

1 Profiles & Layout

1.1

1.2

1.3

2 Process Procedures

2.1

2.2

2.3

3 Calculations

a) Film Thickness

Layer	Theoretical calculation (nm)	Experimental (nm)	% Error	Linewidths (photoresist) (nm)	Linewidths (after PR Strip) (nm)	% Overetch
Field Oxide	505.8	477.2	5.65	?	3000	?
Polysilicon	?	?	?	?	?	?
Gate Oxide	80.1	86.5	7.40	3628	4000	?
Intermed Oxide	386.3	320	17.2	?	?	?
Aluminum	800	?	?	2088	2520	?

b) Sheet Resistance

Layer	Sheet Resistance (??)	Surface concentration (??)
ACTV after Field Oxidation	?	?
Polysilicon	?	?
ACTV after Pre-Dep	?	?
ACTV after Drive-In	?	?
Metal	?	?

c) Overetch

Layer	Measured Linewidth (nm)	% Overetch	Theoretical etch time (min)	Actual etch time (min)	% Overetch
Field Oxide	?	?	4.8	6	25
Polysilicon	?	?	1.6	~ 2.25	41
Gate Oxide	?	?	0.87	?	?
Intermed Oxide	?	?	3.2	4.5	41
Aluminum	?	?	1.4	~ 5	360

1) Theoretical and experimental thicknesses of field oxide, gate and intermediate oxides (Include orientation dependence of oxidation rate but not impurity dependence) (9 points)

For details on the theoretical oxide thickness calculations see Appendix [5.1](#).

Layer	Theoretical (nm)	Experimental (nm)	% Error
Field Oxide	505.8	477.2	5.65
Gate Oxide	80.1	86.5	7.40
Intermed Oxide	386.3	320	17.2

- 2) Junction depths after pre-diffusion and drive-in (theoretical, assume only phosphorous doping with surface concentration limited by solid solubility). You must consider the effect of the initial ion implantation. For pre-deposition you may use the box approximation, but for drive-in you must use the half-gaussian calculation. Why is this? (10 points)

For details on the junction depth calculations see Appendix 5.2. Also the reason we use a box approximation for the pre-diffusion is because we have a constant source profile. However, for drive-in we now have source-limited diffusion.

Step	Junction Depth (nm)
Pre-diffusion	365
Drive-in	1000

- 3) test
test

- 4) Plot or sketch the change of dopant profile from the silicon surface through the source-drain after each thermal step. Quantitatively label significant points such as Peak concentration, Peak Width, Junction Depth. Show movement of the Silicon-Silicon Dioxide interface and qualitatively show non-ideal effects such as dopant redistribution during oxidation. (11 points)

The profiles were all created in Tsuprem-4 using the EE143 process flow.

- Field Oxidation

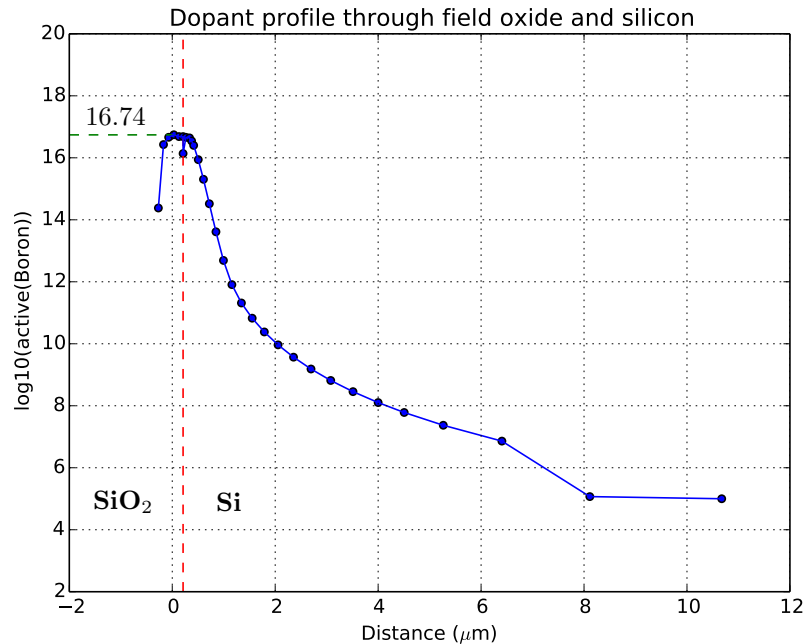


Figure 1: Dopant profile with only field oxide. The Si-SiO_2 interface occurs at $0.2104 \mu\text{m}$. There was about 500 nm of field oxide deposited here. The peak concentration is roughly $10^{16.74}$.

- Gate Oxidation

- 5) test
test

- 6) List an estimate of the Young's modulus, Poisson ratio, and coefficient of thermalexpansion for SiO₂, poly-Si, and Al films as deposited. (You can find these in a table in many physics/ME textbooks, or in a web-based search.) (2 points)

See table below

Material	Young's modulus (GPa)	coeff. of thermal expansion (K ⁻¹)	Poisson's ratio (a.u.)
SiO ₂ [3]	57(dry)-70(wet)	$5.6 \cdot 10^{-7}$	0.17
poly-Si [2]	169 ± 6.15	$4.6 \cdot 10^{-6}$	$0.22 \pm .011$
Aluminum [4]	70	$22.2 \cdot 10^{-6}$	0.33

Figure 2: Values were found from various journals/articles found online ([2],[3], and[4]) and many of these values are calculated for thin films of the material.

4 Questions

- 1) What type of photoresist (positive or negative? I-line or G-line?) do we use in the lab? What do I-line and G-line refer to? Briefly describe how the resist responds to the process steps like spinning, UV light exposure and development.
- 2) What is the purpose of baking the wafers at 120 °C before depositing HMDS? What is the purpose of the 90 °C bake after spinning on photoresist? What happens if the soft bake is too hot and too long (say 120 °C, 5 minutes)?
- 3) What is the purpose of hard bake? What happens if we skip this step? What may happen if the bake is done at a temperature above 120 °C (say 200 °C)?
- 4) We do lithography steps under yellow light only. What is the consequence if we expose the wafers to fluorescent light before development? What if we expose them to fluorescent light after development? Would red light damage your process?
- 5) What are the differences between wet and dry oxidation that lead us to use one for the gate oxide and one for the field/intermediate oxide? What is the purpose of annealing in nitrogen after oxidation?
- 6) How do you determine etching time using theoretical etch rate in literature? List two ways to determine etch time empirically from lab measurements, when you etch the layers. (Hint: these methods include visual cues.). How close are the experimental and the theoretically calculated values?
- 7) Before n+ deposition (prior to SOG spinning), we clean in Piranha but not in HF. Before gate oxidation, we clean in both. Why the difference?
- 8) Why is 5:1 BHF (5:1 NH₄F:HF) used for etching features in the oxide while 10:1 BHF is used for cleaning and spin-on-glass stripping? Why buffered HF?
- 9) What would happen if we skipped the HF dip before metallization?
- 10) What is etch selectivity?
- 11) Why do we first use the roughing pump and then the diffusion pump when pumping down the aluminum deposition system? Why must the foreline pressure be kept below 100 mTorr?

- 12) What is the Al etchant composed of? What happens if you use it at room temperature? What is the purpose of sintering? What will result if sintering step is skipped? What happens if sintering temperature is too hot or too low?
- 13) Briefly explain the mechanism of XeF_2 etching. Is the etch isotropic or anisotropic? In an integrated CMOS/MEMS process, is there any consequence to using KOH instead of XeF_2 for etch?
- 14) . What would happen if a thick oxide film was left on the wafers as it went into the XeF_2 etching step?
- 15) Identify two of the 11 major processing steps that are unnecessary to fabricate a functional oxide cantilever beam. Why are they unnecessary?

5 Appendix

5.1 Oxide Thickness calculations

Film thickness calculation for oxides:

$$X_{ox} = \frac{0.5B}{B/A} \left[\sqrt{1 + \frac{4}{B} \left(\frac{B}{A}\right)^2 (t + \tau) - 1} \right] \quad (1)$$

$$\tau = \frac{X_i^2}{B} + \frac{X_i}{B/A} \quad (2)$$

where

$$B/A = D_o e^{\frac{-E_a}{kT}} \text{ (Use table 3.1 [1] to find } E_a \text{ and } D_o)$$

$$B = D_o e^{\frac{-E_a}{kT}} \text{ (Use table 3.1 [1] to find } E_a \text{ and } D_o)$$

t = Time of oxide growth

τ = Time of initial oxide growth already present

X_i = length of initial oxide growth

Example: Calculated oxide thickness of Intermed Oxide:

Given: 5 min dry oxidation at 1050°C and 12 + 25 min wet oxidation annealing at 1050°C , calculate oxide growth.

First we consider the 5 min dry oxidation. Using table 3.1 [1] for a $< 100 >$ Silicon, and using dry oxidation, we see that for the linear rate constant (B/A), $E_A = 2.00$ eV and $D_o = 3.71 \times 10^6 \mu\text{m/hr}$. For the parabolic rate constant (B), $E_A = 1.23$ eV and $D_o = 772 \mu\text{m/hr}$.

Using an arrhenius equation where k = Boltzmann's constant, and T = temperature.

$$B/A = D_o e^{\frac{-E_A}{kT}} = 3.71 \times 10^6 e^{\frac{-2.00 \times 1.602 \times 10^{-19}}{1.38 \times 10^{-23} (1050^\circ\text{C} + 273)}} = 0.0887 \mu\text{m/hr}$$

$$B = D_o e^{\frac{-E_A}{kT}} = 772 e^{\frac{-1.23 \times 1.602 \times 10^{-19}}{1.38 \times 10^{-23} (1050^\circ\text{C} + 273)}} = 0.0159 \mu\text{m}^2/\text{hr}$$

Since there is no initial oxide here, $\tau = 0$,

$$X_{ox} = \frac{0.5B}{B/A} \left[\sqrt{1 + \frac{4}{B} \left(\frac{B}{A}\right)^2 (t + \tau) - 1} \right] = \frac{0.5(0.0159)}{0.0887} \left[\sqrt{1 + \frac{4}{0.0159} (0.0887)^2 \left(\frac{5\text{min}}{60\text{min/hr}} + 0\right) - 1} \right] \approx 7.11 \text{ nm}$$

Now after this dry oxidation, we have a 37 minute wet oxidation at 1050°C . Using table 3.1 [1] again, but this time using the constants that apply for wet oxidation,

$$B/A_{\text{wet}} = D_o e^{\frac{-E_A}{kT}} = 9.70 \times 10^7 e^{\frac{-2.05 \times 1.602 \times 10^{-19}}{1.38 \times 10^{-23} (1050^\circ\text{C} + 273)}} = 1.50 \mu\text{m/hr}$$

$$B_{\text{wet}} = D_o e^{\frac{-E_A}{kT}} = 386 e^{\frac{-0.78 \times 1.602 \times 10^{-19}}{1.38 \times 10^{-23} (1050^\circ\text{C} + 273)}} = 0.411 \mu\text{m}^2/\text{hr}$$

This time we do have an initial oxidation time τ because of the dry oxidation we did in the previous step. Here X_i is the oxide length we calculated for the dry oxidation growth,

$$\tau = \frac{X_i^2}{B_{\text{wet}}} + \frac{X_i}{B/A_{\text{wet}}} = \frac{0.00711^2}{0.411} + \frac{0.00711}{1.50} \approx 0.00488\text{hrs}$$

And finally our oxide growth is,

$$X_{ox} = \frac{0.5B}{B/A} \left[\sqrt{1 + \frac{4}{B} \left(\frac{B}{A} \right)^2 (t + \tau)} - 1 \right] = \frac{0.5(0.411)}{1.50} \left[\sqrt{1 + \frac{4}{0.411} (1.50)^2 \left(\frac{(12 + 25)\text{min}}{60\text{min/hr}} + 0.00488\text{hrs} \right)} - 1 \right] \approx 386.3 \text{ nm}$$

5.2 Junction Depth Calculations

Junction depth calculation for box approximation (limited-source diffusion):

$$x_j = 2\sqrt{Dt \ln(N_o/N_B)} \quad (3)$$

and for a half gaussian (constant-source diffusion):

$$x_j = 2\sqrt{Dt} \operatorname{erfc}^{-1}(N_B/N_o) \quad (4)$$

where,

$$D = D_o e^{-\frac{E_A}{kT}} \text{ (Diffusion coefficient)}$$

t = time of diffusion

N_B = Background impurity concentration

N_o = Surface concentration limited by solid solubility

Example: Calculate the junction depth after pre-diffusion and drive in.

According to the process flow [5], our silicon wafer has a resistivity of about 14-16 ohm-cm. From the same process flow we know that we had a phosphorus doped, solid solubility limited constant diffusion at 1050°C. Using figure 4.6 [1] we see that at a temperature of 1050°C our phosphorus surface concentration $N_o \approx 10^{21}/\text{cm}^3$. Now using the Resistivity of our wafer and figure 4.8 [1], we see that we have an impurity concentration $N_B \approx 8 \times 10^{14}/\text{cm}^3$.

Using table 4.1 [1], we can calculate our diffusion coefficient. Note that pre-diffusion was done at 1050°C for 5 minutes.

$$D = D_o e^{-\frac{E_A}{kT}} = 10.5 \text{ cm}^2/\text{sec} \exp\left(\frac{-3.69 * 1.602 \times 10^{-19}}{1.38 \times 10^{-23}(1050 + 273)}\right) = 9.11 \times 10^{-14} \text{ cm}^2/\text{sec}$$

Now we can plug everything into our solid solubility limited box approximation equation:

$$x_j = 2\sqrt{Dt} \operatorname{erfc}^{-1}(N_B/N_o) = 2\sqrt{(9.11 \times 10^{-14})(300\text{sec})} \operatorname{erfc}^{-1}(8 \times 10^{14}/10^{21}) \approx 365 \text{ nm}$$

Now for drive-in we kept the temperature the same, 1050°C, but kept the wafer inside the furnace for 37 minutes (2220 seconds). Also we can no longer assume a simple box approximation, we must use a half gaussian; this means that our surface concentration is going to change with drive-in.

We will use the following equation,

$$N_B = (Q/\sqrt{\pi D_2 t_2}) \exp\left(-\left(\frac{x_j}{2\sqrt{D_2 t_2}}\right)^2\right) \quad (5)$$

where Q is the dose rate,

$$Q = 2N_o \sqrt{D_1 t_1/\pi} \quad (6)$$

Combining the two equations and noting that $D_1 = D_2$ because we are using the same temperature, 1050°C, for both pre-diffusion and drive-in (t_1 is the pre-diffusion time and t_2 is the drive in time),

$$N_B = (2N_o/\pi) \sqrt{\frac{t_1}{t_2}} \exp\left(-\left(\frac{x_j}{2\sqrt{D_2 t_2}}\right)^2\right)$$

Solving this for x_j yields,

$$x_j = 2\sqrt{D_2 t_2 \ln\left(\frac{(2N_o/\pi N_B)(\sqrt{t_1/t_2})}{1}\right)} = 2\sqrt{(9.11 \times 10^{-14})(2220) \ln\left(\frac{(2(10^{21})/\pi(8 \times 10^{14}))(\sqrt{300/2220})}{1}\right)} \approx 1000 \text{ nm}$$

5.3 Dopant Profiles.

- Field Oxide

According to the EE143 process flow, There was an initial blanket implant of B11 $3\text{E}12\text{cm}^{-3}$ on our $\langle 100 \rangle$ wafer. Also our wafer had a resistivity of 14-16cm which corresponds to a background concentration of about $8\text{E}14\text{cm}^{-3}$. Now for the field oxide, we used 5-80-5 minute dry,wet,dry oxidation to create about 500 nm of oxide. Putting all this information into Tsuprem-4 generates the plot in Figure 1.

Script file:

```
$ field oxide

$ Initialization
Initialize <100> material=silicon Phosphorus=8e14 width=1.5 dX=0.005

$ Blanket implant here
Implant B11 Energy=60 Dose=3e12

$ 5-80-5 oxidation
Diffusion Time=5 Temperature=1000 Dry02
Diffusion Time=80 CONTINUE Temperature=1000 Wet02
Diffusion Time=5 CONTINUE Temperature=1000 Dry02

$ plotting
Select z=log10(active(boron))
Plot.1d
Print.1d
```

- Gate Oxide

6 References

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3. Kim, Min. "Influence of Substrates on the Elastic Reaction of Films for the Microindentation Tests." *Thin Solid Films* 283 (1996): 15. Web.
4. Chinmulgund, M. "Effect of Ar Gas Pressure on Growth, Structure, and Mechanical Properties of Sputtered Ti, Al, TiAl, and Ti3Al Films." *Thin Solid Films* 270.1-2 (1995): 260-63. Web.