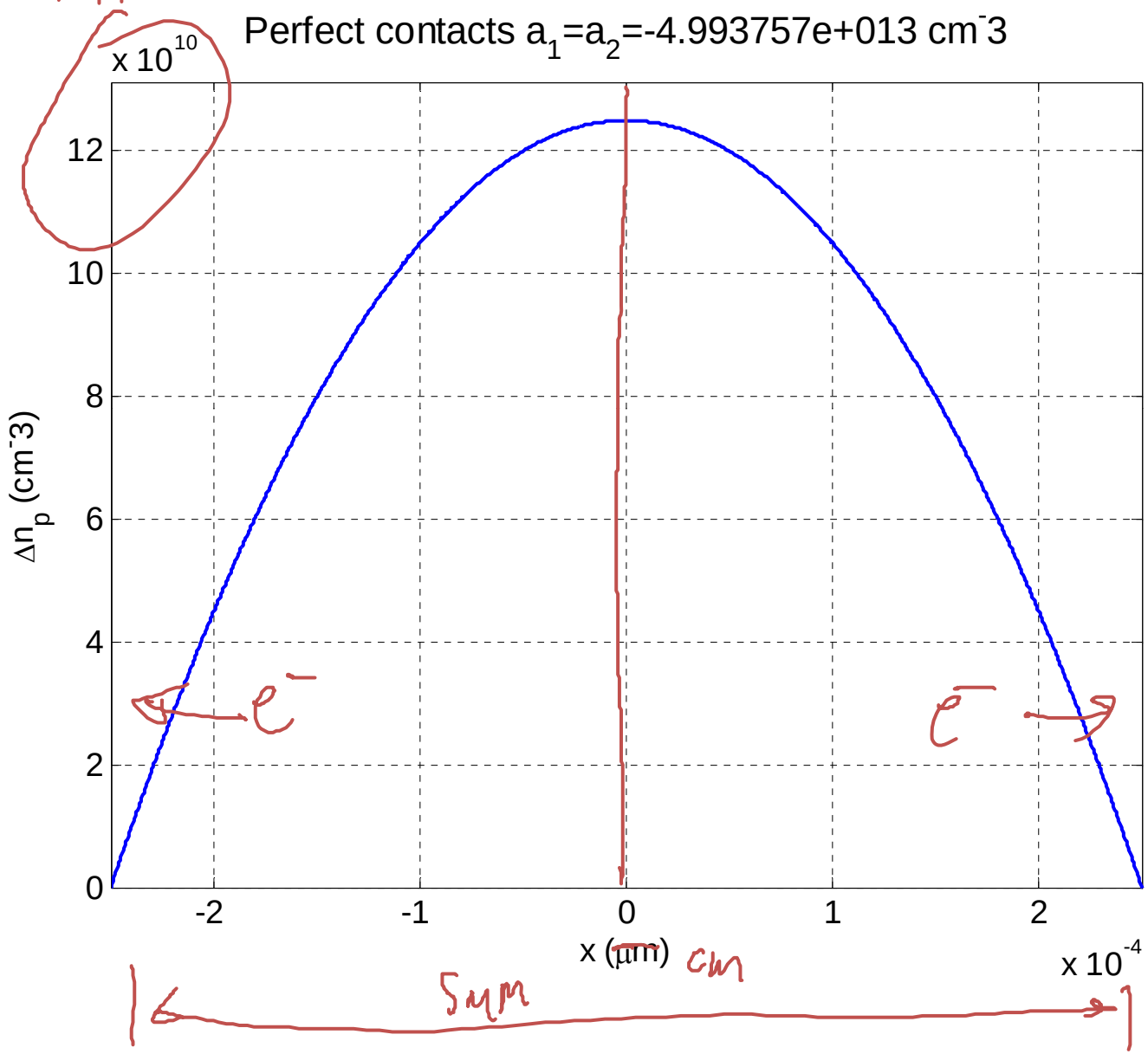
$$= A_1 \left(2\cosh\left(\frac{x}{L_n}\right)\right) + G_L \tau_n$$

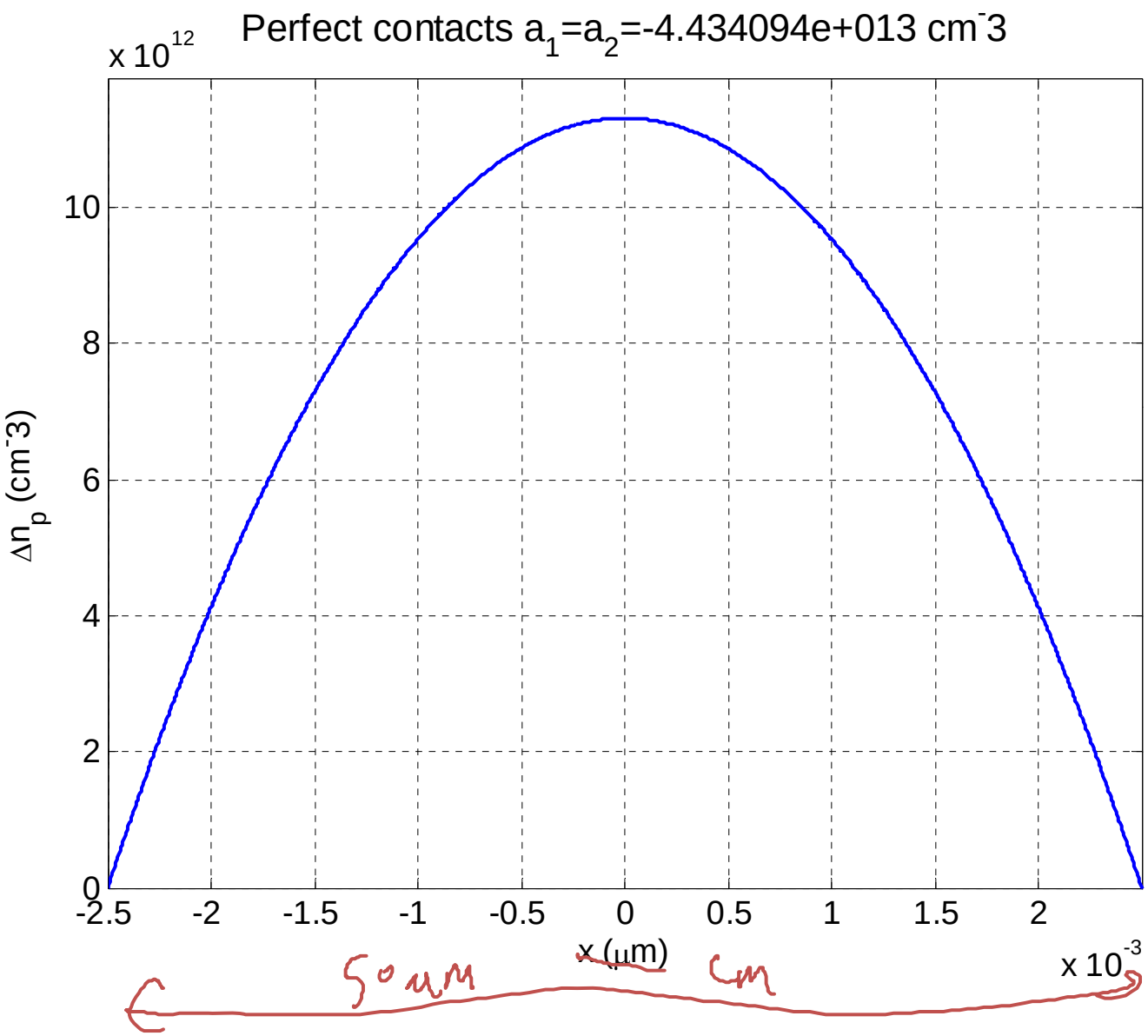
$$L_n = [D_n \tau_n]^{1/2} = \left[25\ \frac{cm^2}{s} \cdot 10^{-6}\ s\right]^{1/2} = 5 \times 10^{-3}\ cm$$

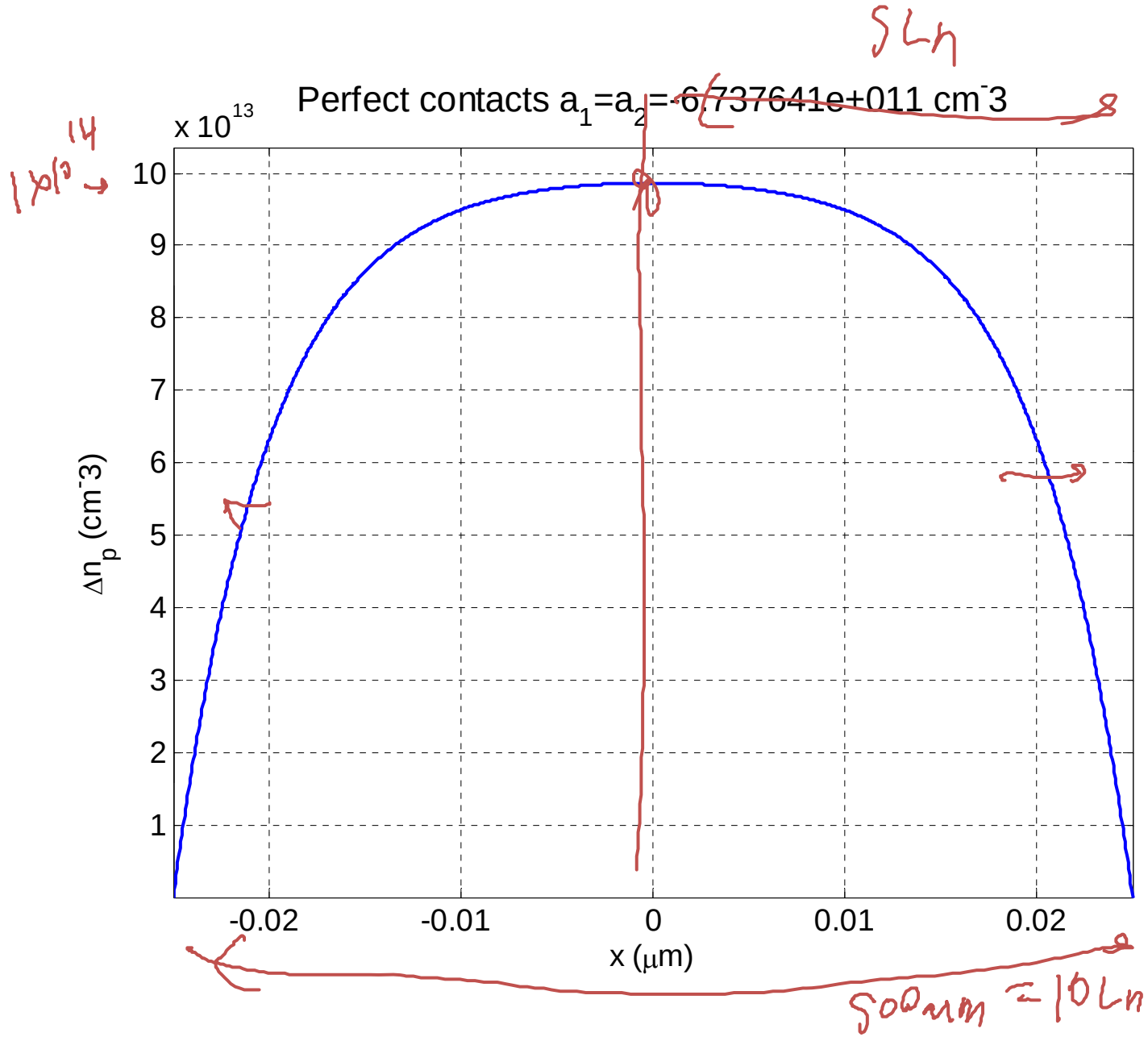
$$= 50\ \mu m$$

$\sim 1.1 \times 10^{13}\ cm^{-3}$

$L_n = 5\ \mu m$

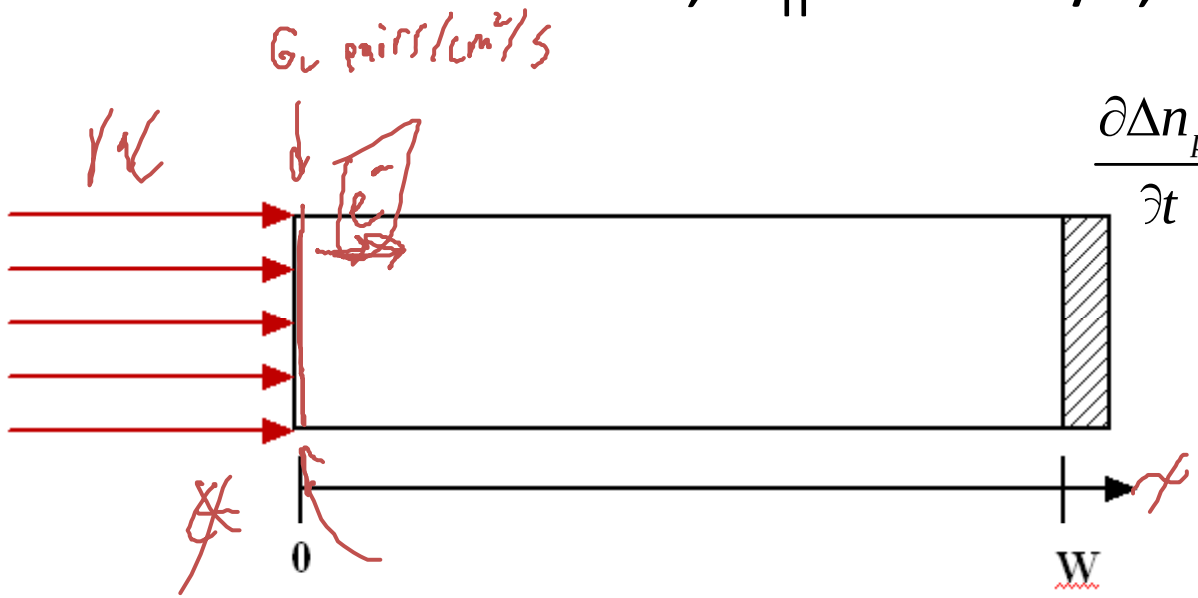



Perfect contacts a1=a2=-4.434094e+013 cm^-3
x 10^12
10
8
6
4
2
0
Δnp (cm^-3)
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
x (μm)
x 10^-3
50 um
cm


Perfect contacts a1=a2=6.737641e+011 cm^-3
x 10^13
10
9
8
7
6
5
4
3
2
1
Δnp (cm^-3)
-0.02
-0.01
0
0.01
0.02
x (μm)
5Ln
1x10^14
500nm = 10Ln

Example 3: Generation on End

- A nondegenerate uniformly doped p-type region uniformly illuminated with generation rate G_L pairs/cm^2/s in steady state at x=0
- Perfect Contacts, D_n=25cm^2/s, G_L=5x10^{18}cm^{2}s^{-1}



$$\frac{\partial \Delta n_p}{\partial t} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

$$\underbrace{\frac{\partial \Delta n_p}{\partial t} = 0}_{\text{steady state}} = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L \delta(x)$$

impulse

Bulk

$x > 0$ $\quad 0 = D_n \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n}$

$$\Delta n_p(x) = A_1 e^{-x/L_n} + A_2 e^{+x/L_n}$$

$$\cancel{\frac{\partial \Delta n_p}{\partial x} \to \infty}$$

B.C. $\Delta n_p(W) = 0 = A_1 e^{-W/L_n} + A_2 e^{+W/L_n}$

$x = 0$?

$x = 0$ $\quad \boxed{-D_n \left.\frac{\partial \Delta n_p}{\partial x}\right|_0 = G_L}$

$cm^{-2} \cdot s^{-1}$

leaving = creation

$$\Delta n_p(W) = 0 \Rightarrow A_2 = -A_1 e^{-2W/L_n}$$

$$-D_n \frac{\partial \Delta n_p}{\partial x}\Big|_0 = -D_n\left[-\frac{A_1}{L_n} + \frac{A_2}{L_n}\right] = G_L$$

$$\Delta n_p = A_1 e^{-x/L_n} + A_2 e^{+x/L_n}$$

$$A_1 = \left(\frac{G_L L_n}{D_n}\right)\left(\frac{1}{1+e^{-2W/L_n}}\right)$$

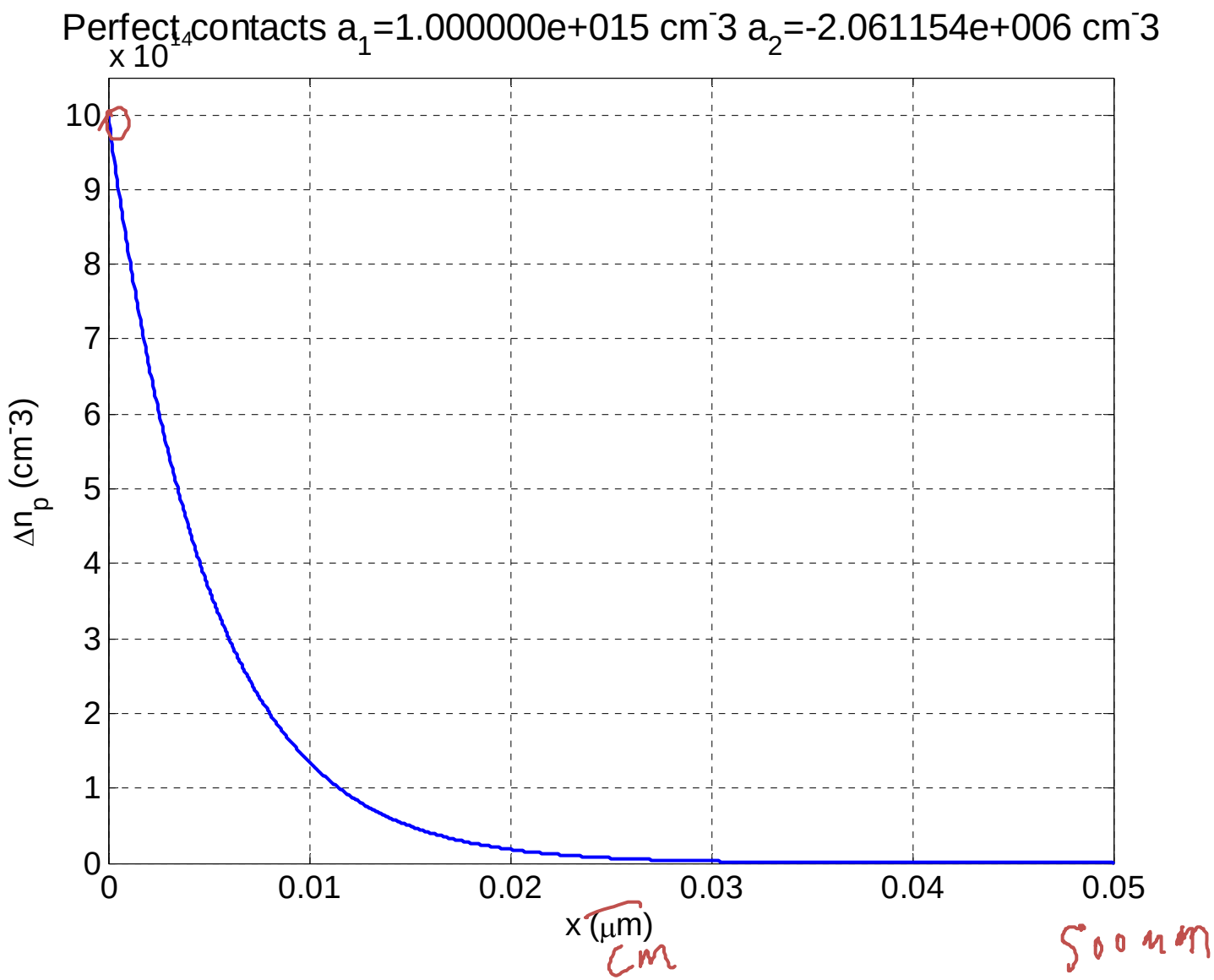
$$A_2 = -\left(\frac{G_L L_n}{D_n}\right)\left(\frac{e^{-2W/L_n}}{1+e^{-2W/L_n}}\right)$$

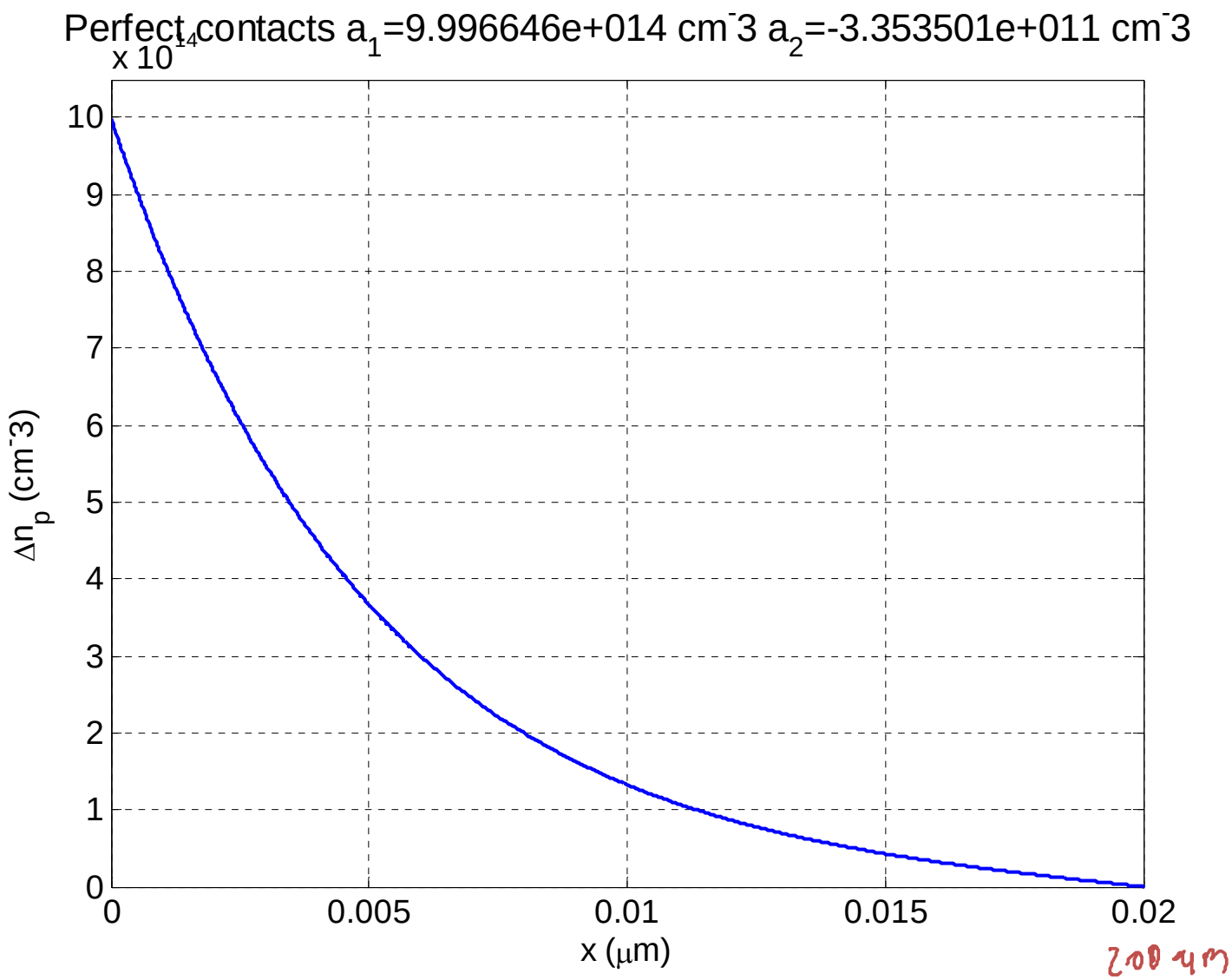
$$G_L = 5\times10^{18}\ cm^{-2}\cdot s^{-1}$$

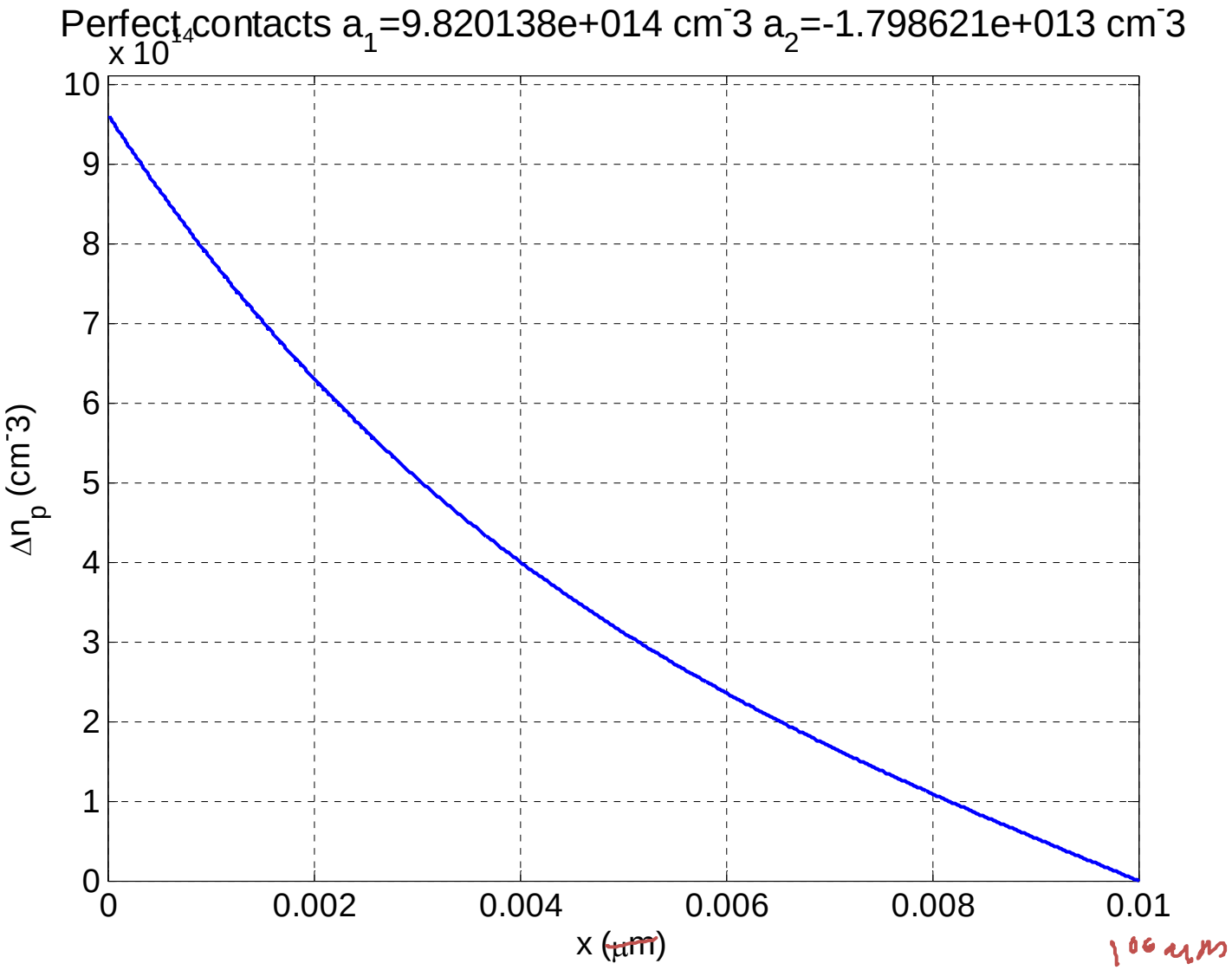
$$L_n = 50\ \mu m = 5\times10^{-3}$$

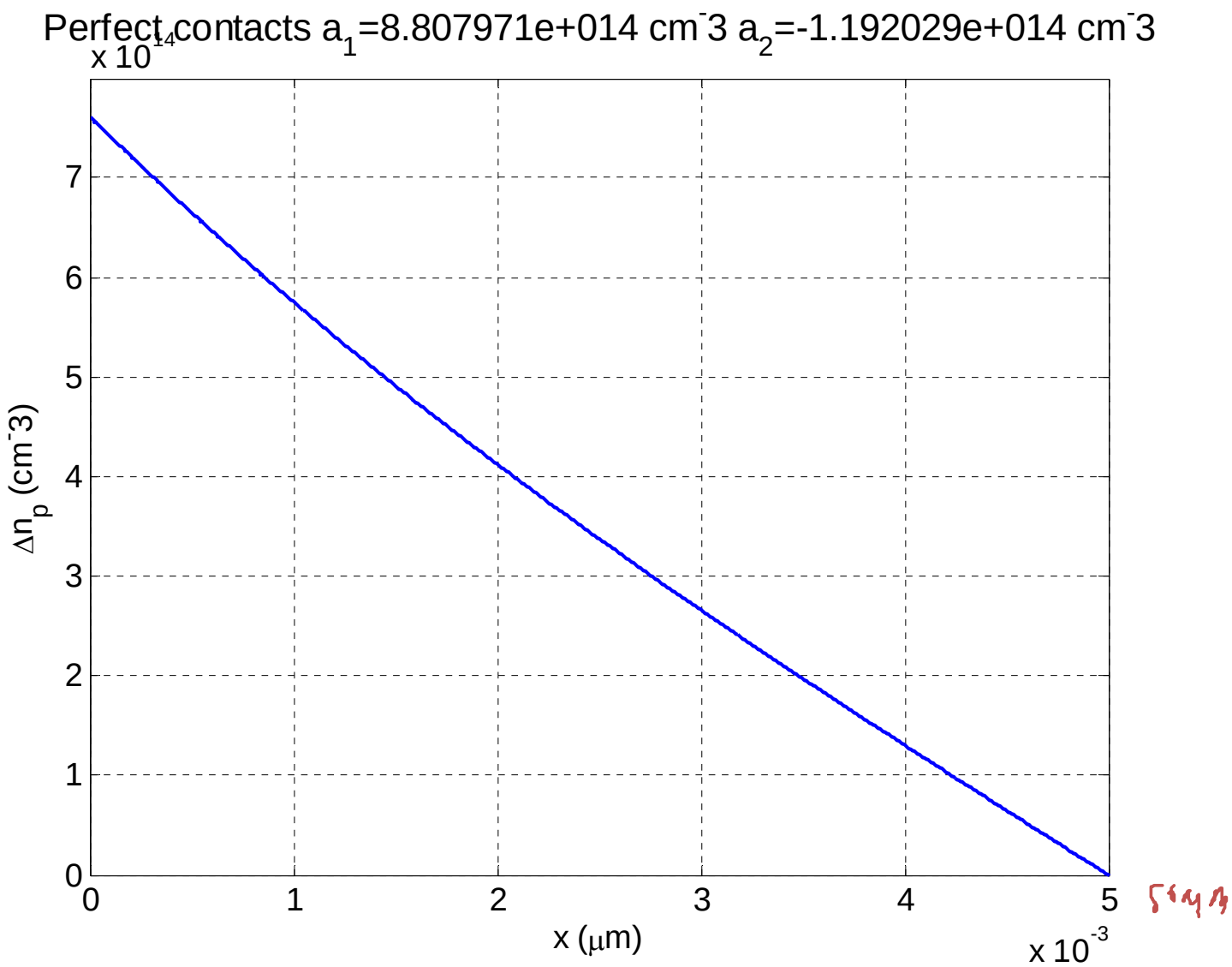
$$D_n = 25\ cm^2/s$$

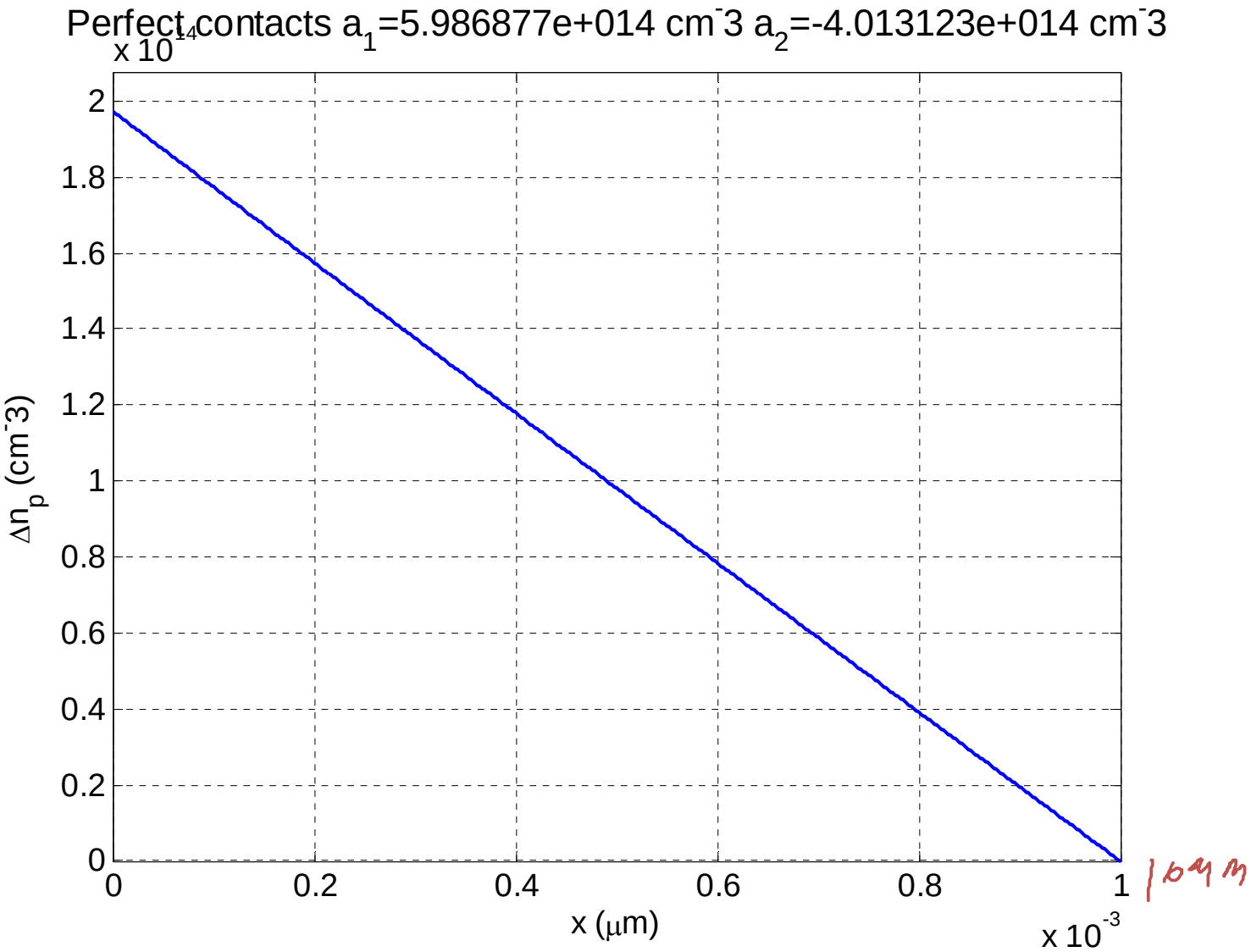
$$\left(\frac{G_L L_n}{D_n}\right) = 1\times10^{15}\ cm^{-3}$$


Perfect contacts a1=1.000000e+015 cm-3 a2=-2.061154e+006 cm-3
x 10^14
10
9
8
7
6
5
4
3
2
1
0
Δnp (cm-3)
0
0.01
0.02
0.03
0.04
0.05
x (μm)
cm
500 nm


Perfect contacts a1=9.996646e+014 cm-3 a2=-3.353501e+011 cm-3
x 10^14
10
9
8
7
6
5
4
3
2
1
0
Δnp (cm-3)
0
0.005
0.01
0.015
0.02
x (μm)
200 μm


Perfect contacts a1=9.820138e+014 cm-3 a2=-1.798621e+013 cm-3
x 10^14
10
9
8
7
6
5
4
3
2
1
0
Δnp (cm-3)
0
0.002
0.004
0.006
0.008
0.01
x (μm)
100 nm


Perfect contacts a1=8.807971e+014 cm-3 a2=-1.192029e+014 cm-3
x 10^14
7
6
5
4
3
2
1
0
Δnp (cm-3)
0
1
2
3
4
5
x (μm)
x 10^-3


Perfect contacts a1=5.986877e+014 cm-3 a2=-4.013123e+014 cm-3
x 10^14
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Δnp (cm-3)
0
0.2
0.4
0.6
0.8
1
x (μm)
x 10^-3
100 μm