

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	?	?	?	2088	2520	?

b) Sheet Resistance

c) Overetch

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.

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

4 Questions

1. The lab uses positive photoresist. The lithography machine uses a light that has g line wavelength. The I and G lines refer to the wavelength of the light coming off the light bulb that reacts with photoresist. G line is roughly xx wavelength and I line is xx wavelength.

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

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

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

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 and annealing at 1050°C, calculated 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. 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 [2], 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 $N_B \approx 8 \times 10^{14}$.

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,

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