Homework 3 Solution

1) Direct tunneling

a) $J_{DirTun} = V \frac{K_{DT}}{t_{ox}} e^{-\beta t_{ox}}$ where V = oxide voltage.

$= \mathcal{E}_{ox} K_{DT} e^{-\beta t_{ox}}$

here

$\beta = -2\sqrt{2m^*\phi}/\hbar$ for oxide: $\phi = 3.1\,eV$, $m^* = 0.4\,m_o$

b) Fowler Nordheim

$$J_{FN} = K_{FN}\,\mathcal{E}_{ox}^2\, e^{-B/\mathcal{E}_{ox}}$$

c) Frenkel Poole

$$J_{FP} = K_{FP}\,\mathcal{E}_{ox}\, e^{-\alpha(\phi_B - \sqrt{\mathcal{E}_{ox}})}$$

assume $\phi_B > \sqrt{\mathcal{E}_{ox}}$

related to trap depth

at $t_{ox} = 10\,nm$, $\mathcal{E}_{ox} = 10\,MV/cm$

assume $J = 1\,\mu A/\mu m^2$ for all 3 mechanisms

so

A. $J_{DT} = 1\,\frac{\mu A}{\mu m^2} = 10\,\frac{MV}{cm} K_{DT}\, e^{-\beta \times 10nm}$

here $\beta = -2\,\dfrac{\sqrt{2\times 0.4 m_o \times 9.1\times10^{-31}kg \times 3.1eV \times 1.6\times10^{-19} J/eV}}{\frac{6.625\times10^{-34}\,J\text{-}s}{2\pi}}$

$= 1.14\times10^{10}\,m^{-1} = 1.14\times10^{8}\,cm^{-1} = 1.14\,\mathring{A}^{-1}$

$= 11.4\,nm^{-1}$

so $J_{DT} = K_{DT}\, 10 \frac{mV}{cm}\, e^{-\frac{11.4}{nm} \times 10\,nm} = 1 \frac{\mu A}{\mu m^2}$

$$1 \frac{\mu A}{\mu m^2} = 10 K_{DT} \cancel{\mathcal{E}_{ox}} \left(\frac{mV}{cm}\right) e^{-114}$$

$$K_{DT} = \frac{(1/10)\,\mu A/\mu m^2}{\cancel{\mathcal{E}_{ox}}\left(\frac{mV}{cm}\right)} e^{+114}$$

$$10^{114/2.3} = 10^{49.56}$$

$$K_{DT} = \left[10^{48.56} \frac{\mu A/\mu m^2}{\cancel{\mathcal{E}_{ox}}\left(\frac{mV}{cm}\right)} \right]$$

B Fowler Nordheim Tunneling

$$J_{FN} = K_{FN}\, \mathcal{E}_{ox}^2\, e^{-B/\mathcal{E}_{ox}} = 1\,\mu A/\mu m^2$$

at 10 nm & 10 MV/cm.

does not depend on thickness explicitly → just thru $\mathcal{E}_{ox}$

so $J_{FN} = 1\,\mu A/\mu m^2$ for $t_{ox} = 1-10$ nm

$\mathcal{E}_{ox} = 10$ MV/cm held constant

for different fields:

$$\frac{J_{FN}(\mathcal{E}_{ox})}{J_{FN}(10\,MV/cm)} = \left(\frac{\mathcal{E}_{ox}}{10\,MV/cm}\right)^2 e^{-B\left(\frac{1}{\mathcal{E}_{ox}} - \frac{1}{10\,MV/cm}\right)}$$

do not know B

$$= \frac{J_{FN}(\mathcal{E}_{ox})}{1\,\mu A/\mu m^2}$$

c Frenkel - Poole Emission Tunneling

$$J_{FP} = K_{FP}\, \mathcal{E}_{ox}\, e^{-\alpha(\phi_{trap} - \sqrt{\mathcal{E}_{ox}})} \quad \text{for } \phi_{trap} > \sqrt{\mathcal{E}_{ox}}$$

$$= 1\,\mu A/\mu m^2 \quad \text{for } \mathcal{E}_{ox} = 10\text{ mV/cm}, \; t_{ox} = 10\text{ nm}$$

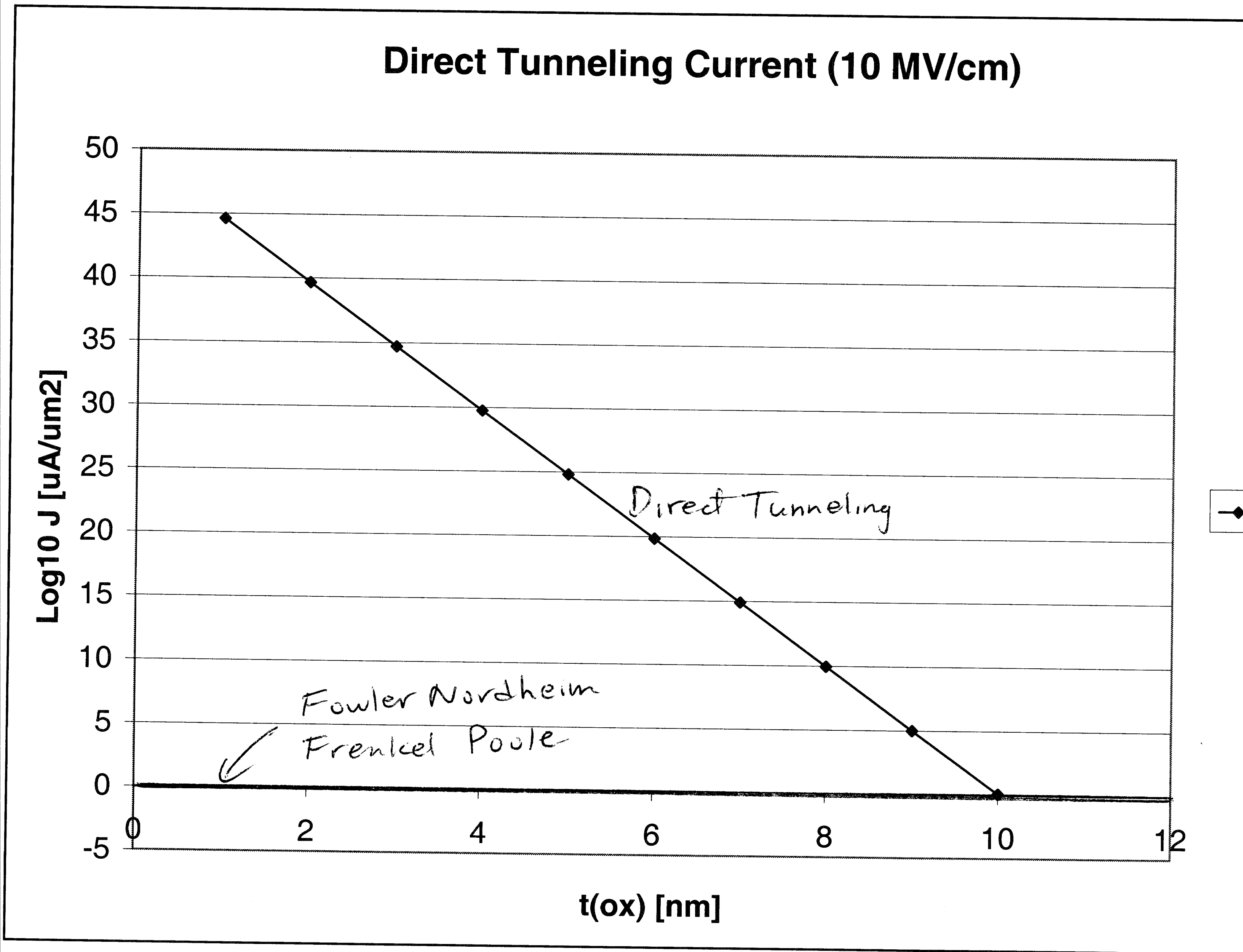
not thickness dependent explicitly - except thru $\mathcal{E}_{ox}$ for different fields

$$\frac{J_{FP}(\mathcal{E}_{ox})}{J_{FP}(10\text{mV/cm})} = \left(\frac{\mathcal{E}_{ox}}{10\text{mV/cm}}\right) e^{-\alpha\phi_{trap} - \alpha\sqrt{\mathcal{E}_{ox}} + \alpha\phi_{trap} + \alpha\sqrt{10\text{mV/cm}}}$$

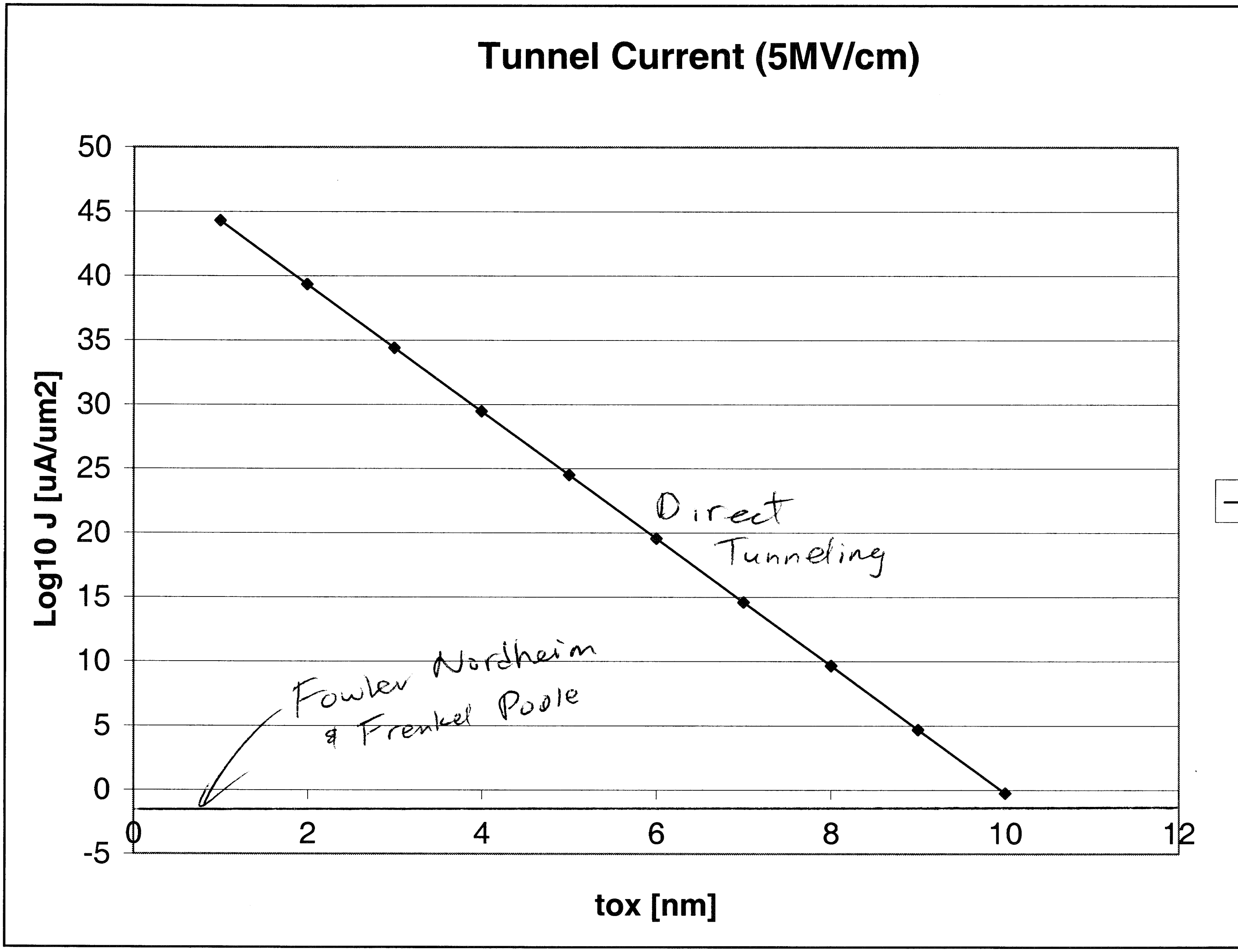
$$= \left(\frac{\mathcal{E}_{ox}}{10\text{mV/cm}}\right) e^{-\alpha\left[\sqrt{\mathcal{E}_{ox}} - \sqrt{10\text{mV/cm}}\right]}$$

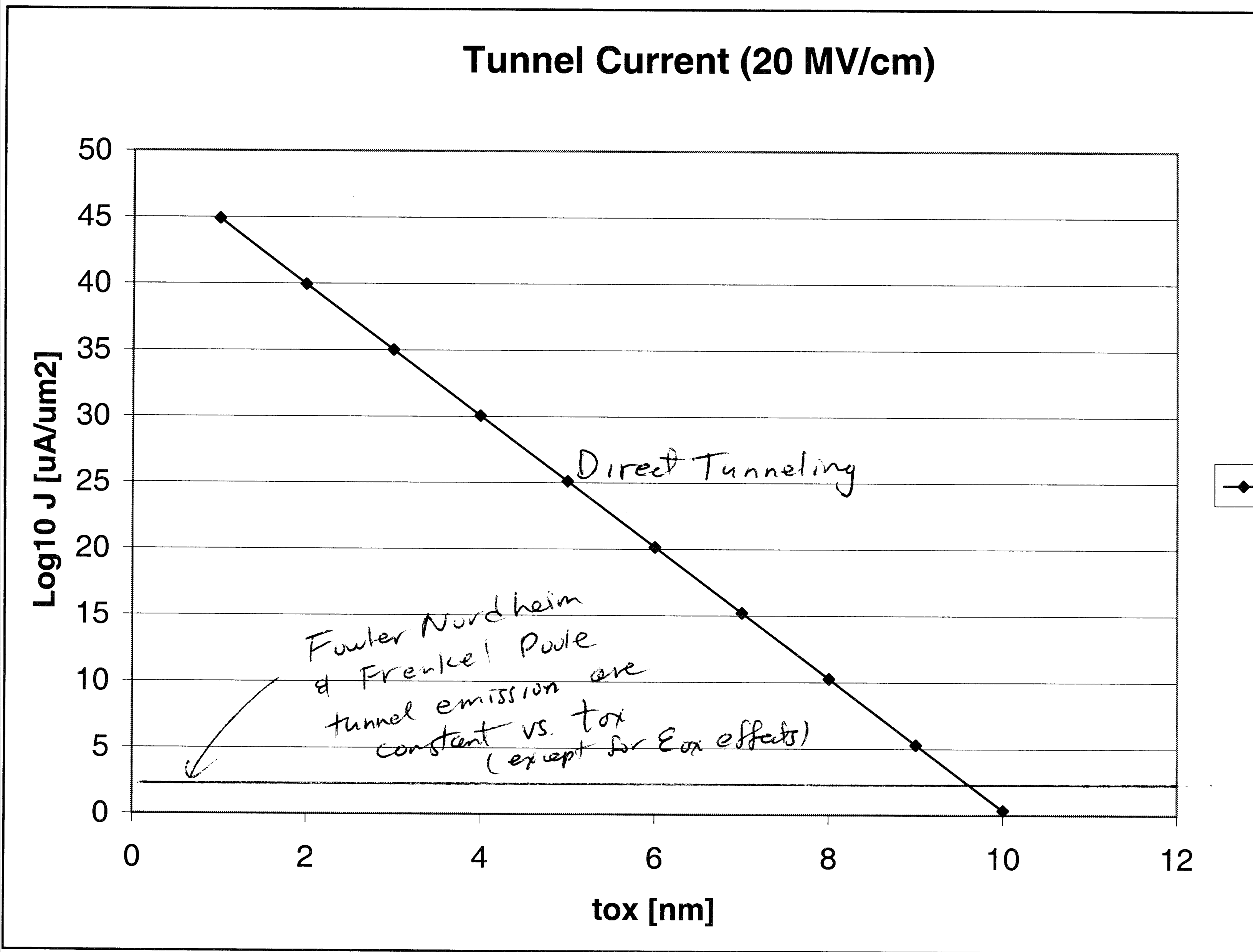
$$= \frac{J_{FP}(\mathcal{E}_{ox})}{1\,\mu A/\mu m^2}$$

do not know α



Direct Tunneling Current (10 MV/cm)
Log10 J [uA/um2]
t(ox) [nm]
50
45
40
35
30
25
20
15
10
5
0
-5
0
2
4
6
8
10
12
Direct Tunneling
Fowler Nordheim
Frenkel Poole


Tunnel Current (5MV/cm)
Log10 J [uA/um2]
tox [nm]
50
45
40
35
30
25
20
15
10
5
0
-5
0
2
4
6
8
10
12
Direct
Tunneling
Fowler Nordheim
& Frenkel Poole


Tunnel Current (20 MV/cm)
Log10 J [uA/um2]
tox [nm]
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
Direct Tunneling
Fowler Nordheim
& Frenkel Poole
tunnel emission are
constant vs. tox
(except for Eox effects)