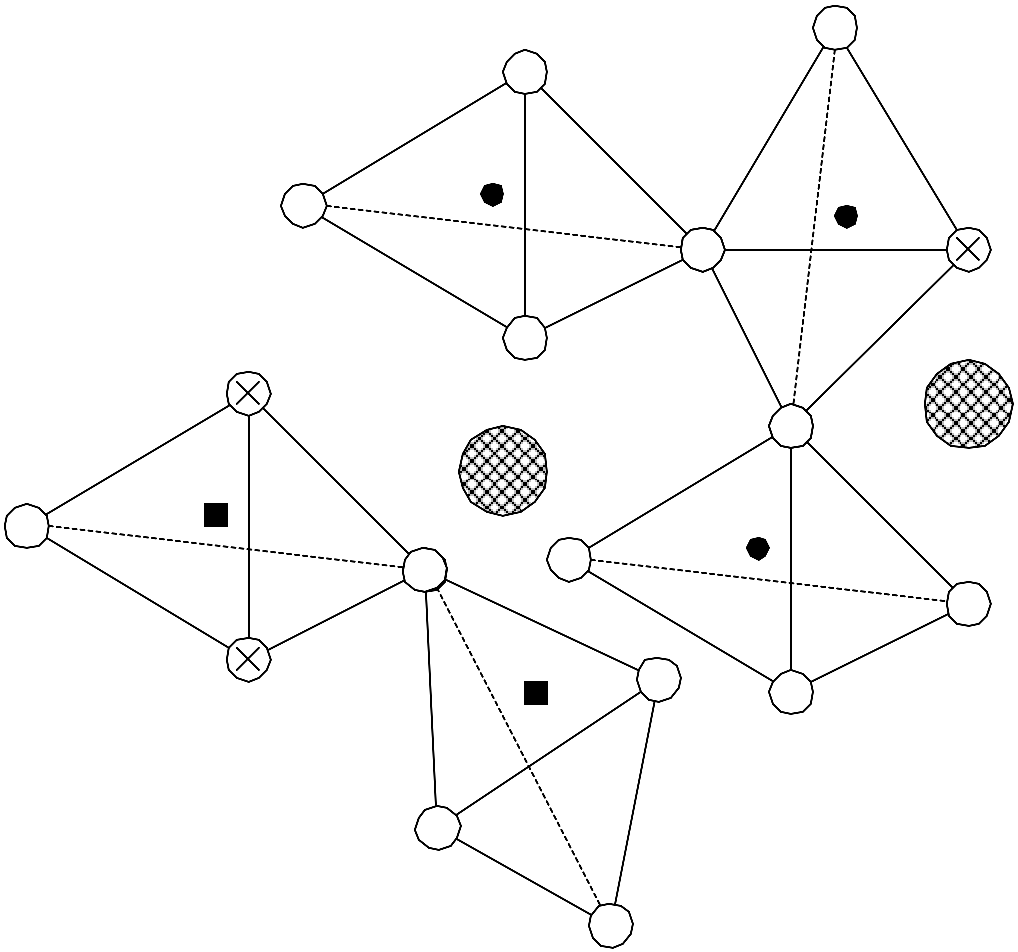
Silicon dioxide

- What is SiO_2?
- What is SiO_2 used for?
- Advantages and Disadvantages of SiO_2
- How is it grown?
  - Dry
  - Wet
- Numerical Examples

What is SiO_2?

- Two forms
  - Single crystal (quartz)
  - Amorphous
- We are interested in Amorphous SiO_2
  - Random three dimensional network of SiO_2 constructed from polyhedra of oxygen ions.
  - This material is more porous than Quartz (density of 2.15-2.25g/cm^3 compared to 2.65 25g/cm^3)

What is SiO_2?



Network modifier

Nonbridging oxygen

Silicon

Network former

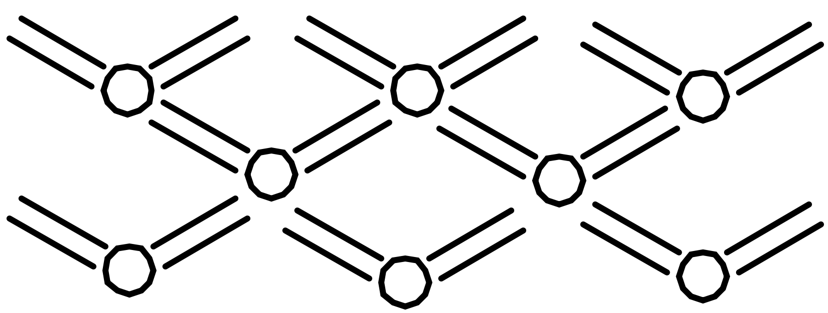
Bridging oxygen

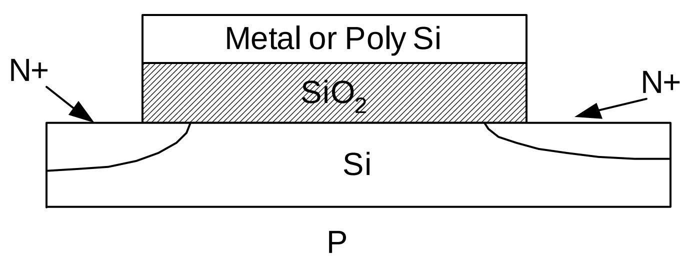
The O-Si-O Bond angle is 109^o

Tetrahedral distance bewtween Si and O ions is 1.6Å

What is SiO_2 used for?

- MOS Metal Oxide Semiconductor
- Device passivation
  - Combines with dangling bonds to reduce surface states



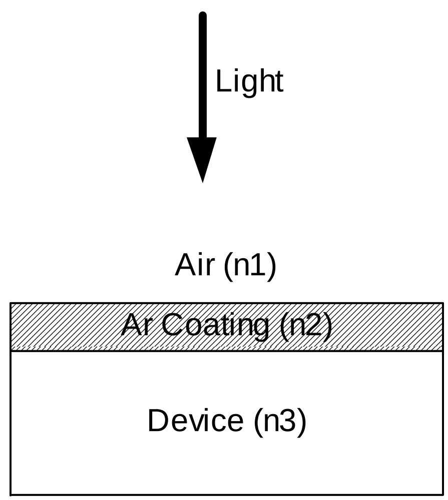


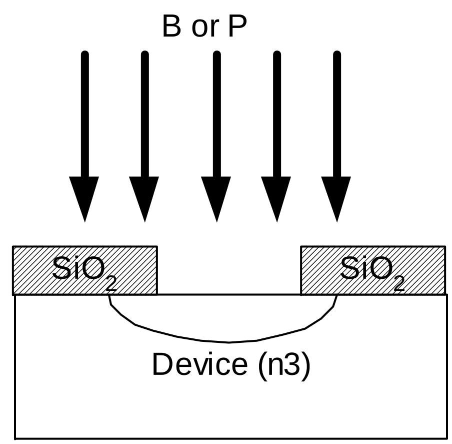
What is SiO_2 used for?

- Diffusion Masks
  - Block the diffusion of B and P for example
- Antireflective coating for Photodevices

$$n_2 = \sqrt{n_1 n_3},$$

$$\text{thickness} = \frac{\lambda}{4n_2}$$





Advantages and Disadvantages of SiO_2

- CMOS digital logic gates use little power when not switching logic state, thus high levels of integration are possible because the standby power consumption is low.
- SiO_2 is a native film that is quite easy to grow. All that is required is heat and oxygen or steam.

Advantages and Disadvantages of SiO_2

- SiO_2 consumes Si while growing. 44% of the SiO_2 layer comes from the original Si.
  - This leads to a non-planer structure after each oxidation step.
- Due to the large increase in volume there is 2-4×109 dyn cm-1 of compressive strain.
  - This causes dislocations.
- Oxidation-Induced Stacking Faults (these can be removed by a high temp treatment.

Advantages and Disadvantages of SiO_2

- The large dielectric constant leads to larger capacitance values for a given thickness (compared to silicon nitride).

How is it grown?

- The oxidizing species must diffuse through the SiO2 layer that has already grown. This leads to a linear regime of growth and a parabolic regime of growth. Given by the equation:

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

How is it grown?

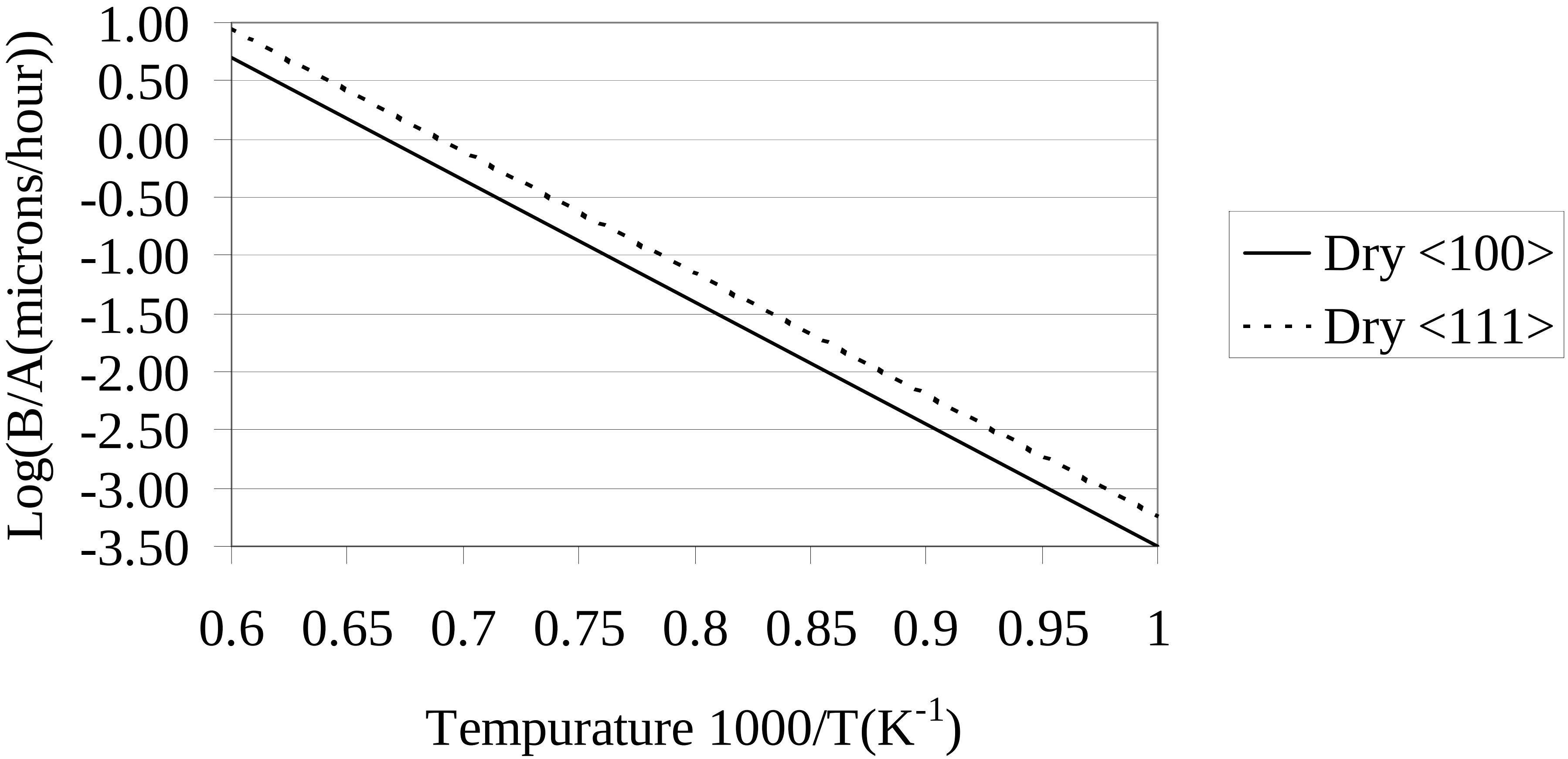
- Dry oxidation: Flow dry O2 over sample at elevated temperatures.

$$Si + O_2 \longrightarrow SiO_2$$

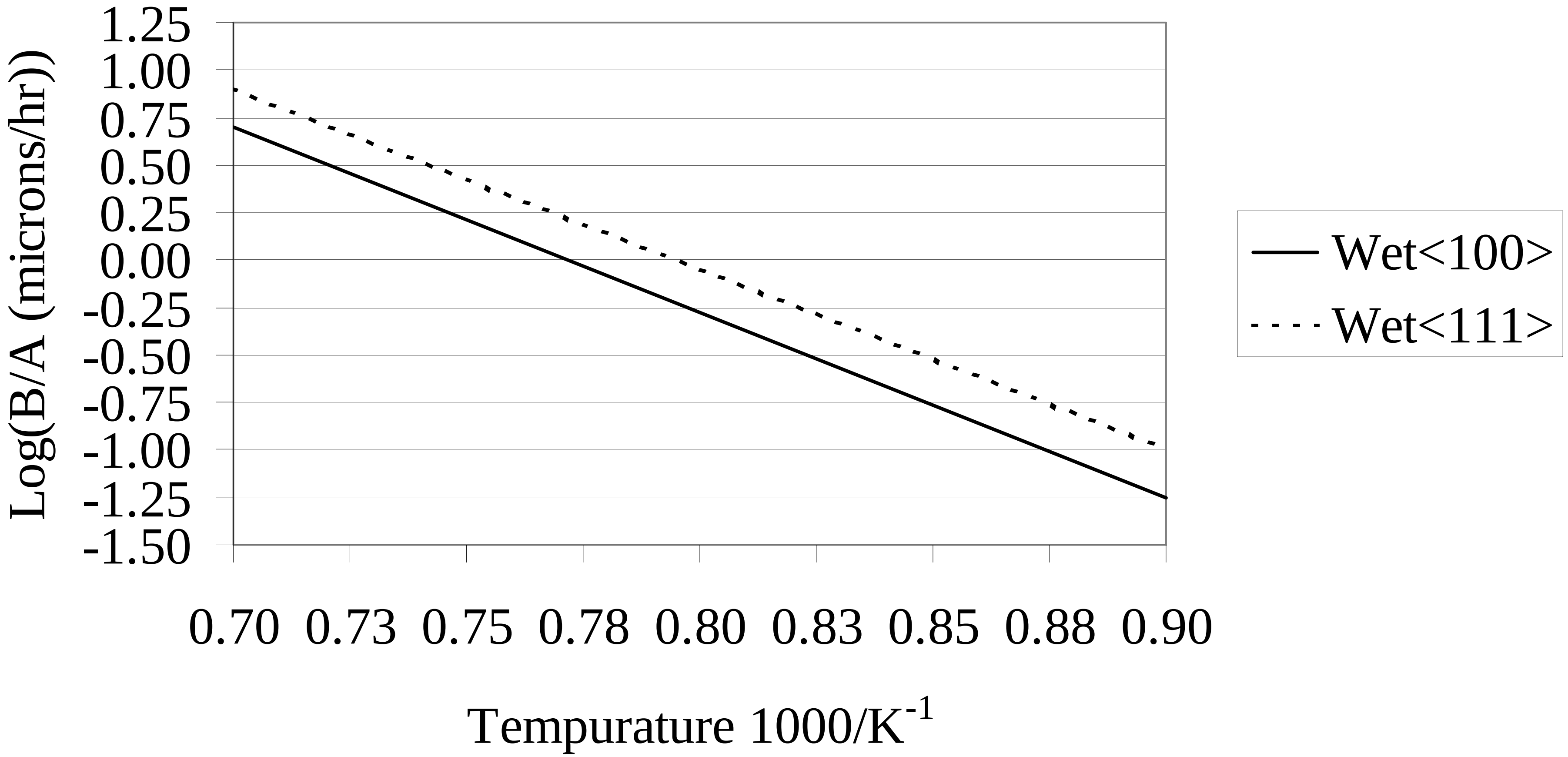
- Wet oxidation: Bubble N_2 through a water bubbler @95C^o over sample at elevated temperatures.

$$Si + 2H_2O \longrightarrow SiO_2 + 2H_2$$

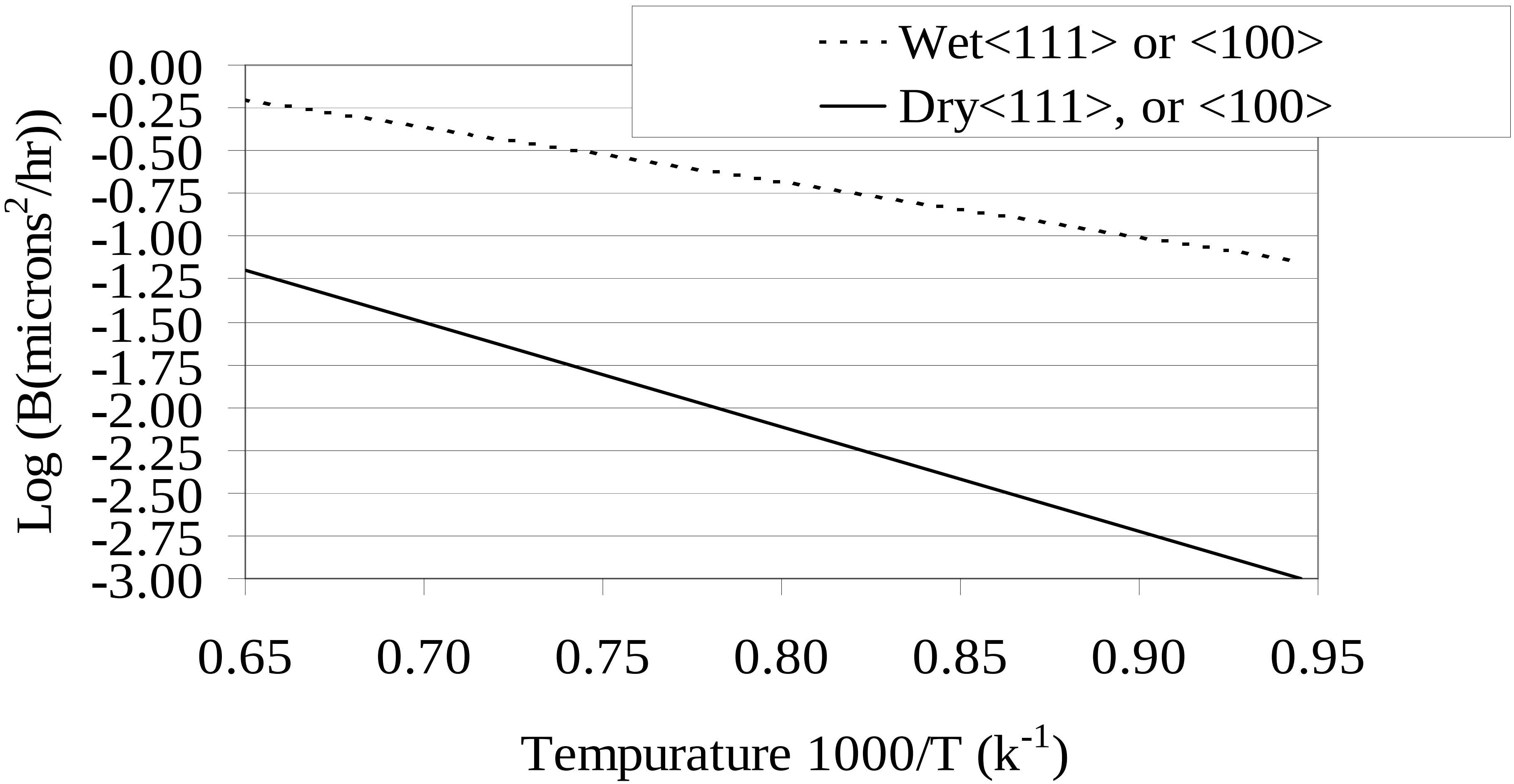
Linear Rate Constant versus Tempurature



Wet Oxidation



Parabolic Rate Constant versus Tempurature



Example 1

- Need to grow an Anti Reflective Coating for silicon based solar cells.
- Commercial cells are “blue” corresponding to a SiO_2 thickness (X_o)=0.1µm.
- The after orientation is <111> due to the fact <111> Silicon has a longer lifetime, thus a longer diffusion length and thus more efficiency cells than <100>

Choose wet/dry process and temperature

- We will choose 1150^{o}C and wet because this should minimize our process time.

	Wet Oxidation			
<100> Silicon	Do			
Linear (B/A)	9.70E+07	um/hr	2.05	eV
Parabolic (B)	386	um^2/hr	0.78	eV
<111> Silicon				
Linear (B/A)	1.63E+08	um/hr	2.05	eV
Parabolic (B)	3.86E+02	um^2/hr	0.78	eV

	Dry Oxidation			
<100> Silicon				
Linear (B/A)	3.71E+06	um/hr	2	eV
Parabolic (B)	772	um^2/hr	1.23	eV
<111> Silicon				
Linear (B/A)	6.23E+06	um/hr	2	eV
Parabolic (B)	7.72E+02	um^2/hr	1.23	eV

First Pass

$k := 8.62 \cdot 10^{-5} \frac{V}{K}$ wet <111> Si

$$\frac{B}{A} = D_o \cdot \exp\left(\frac{-E_A}{kT}\right)$$

$D_o := 1.63 \cdot 10^8 \frac{\mu m}{hr}$ $E_A := 2.05V$

$T := (1150 + 273)K$ $\frac{-E_A}{k \cdot T} = -16.713$

$$\text{Linear} = \frac{B}{A}$$

$$\text{Linear} := D_o \cdot \exp\left(\frac{-E_A}{k \cdot T}\right)$$

$$\text{Linear} = 8.996 \frac{\mu m}{hr}$$

$$B = D_o \cdot \exp\left(\frac{-E_A}{kT}\right)$$

$D_o := 386 \frac{\mu m^2}{hr}$ $E_A := 0.78V$

$T := (1150 + 273)K$ $\frac{-E_A}{k \cdot T} = -6.359$

$B := D_o \cdot \exp\left(\frac{-E_A}{k \cdot T}\right)$ $B = 0.668 \frac{\mu m^2}{hr}$

$$X_o := 0.1\mu m$$

$\text{Time} := \frac{{X_o}^2}{B} + \frac{X_o}{\text{Linear}}$ $\text{Time} = 0.026\,hr$

Time too short for our furnace!

Second Pass (900ºC)

$k := 8.62\cdot10^{-5}\,\frac{V}{K}$ wet <111> Si

$\frac{B}{A} = D_o\cdot\exp\left(\frac{-E_A}{kT}\right)$

$D_o := 1.63\cdot10^{8}\,\frac{\mu m}{hr}$ $E_A := 2.05V$

$T := (900 + 273)K$ $\frac{-E_A}{k\cdot T} = -20.274$

$Linear = \frac{B}{A}$

$Linear := D_o\cdot\exp\left(\frac{-E_A}{k\cdot T}\right)$

$Linear = 0.255\,\frac{\mu m}{hr}$

$B = D_o\cdot\exp\left(\frac{-E_A}{kT}\right)$

$D_o := 386\,\frac{\mu m^2}{hr}$ $E_A := 0.78V$

$T := (900 + 273)K$ $\frac{-E_A}{k\cdot T} = -7.714$

$B := D_o\cdot\exp\left(\frac{-E_A}{k\cdot T}\right)$ $B = 0.172\,\frac{\mu m^2}{hr}$

$X_o := 0.1\mu m$

$Time := \frac{X_o{}^2}{B} + \frac{X_o}{Linear}$ $Time = 0.45\,hr$

Time just right for our furnace!

$Time = 26.98\,min$

Wet Oxide

				Wet Oxidation			
<100> Silicon				Do			
Linear (B/A)				9.70E+07	um/hr	2.05	eV
Parabolic (B)				386	um^2/hr	0.78	eV
<111> Silicon							
Linear (B/A)				1.63E+08	um/hr	2.05	eV
Parabolic (B)				3.86E+02	um^2/hr	0.78	eV
		Temp oC	Temp (K)	Do	Ea/KT	Do*exp(-Ea/kT)	
Example 1	B/A	1150	1423	1.63E+08	16.71251058	8.995731445	
.1um, 1150oC	B	1150	1423	3.86E+02	6.358906464	0.668265924	
Wet							
<111> Si							
			B/A	B	Thickness (um)	Time=Xo^2/B+Xo/(B/A) (hr)	
			8.995731	0.668265924	0.1	0.026080486	
						Time(min)=	1.564829

				Wet Oxidation			
<100> Silicon				Do			
Linear (B/A)				9.70E+07	um/hr	2.05	eV
Parabolic (B)				386	um^2/hr	0.78	eV
<111> Silicon							
Linear (B/A)				1.63E+08	um/hr	2.05	eV
Parabolic (B)				3.86E+02	um^2/hr	0.78	eV
		Temp oC	Temp (K)	Do	Ea/KT	Do*exp(-Ea/kT)	
Example 2	B/A	900	1173	1.63E+08	20.27442673	0.255338294	
.1um, 1150oC	B	900	1173	3.86E+02	7.714172121	0.1723316	
Wet							
<111> Si							
			B/A	B	Thickness (um)	Time=Xo^2/B+Xo/(B/A) (hr)	
			0.255338	0.1723316	0.1	0.449664963	
						Time(min)=	26.9799

Dry Oxide Examples

<100> Silicon							
Linear (B/A)				3.71E+06	um/hr	2	eV
Parabolic (B)				772	um^2/hr	1.23	eV
<111> Silicon							
Linear (B/A)				6.23E+06	um/hr	2	eV
Parabolic (B)				7.72E+02	um^2/hr	1.23	eV
		Temp oC	Temp (K)	Do	Ea/KT	Do*exp(-Ea/kT)	
Example 1	B/A	1150	1423	6.23E+06	16.30489	0.516850571	
.1um, 1150oC	B	1150	1423	7.72E+02	10.02751	0.034097821	
Dry							
<111> Si							
			B/A	B	Thickness (um)	Time=Xo^2/B+Xo/(B/A) (hr)	
			0.516851	0.034097821	0.1	0.486753392	
						Time(min)=	29.2052

<100> Silicon				Do			
Linear (B/A)				3.71E+06	um/hr	2	eV
Parabolic (B)				772	um^2/hr	1.23	eV
<111> Silicon							
Linear (B/A)				6.23E+06	um/hr	2	eV
Parabolic (B)				7.72E+02	um^2/hr	1.23	eV
		Temp oC	Temp (K)	Do	Ea/KT	Do*exp(-Ea/kT)	
Example 2	B/A	900	1173	6.23E+06	19.77993	0.016001999	
.1um, 1150oC	B	900	1173	7.72E+02	12.16466	0.004023225	
Dry							
<111> Si							
			B/A	B	Thickness (um)	Time=Xo^2/B+Xo/(B/A) (hr)	
			0.016002	0.004023225	0.1	8.734787461	
						Time(min)=	524.0872