

# MIS Case Study using Sentaurus

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# Use Analytical Equations to determine possible Oxide thickness Substrate doping pairs

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

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

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

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

$$\epsilon_{\text{oxide}} := 3.9 \cdot 8.85 \cdot 10^{-14} \frac{\text{F}}{\text{cm}}$$

$$Q_i := 5 \cdot 10^{11} \cdot \frac{q}{\text{cm}^2}$$

$$\phi_{\text{ms}} := -.6 \text{ V} - \frac{k \cdot T}{q} \cdot \ln \left( \frac{N_A}{n_i} \right)$$

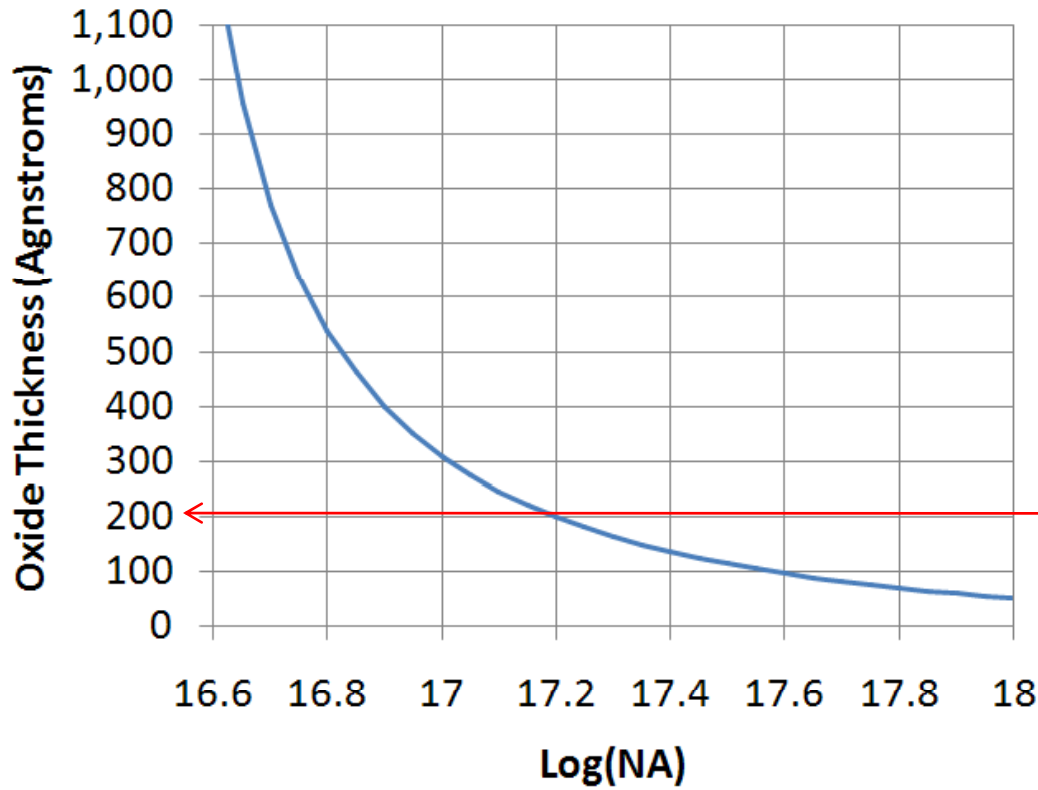
$$\phi_F := \frac{k \cdot T}{q} \cdot \ln \left( \frac{N_A}{n_i} \right)$$

$$Q_D := -2 \cdot \left( \epsilon_{\text{Si}} \cdot q \cdot N_A \cdot \phi_F \right)^{\frac{1}{2}}$$

Min Tox




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

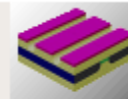


$$V_{\text{T0}} := \phi_{\text{ms}} - \frac{Q_i}{C_{\text{oxide}}} - \frac{Q_D}{C_{\text{oxide}}} + 2 \cdot \phi_F$$



# Choose $T_{ox}=300\text{Angstroms}$ , $1.58 \times 10^{17} \text{cm}^{-3}$

- Verify in TCAD with “drawn features”
- Make sure grid is appropriate

 SentaursSE				 SentaursD			 Inspect			
W_SUB	TOX	NA	NG		QSS		VT	NA_CV	N	Qi
3	0.0300	1.58e17	20	--	5e11	--	1.12	1.18e+17	1.98	2.14e+11
			25	--	5e11	--	1.12	1.18e+17	1.98	2.14e+11
			30	--	5e11	--	1.12	1.18e+17	1.98	2.14e+11
			35	--	5e11	--	1.12	1.18e+17	1.98	2.14e+11
			40	--	5e11	--	1.01	1.36e+17	2.04	3.77e+11
			70	--	5e11	--	1.01	1.36e+17	2.04	3.77e+11



 SentaursSE				 SentaursD			 Inspect			
W_SUB	TOX	NA	NG		QSS		VT	NA_CV	N	Qi
3	0.0300	7e+16	40	--	5e11	--	0.45	6.48e+16	1.74	3.77e+11
		9e+16	40	--	5e11	--	0.67	8.44e+16	1.84	3.46e+11
		1.1e+17	40	--	5e11	--	0.83	9.78e+16	1.89	3.08e+11
		1.3e+17	40	--	5e11	--	0.96	1.08e+17	1.94	2.69e+11
		1.5e+17	40	--	5e11	--	0.95	1.28e+17	2.01	3.82e+11
		1.58e+17	40	--	5e11	--	1.01	1.36e+17	2.04	3.77e+11
		8.4e+16	40	--	5e11	--	0.61	7.98e+16	1.81	3.57e+11

$T_{ox}, 300\text{Angstroms}, NA=8.4 \times 10^{16} \text{cm}^{-3}$

# Develop Gate Oxide Process

- Two Recipes.

$$X^2 + A(\mu m)X = B(\mu m^2 / hr)t(hr)$$

 SemiaurusP		 Inspect						
Gate_Ox_Time	Gate_Ox_Tmp	NA		QSS	Tox	NA	NA_EXT	VT
8	1100	8.4e16	--	5e11	3.113e-02	8.4e16	-3.415e+16	-0.03
		1.68e+17	--	5e11	3.112e-02	1.68e+17	-6.824e+16	0.36
		2.52e+17	--	5e11	3.113e-02	2.52e+17	-9.485e+16	0.60
30	1000	8.4e16	--	5e11	3.105e-02	8.4e16	-2.656e+16	-0.15
		1.68e+17	--	5e11	3.105e-02	1.68e+17	-5.309e+16	0.20
		3.0e+17	--	5e11	3.105e-02	3.0e+17	-9.470e+16	0.60

Tox, 310 Angstroms, NA=3.0x10<sup>17</sup>cm<sup>-3</sup>

# Develop Well Drive Process

- Assume first that all drive in is in the well drive step (Q=3e14 E=100kEV)

$$\begin{aligned}
 E_{A\_normal} &:= 3.5 & q &:= 1.6 \cdot 10^{-19} & D_0 &:= 10.0 & k &:= 1.38 \cdot 10^{-23} \\
 T_{WD} &:= 273 + 1150 & t_{WD} &:= 21 \cdot 60 \cdot 60 & D_{WD} &:= D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{WD}}\right) \\
 D_{WD} \cdot t_{WD} &= 3.117 \times 10^{-7} & Q &:= 3 \times 10^{14} \\
 N_{A\_Surf} &:= \frac{Q}{\sqrt{\pi \cdot D_{WD} \cdot t_{WD}}} & N_{A\_Surf} &= 3.032 \times 10^{17}
 \end{aligned}$$

21 hours. A Little Long, but it just might work.

This assumes that the bulk NA and the surface concentration will be the same.  
(Before B segregation.)

# Model all diffusions (NO OED)

$$E_{A\_normal} := 3.5 \quad q := 1.6 \cdot 10^{-19} \quad D_0 := 10.0 \quad k := 1.38 \cdot 10^{-23}$$

$$T_{WD} := 273 + 1150 \quad t_{WD} := 21 \cdot 60 \cdot 60 \quad D_{WD} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{WD}}\right)$$

$$D_{WD} \cdot t_{WD} = 3.117 \times 10^{-7} \quad Q := 3 \times 10^{14}$$

$$N_{A\_Surf} := \frac{Q}{\sqrt{\pi \cdot D_{WD} \cdot t_{WD}}} \quad N_{A\_Surf} = 3.032 \times 10^{17}$$

$$T_{FO} := 273 + 1100 \quad t_{FO} := 60 \cdot 60 \quad D_{FO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{FO}}\right)$$

$$D_{FO} \cdot t_{FO} = 5.254 \times 10^{-9}$$

$$T_{SD} := 273 + 1100 \quad t_{SD} := 60 \cdot 60 \quad D_{SD} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{SD}}\right)$$

$$D_{SD} \cdot t_{SD} = 5.254 \times 10^{-9}$$

$$T_{GO} := 273 + 1000 \quad t_{GO} := 30 \cdot 60 \quad D_{GO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{GO}}\right)$$

$$D_{GO} \cdot t_{GO} = 2.577 \times 10^{-10}$$

$$Dt_{Total} := D_{WD} \cdot t_{WD} + D_{FO} \cdot t_{FO} + D_{SD} \cdot t_{SD} + D_{GO} \cdot t_{GO}$$

$$Dt_{Total} = 3.225 \times 10^{-7}$$

$$N_{A\_Surf} := \frac{Q}{\sqrt{\pi \cdot Dt_{Total}}} \quad N_{A\_Surf} = 2.981 \times 10^{17}$$

Everything Still Good.

# Model all diffusions (with OED)

$$\Delta D := 6.25 \cdot 10^{-4}$$

$$T_{FO} := 273 + 1100 \quad t_{FO} := 60 \cdot 60 \quad D_{FO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{FO}}\right) + \Delta D \cdot \exp\left(\frac{-2.55}{\left(\frac{k \cdot T_{FO}}{q}\right)}\right)$$

$$D_{FO} \cdot t_{FO} = 6.255 \times 10^{-9}$$

$$T_{GO} := 273 + 1000 \quad t_{GO} := 30 \cdot 60 \quad D_{GO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{GO}}\right) + \Delta D \cdot \exp\left(\frac{-2.55}{\left(\frac{k \cdot T_{GO}}{q}\right)}\right)$$

$$D_{GO} \cdot t_{GO} = 3.499 \times 10^{-10}$$

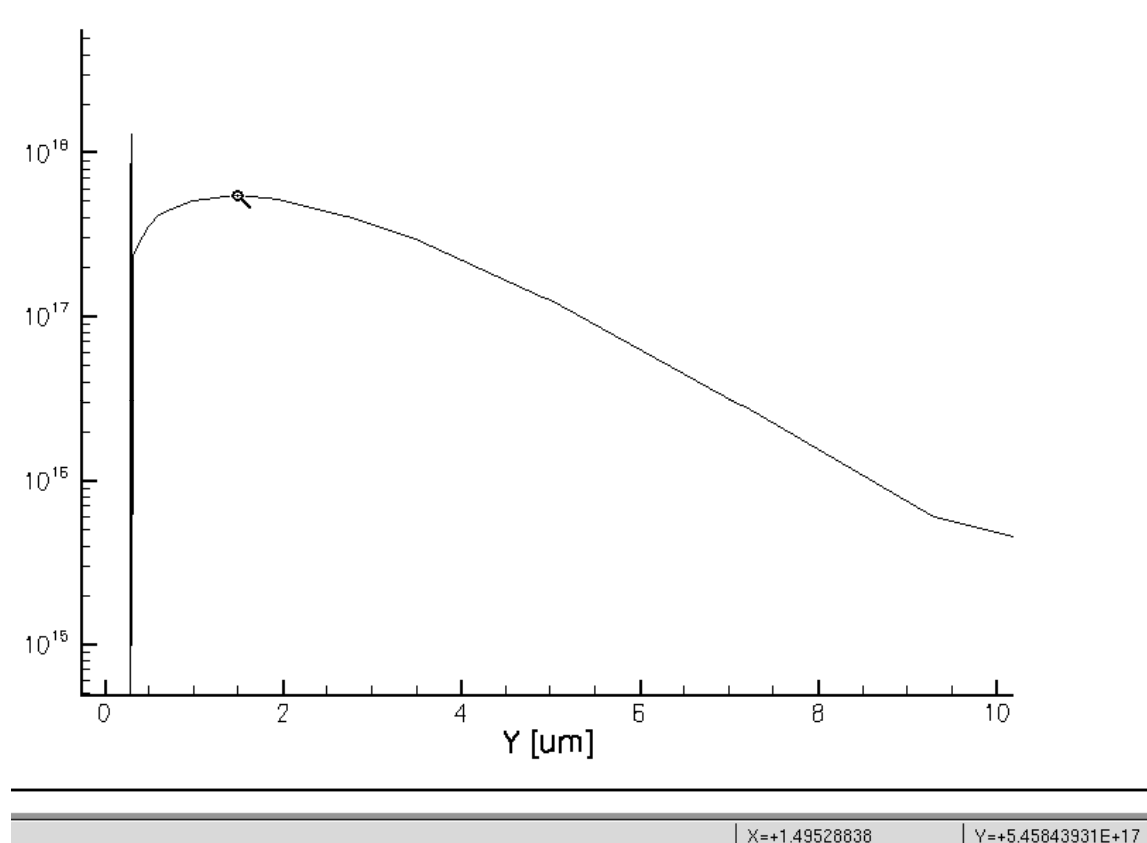
$$Dt_{Total} := D_{WD} \cdot t_{WD} + D_{FO} \cdot t_{FO} + D_{SD} \cdot t_{SD} + D_{GO} \cdot t_{GO} \quad +$$

$$Dt_{Total} = 3.236 \times 10^{-7}$$

$$N_{A\_Surf} := \frac{Q}{\sqrt{\pi \cdot Dt_{Total}}} \quad N_{A\_Surf} = 2.976 \times 10^{17}$$

No appreciable difference.

After running the full process deck, the VT is found to be 1.34 volts.



Vt was a lot bigger due to the fact bulk was supposed to be  $3 \times 10^{17} \text{cm}^{-3}$  not  $5.45 \times 10^{17} \text{cm}^{-3}$ .

TOX	NA	VT	NA_CV	N	QSS
3.104e-02	1.894e+17	1.34	2.82e+17	2.39	6.54e+11

## The specification of 0.6 Volts was not met. What are our options?

- Assume that there is an effect in the TCAD that we are not modeling and just start increasing the well drive time until we meet specification.
- This sounds reasonable because in the past we have used hand calculation to get close to an answer and then “explored the design space” with the TCAD tool.
- We are off in NA by a factor of two, can we see how much time we need to change NA by a factor of two using our hand calculations?

$$\begin{aligned}
 E_{A\_normal} &:= 3.5 & q &:= 1.6 \cdot 10^{-19} & D_0 &:= 10.0 & k &:= 1.38 \cdot 10^{-23} \\
 T_{WD} &:= 273 + 1150 & t_{WD} &:= 72 \cdot 60 \cdot 60 & D_{WD} &:= D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{\frac{k \cdot T_{WD}}{q}}\right) \\
 D_{WD} \cdot t_{WD} &= 1.069 \times 10^{-6} & Q &:= 3 \times 10^{14} & N_{A\_Surf} &:= \frac{Q}{\sqrt{\pi \cdot D_{WD} \cdot t_{WD}}} & N_{A\_Surf} &= 1.637 \times 10^{17}
 \end{aligned}$$

To reduce NA by a factor of two requires a three day diffusion!  
 Why does our design seem to require three days vs. one day?

## Why does our design seem to require three days vs. one day?

- This is really bothersome to have a calculation that is off by several days, is not very helpful.
- After experiments with several well drive temperatures and time and comparing the results to hand calculations, there all ways seem to be a large error.
- A quick review of other texted showed that not every one agrees on the diffusion constant of Boron.

# Try a different diffusion constant

$$D_0 := 0.76 \quad q := 1.6 \cdot 10^{-19} \quad E_{A\_normal} := 3.46 \quad k := 1.38 \cdot 10^{-23}$$

$$T_{WD} := 273 + 1150 \quad t_{WD} := 21 \cdot 60 \cdot 60 \quad D_{WD} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{\frac{k \cdot T_{WD}}{q}}\right)$$

$$D_{WD} \cdot t_{WD} = 3.282 \times 10^{-8} \quad Q := 3 \times 10^{14} \quad N_{A\_Suf} := \frac{Q}{\sqrt{\pi \cdot D_{WD} \cdot t_{WD}}} \quad N_{A\_Suf} = 9.343 \times 10^{17}$$

$$T_{FO} := 273 + 1100 \quad t_{FO} := 60 \cdot 60 \quad D_{FO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{\frac{k \cdot T_{FO}}{q}}\right)$$

$$D_{FO} \cdot t_{FO} = 5.598 \times 10^{-10}$$

$$T_{SD} := 273 + 1100 \quad t_{SD} := 60 \cdot 60 \quad D_{SD} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{\frac{k \cdot T_{SD}}{q}}\right)$$

$$D_{SD} \cdot t_{SD} = 5.598 \times 10^{-10}$$

$$T_{GO} := 273 + 1000 \quad t_{GO} := 30 \cdot 60 \quad D_{GO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{\frac{k \cdot T_{GO}}{q}}\right)$$

$$D_{GO} \cdot t_{GO} = 2.82 \times 10^{-11}$$

$$Dt_{Total} := D_{WD} \cdot t_{WD} + D_{FO} \cdot t_{FO} + D_{SD} \cdot t_{SD} + D_{GO} \cdot t_{GO}$$

$$Dt_{Total} = 3.396 \times 10^{-8}$$

$$N_{A\_Suf} := \frac{Q}{\sqrt{\pi \cdot Dt_{Total}}} \quad N_{A\_Suf} = 9.184 \times 10^{17}$$

No OED Diffusion constant from Wolf.

# Why does our design seem to require three days vs. one day?

$$\Delta D := 6.25 \cdot 10^{-4}$$

$$T_{FO} := 273 + 1100 \quad t_{FO} := 60 \cdot 60 \quad D_{FO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{FO}}\right) + \Delta D \cdot \exp\left[\frac{-2.55}{\left(\frac{k \cdot T_{FO}}{q}\right)}\right]$$

$$D_{FO} \cdot t_{FO} = 1.561 \times 10^{-9}$$

$$T_{GO} := 273 + 1000 \quad t_{GO} := 30 \cdot 60 \quad D_{GO} := D_0 \cdot \exp\left(\frac{-E_{A\_normal}}{k \cdot T_{GO}}\right) + \Delta D \cdot \exp\left(\frac{-2.55}{\left(\frac{k \cdot T_{GO}}{q}\right)}\right)$$

$$D_{GO} \cdot t_{GO} = 1.204 \times 10^{-10}$$

$$Dt_{Total} := D_{WD} \cdot t_{WD} + D_{FO} \cdot t_{FO} + D_{SD} \cdot t_{SD} + D_{GO} \cdot t_{GO}$$

$$Dt_{Total} = 3.506 \times 10^{-8}$$

$$N_{A\_Surf} := \frac{Q}{\sqrt{\pi \cdot Dt_{Total}}} \quad N_{A\_Surf} = 9.04 \times 10^{17}$$

With OED. This seems a factor of two, too slow to get NA

Now takes nine days! TCAD matches pretty well for a nine day well drive

This shows that we have agreement between TCAD and hand calculations. Nine days is still too long

TOX	NA	VT	NA_CV	N	QSS
3.103e-02	8.362e+16	0.59	1.33e+17	1.97	6.00e+11

## Nine days is still too long, what do we do?

We could run the well drive for 24 hours and what ever the VT becomes is our new specification.

Develop a TOX process in our lab that can support a thin TOX  
(If we can not control NA, Control TOX)

Use the fact that boron segregation is more severe at 900 Celsius, this oxidation temp will lower the surface boron concentration.

Gate_Ox_Tmp	NG	QSS	Tox	NA	VT	NA_CV
900	50	5e11	2.593e-02	9.181e+16	0.75	1.93e+17
900	50	5e11	2.743e-02	9.904e+16	0.67	1.62e+17
900	50	5e11	2.891e-02	1.023e+17	0.65	1.51e+17

What to do?

There are at least three different values for Do and Ea in various texts all based on experimental results. The most accurate thing to do Would be to do a simple well drive and use the Hg probe CV meter to determine which model is correct.