

# MIS SiO<sub>2</sub> Growth TCAD Example

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# Really Quick Example

- Use Hand Calculations to come up with an oxide thickness substrate doping pair to achieve  $V_T$
- Verify in Sentaurus Device
- Use H.C to estimate oxide growth time and temperature
- Use Sentaurus Process to verify growth recipe

# Standard Example

- $V_T = 1 \text{ V}$
- AL Gate
- $Q_i = 5 \times 10^{10} \text{ q/cm}^2$
- Min N is possible

# Assume NA, QI

$$q := 1.6 \cdot 10^{-19} \text{ C} \quad \varepsilon_{\text{Si}} := 11.8 \cdot 8.85 \cdot 10^{-14} \frac{\text{F}}{\text{cm}} \quad k := 1.38 \cdot 10^{-23} \frac{\text{J}}{\text{K}}$$

$$T := 300 \text{ K}$$

$$N_A := 1 \cdot 10^{16} \text{ cm}^{-3} \quad \varepsilon_{\text{oxide}} := 3.9 \cdot 8.85 \cdot 10^{-14} \frac{\text{F}}{\text{cm}}$$

$$n_i := 9.65 \cdot 10^9 \text{ cm}^{-3}$$

$$Q_i := 5 \cdot 10^{10} \cdot \frac{q}{\text{cm}^2} \quad Q_i = 8 \times 10^{-9} \text{ C cm}^{-2}$$

$$\phi_{\text{ms}} := -0.6 \text{ V} - \frac{k \cdot T}{q} \cdot \ln \left( \frac{N_A}{n_i} \right)$$

$$\phi_{\text{ms}} = -0.958 \text{ V}$$

# Assume NA, QI

$$\phi_F := \frac{k \cdot T}{q} \cdot \ln\left(\frac{N_A}{n_i}\right)$$

$$Q_D := -2 \cdot \left(\epsilon_{Si} \cdot q \cdot N_A \cdot \phi_F\right)^{\frac{1}{2}} \quad Q_D = -4.894 \times 10^{-8} \frac{C}{cm^2}$$

$$d := .11 \cdot 10^{-4} \text{ cm}$$

+

$$C_{oxide} := \frac{\epsilon_{oxide}}{d}$$

$$V_{T0} := \phi_{ms} - \frac{Q_i}{C_{oxide}} - \frac{Q_D}{C_{oxide}} + 2 \cdot \phi_F$$

$$V_{T0} = 1.063 \text{ V}$$

# Assume NA, QI

$$\Gamma_b := \frac{\sqrt{2 \cdot q \cdot N_A \cdot \epsilon_{Si}}}{C_{oxide}} \quad V_S := 0 \quad \Phi_F := U_T \cdot \ln\left(\frac{N_A}{n_i}\right)$$

$$N_{MIN} := 1 + \frac{\Gamma_b}{2 \cdot \sqrt{2 \cdot \Phi_F + V_S}} \quad N_{MIN} = 2.088$$

# Verify in Structure Editor/Sdevice

	 SentaurusSE				 SentaurusD		 Inspect				
	T_SUB	W_SUB	TOX	NA		QSS		VT	NA_CV	N	Qi
--	1	2	.11	1e16	--	5e10	--	0.97	1.09e+16	2.07	5.86e+10

# Choose a Time/Temperature Wet/dry growth Recipe

- Try 1100C (based on experience)
- Dry because it is a get oxide

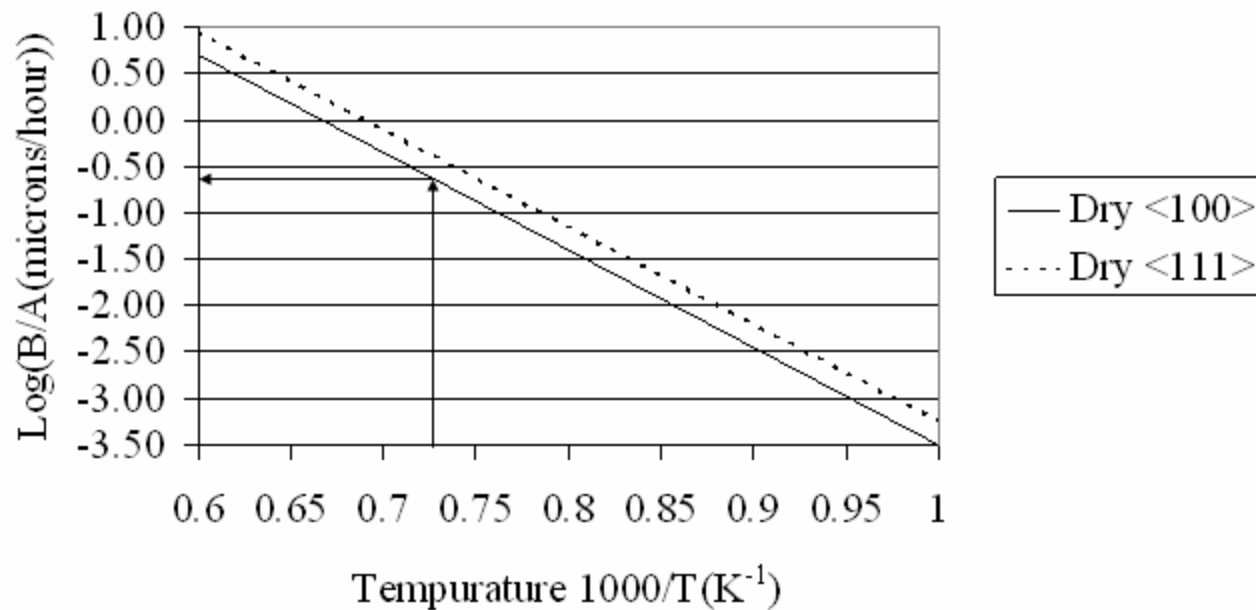
- $\langle 100 \rangle$  Si tc minimize  $\Delta f_c$  or  $\Delta j$   

$$T := \frac{1000}{1100 + 273} \quad T = 0.728$$

$$\text{Log}(B/A) = -.6$$

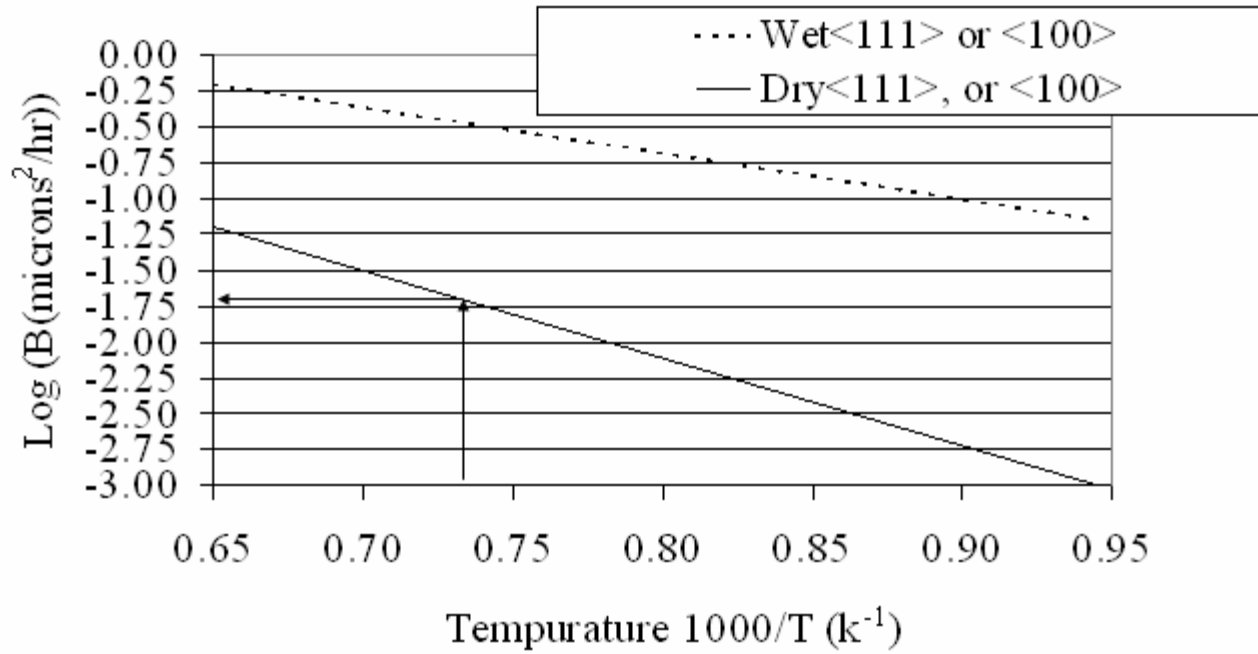
$$T := \frac{1000}{1100 + 273} \quad T = 0.728$$

Linear Rate Constant versus Temperature



# Log(B)=-1.7

Parabolic Rate Constant versus Temperature



# Sample Recipe

$$B := 10^{-1.7} \quad B = 0.02$$

$$A := \frac{B}{10^{-.6}} \quad A = 0.079$$



$$X := .11$$

$$\text{Time} := \frac{X^2 + A \cdot X}{B} \quad \text{Time} = 1.044 \quad \text{Time} \cdot 60 = 62.661$$

Temp=1100C, 62 minutes

# Use Sproccess To verify

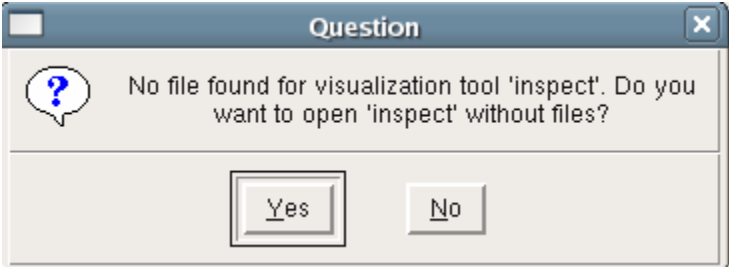
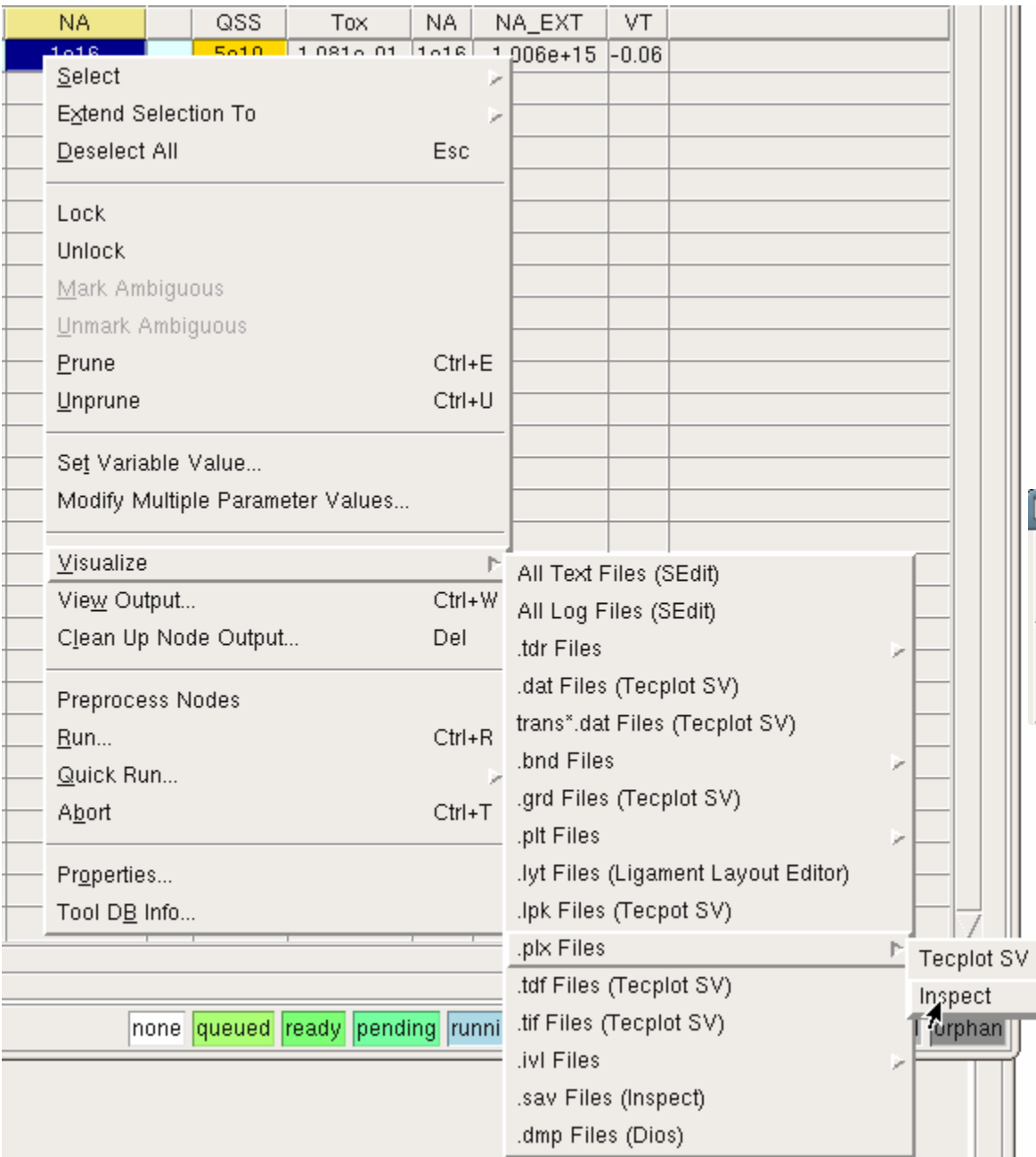
- [http://www.engr.sjsu.edu/dparent/ee225a/mis\\_process.gzp](http://www.engr.sjsu.edu/dparent/ee225a/mis_process.gzp)

 SentryP		 Inspect						
Gate_Ox_Time	Gate_Ox_Tmp	NA		QSS	Tox	NA	NA_EXT	VT
62	1100	1e16	--	5e10	1.081e-01	1e16	-1.006e+15	-0.06

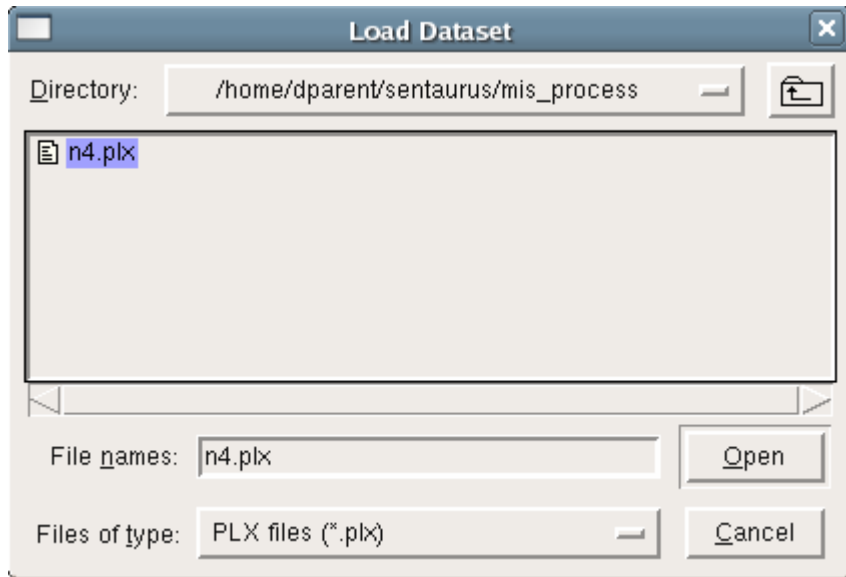
Tox is good, but VT is very far from 1V. What happened?  
Why is NA extracted so far from NA?

# Lets look at doping the doping profile

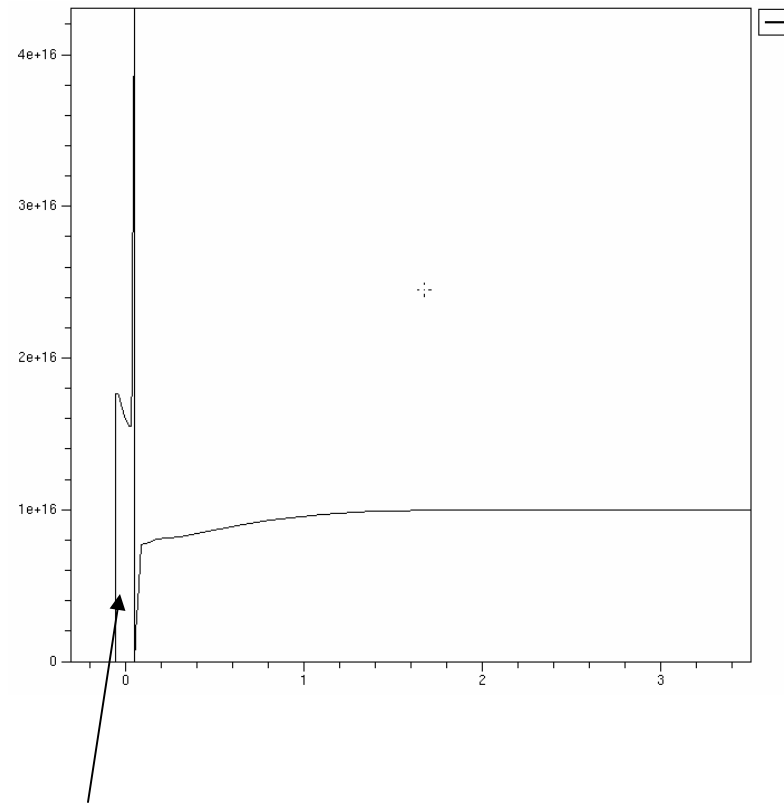
- Go to Visualize...plx files...inspect



Click yes.



# Doping Profile



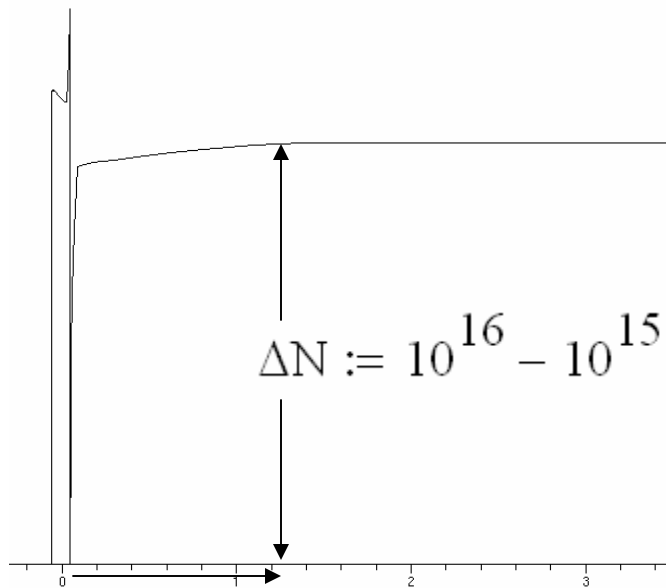
- What happened to my Na at the interface?
- Is VT Really that low?

# Vt is decreased by a low-high profile

$$\Delta N := (10^{16} - 10^{15}) \text{cm}^{-3}$$

$$x_s := 1.1 \cdot 10^{-4} \text{cm}$$

$$q := 1.6 \cdot 10^{-19} \text{C}$$



$$x_s := 1.1 \cdot 10^{-4} \text{cm}$$

$$Q_D := - \left[ 2 \cdot \epsilon_{\text{Si}} \cdot q \cdot N_A \cdot \left( 2 \cdot \phi_F + \frac{q \cdot \Delta N \cdot x_s^2}{2 \cdot \epsilon_{\text{Si}}} \right) \right]^{\frac{1}{2}} \quad Q_D = -1.74 \times 10^{-7} \text{V} \frac{\text{F}}{\text{cm}^2}$$

$$d := 1.1 \cdot 10^{-4} \text{cm}$$

$$C_{\text{oxide}} := \frac{\epsilon_{\text{oxide}}}{d}$$

$$V_{T0} := \phi_{\text{ms}} - \frac{Q_i}{C_{\text{oxide}}} - \frac{Q_D}{C_{\text{oxide}}} + 2 \cdot \phi_F - \frac{q \cdot \Delta N \cdot x_s}{C_{\text{oxide}}}$$

$$V_{T0} = 4.067 \times 10^{-4} \text{V}$$

Why is the boron segregated from the surface?