NANYANG TECHNOLOGICAL UNIVERSITY
SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING
ACADEMIC YEAR 2022-2023
SEMESTER 1

EE3013 SEMINCONDUCTOR DEVICES AND PROCESSING

Thermal Oxidation

Q1. A silicon dioxide layer was grown at 1000°C under steam oxidation on (111) Si for 120-min. Given that A =0.226 μm and B = 0.287 μm^2/hr. Assume that the wafer initially had 100nm of oxide layer, calculate the thickness of the oxide.

Solution:

$$\tau = \frac{t_{oxi}^2}{B} + \frac{t_{oxi}}{B/A} = \frac{t_{oxi}^2 + At_{oxi}}{B}$$

$$\tau = \frac{(0.1\mu m)^2 + 0.226\mu m \times 0.1\mu m}{0.287\mu m^2 / hr} = 0.1135hr$$

The total oxide thickness is:

$$t_{oxt} = \frac{-A + \sqrt{A^2 + 4B(t+\tau)}}{2}$$

$$= \frac{-0.226 + \sqrt{0.226^2 + 4 \times 0.287(2 + 0.1135)}}{2} = 0.67\mu m$$

Q2. A silicon wafer has a 2000Å oxide on its surface. The wafer is put back in the furnace in wet oxygen at 1000°C. How long will it take to grow an additional 3000Å of oxide?

4.1 Dry oxidation coefficients for silicon

	Dry		Wet (640 torr)	
Temp (°C)	***A* (μm)**	***B* (μm²/hr)**	***A* (μm)**	***B* (μm²/hr)**
800	0.370	0.0011	—	—
920	0.235	0.0049	0.50	0.203
1000	0.165	0.0117	0.226	0.287
1100	0.090	0.027	0.11	0.510
1200	0.040	0.045	0.05	0.720

Solution:

From the table in the table, for wet oxidation at 1000°C, A =0.226 µm and B = 0.287 µm²/hr. Inserting these values to find τ

4.1 Dry oxidation coefficients for silicon

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$$\tau = \frac{t_{oxi}^2}{B} + \frac{t_{oxi}}{B/A} = \frac{t_{oxi}^2 + At_{oxi}}{B} = \frac{(0.2\mu m)^2 + 0.226\mu m \times 0.2\mu m}{0.287\mu m^2/hr} = 0.297hr$$

For t_{ox}=0.5µm, $(0.5)^2 + (0.226)(0.5) = (0.287)(t + 0.297)$

Hence, t = 1.265-0.297 = **0.968 hrs**.

Q3. In an oxidation process the growth rate was monitored during the oxide-growth. When the oxide-thickness was 0.5µm and 1µm, the growth rate was determined to be 0.135µm/hr and 0.081µm/hr, respectively. Determine the linear rate constant (B/A) and the parabolic rate constant (B).

Solution:

Equation describing oxide growth: $t_{ox}^2 + At_{ox} = B(t+\tau)$

where, B and (B/A) are the parabolic and linear rate coefficients. τ refers to the time for an initial oxide of thickness t_{oxi} when the growth begins (t= 0). t_{oxi} can be obtained from equation: $t_{oxi}^2 + At_{oxi} = B\tau$

In this problem, t_{oxi} = 0, τ= 0. Thus, $t_{ox}^2 + At_{ox} = Bt$

$$2t_{ox}\frac{dt_{ox}}{dt} + A\frac{dt_{ox}}{dt} = B \quad \Rightarrow \quad \frac{dt_{ox}}{dt} = \frac{B}{A+2t_{ox}}$$

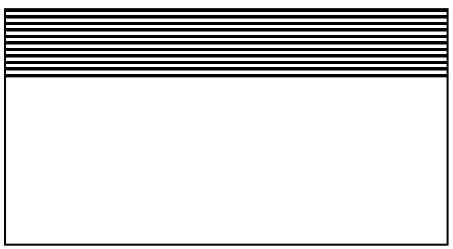
$$\Rightarrow \quad 0.135 = \frac{B}{A+2\times 0.5} \quad \Rightarrow \quad \frac{dt_{ox}}{dt} = \frac{B}{A+2t_{ox}}$$

Solving, A = 0.5 μm, B = 0.2025 μm^2/hr.

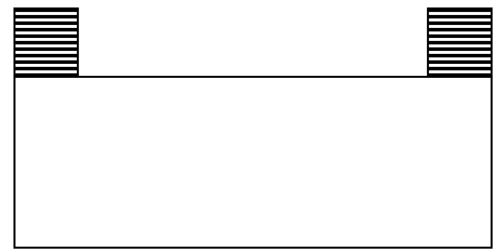
➔ Parabolic Rate Constant = B = 0.2025 μm^2/hr.

➔ Linear Rate Constant = (B/A) = 0.405 μm/hr.

Q4. A p-type (100) Si wafer is placed in a wet oxidation system to grow a field oxide of 5000 A at 1000^{o}C. Determine the time required. After this step, a window is opened in the oxide layer to grow a gate oxide at 1200^{o}C for 12 min. by dry oxidation. Find the thickness of the gate oxide and the total field oxide. Oxide growth rates can be obtained from the charts given in *Lecture Notes.*

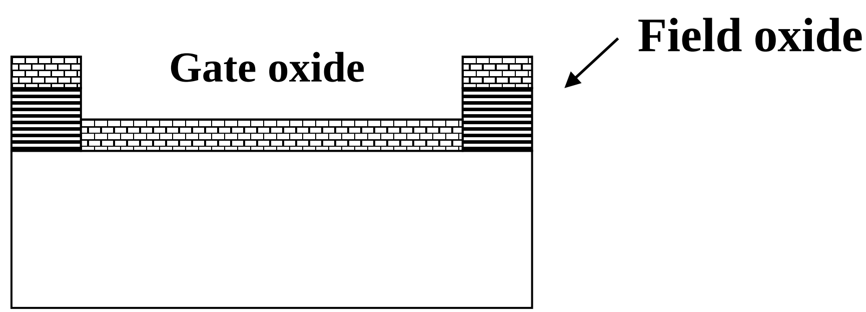


Wet Oxidation at 1000 ^{o}C, for 0.5 micron



Open a window

Dry Oxidation,
1200 ^{o}C, 12 mins
for gate oxide



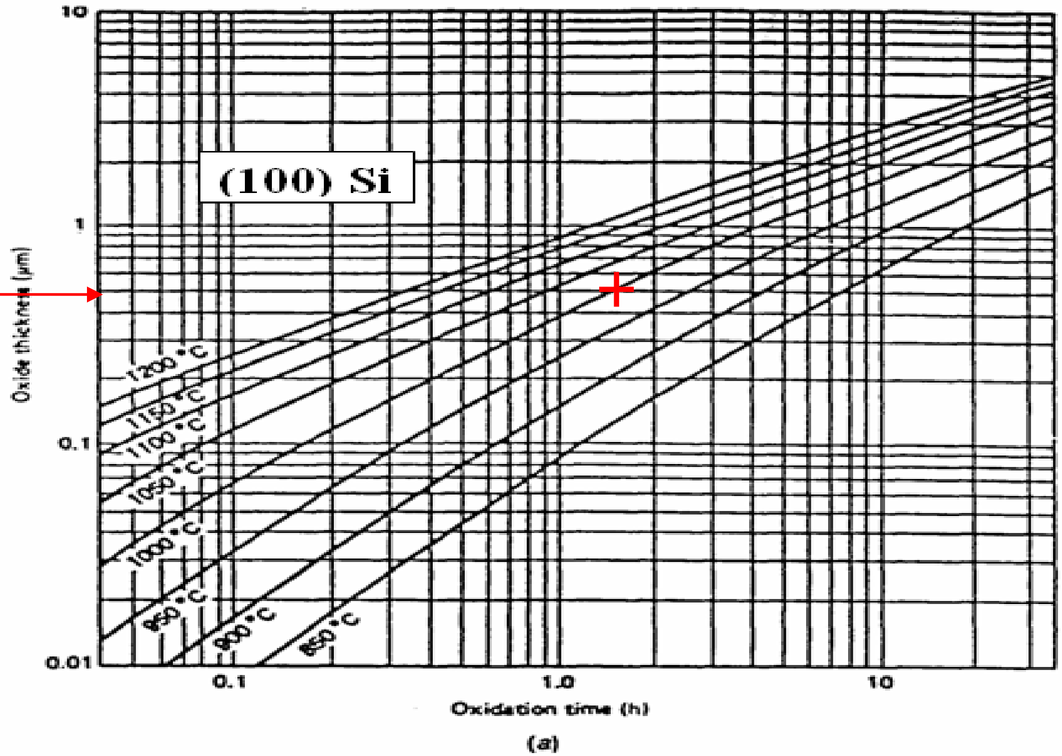
Solution:

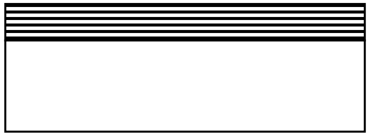
Using chart

1) Time required

For wet oxidation in (100) Si, the time required to grow a 5000 A (**0.5 μm**) oxide at 1000 ^oC = **1.4 hr**.

0.5 μm

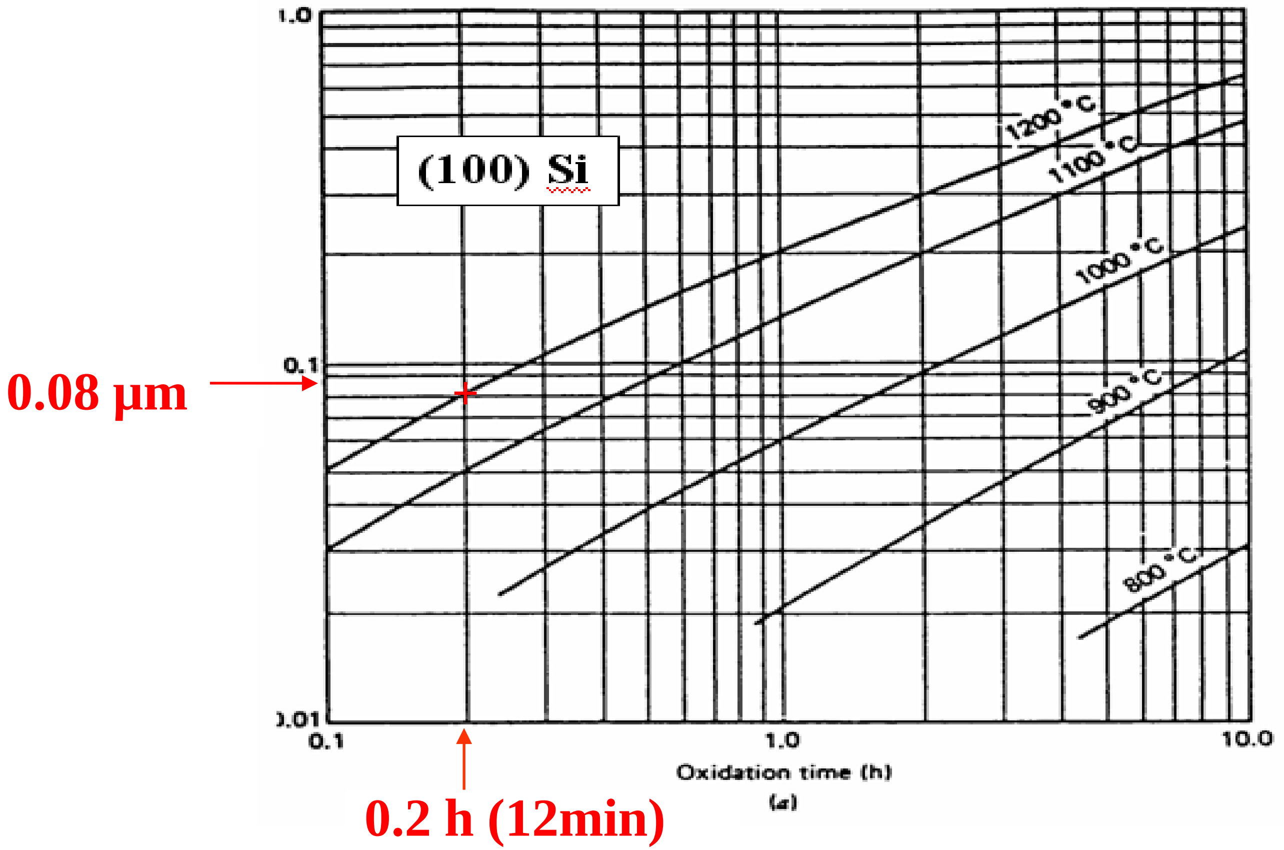




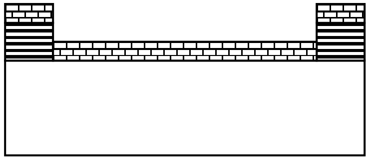
Oxide Growth rate in (100) Silicon for wet Oxygen

2) Gate oxide thickness

For the gate oxide, use the growth chart for dry oxidation: at 1200 ^oC for 0.2 hr (12 min), thickness of gate oxide is 0.08 micron (+).



Oxide Growth rate in (100) Silicon for dry Oxygen



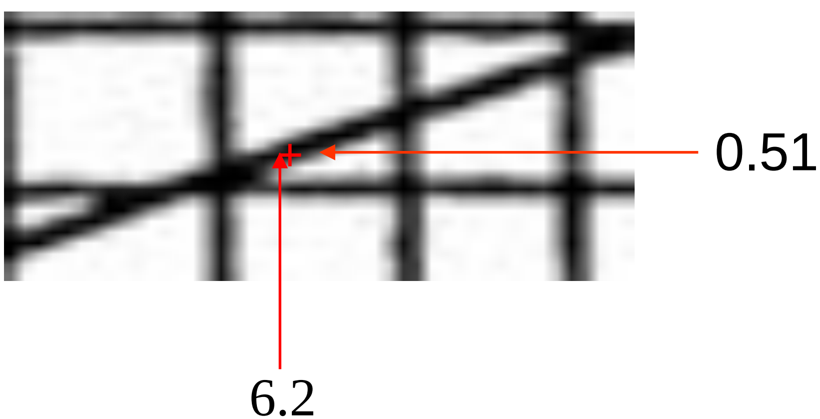
3) Total field oxide thickness

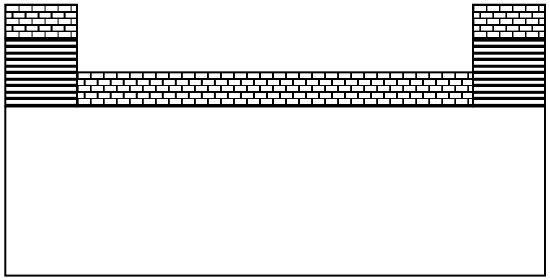
During the gate oxidation, additional field oxide grows on top of an existing 0.5 micron of field oxide.

We first determine how much time it would take to grow a 0.5 micron of oxide by dry oxidation at 1200 ^{o}C. From chart, this is 6 hr (*).

We now have to find the thickness of the oxide that would be obtained for a total oxidation time of (6 + 0.2) hr = 6.2 hr

Using a linear approximation for the incremental part, the thickness obtained is (0.5 + 0.01) micron





Total Field oxide is about 5100 A.

By calculation

1) Time required

Table below (available in lecture notes) can be used to obtain A and B:

4.1 Dry oxidation coefficients for silicon

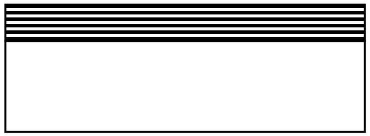
	Dry		Wet (640 torr)	
Temp (°C)	A (μm)	B (μm²/hr)	A (μm)	B (μm²/hr)
800	0.370	0.0011	—	—
920	0.235	0.0049	0.50	0.203
1000	0.165	0.0117	0.226	0.287
1100	0.090	0.027	0.11	0.510
1200	0.040	0.045	0.05	0.720

For wet oxidation at 1000 °C, A = 0.226 μm, B = 0.287 μm²/hr,

$$t_{ox}^2 + At_{ox} = Bt$$

$$t = (t_{ox}^2 + At_{ox}) / B = (0.5^2 + 0.226 \times 0.5) / 0.287$$

$$= 0.363 / 0.287 = 1.3hr$$



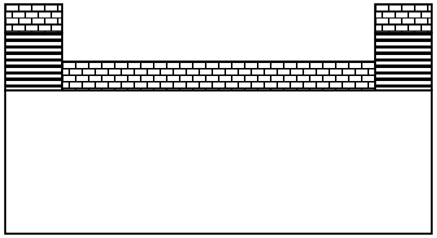
So, for t_{ox} = 0.5 μm, the time required is t = 1.3 hr.

2) Gate oxide thickness

For dry oxidation done at 1200 ^{o}C for 12 minutes (= 0.2 hr), A = 0.04 μm, B = 0.045 μm^2/hr

Solve equation

$$t_{ox}^2 + 0.04 t_{ox} - 0.045 \times 0.2 = 0$$



Gate oxide thickness: t_{ox} = 0.077 μm.

3) Total field oxide thickness

Since there is an initial field oxide thickness (of 0.5 micron) before the dry oxidation, $t_{ox}^2 + At_{ox} = B(t+\tau)$

Note that although the 0.5 μm was grown by wet oxidation at 1000ºC, because the next oxidation is dry oxidation at 1200ºC, we have to find τ in dry oxidation for the 0.5 μm thick oxide in order to calculate the thickness of the next oxide grown by dry oxidation.

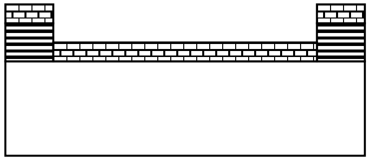
$0.5^2 + A \times 0.5 = B\tau$ where A = 0.04 μm, B = 0.045 μm²/hr.

Solving the equation, we have, τ = 6 hr.

Since the dry oxidation is done for 0.2 hr, the total oxide thickness after the dry oxidation can be obtained

$$t_{ox}^2 + At_{ox} = B(t+\tau)$$

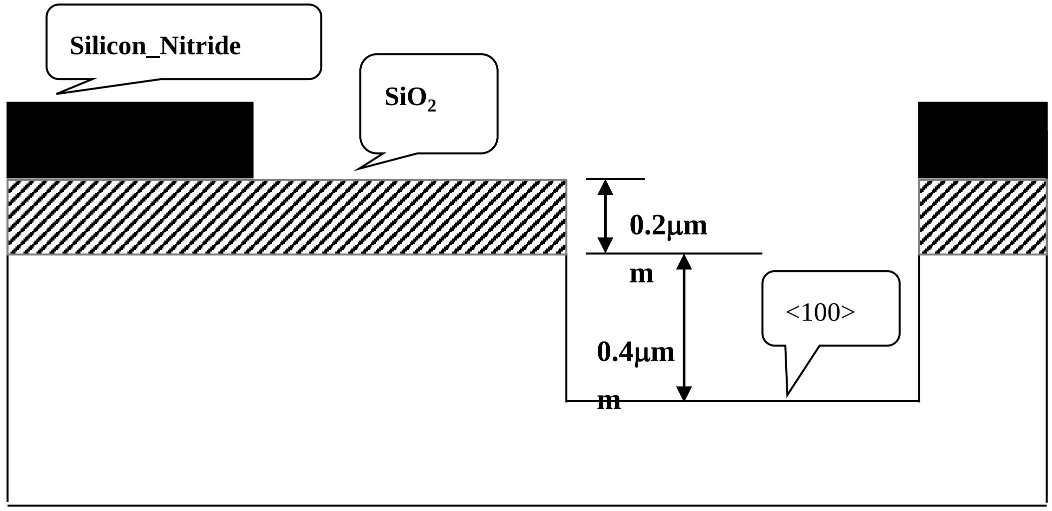
$$t_{ox}^2 + 0.04 \times t_{ox} = 0.045 \times 6.2$$



Hence, t_{ox} = 0.5086 μm

The additional field oxide grown is 0.5086-0.5=0.0086 μm or 86 A (close to the 100 A obtained by chart).

Q5. A silicon wafer with the profile as shown below is placed in a dry oxidation system at 1100^oC. (a) Determine the time required to grow an oxide layer of 0.2 µm thickness on the exposed <100> silicon surface. (b) What is the thickness of the additional oxide grown on the existing SiO_2 layer for the same period of time? Draw the resultant profile after the oxidation.



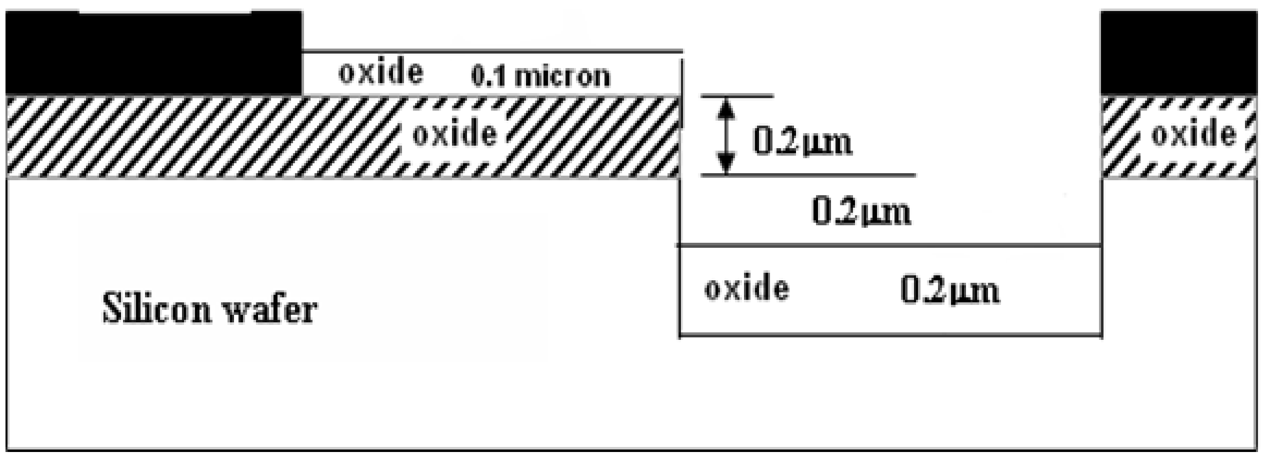
By calculation

(a) Using the values of A and B as given in the Table. For T = 1100ºC, dry oxidation, A = 0.09 μm, B = 0.027 μm^2/hr

For the bare silicon region, time required to grow an oxide layer of thickness 0.2 μm:

$$0.2^2 + 0.09 \times 0.2 = 0.027t$$

Hence, t = 2.15 hr.



(b) To find the corresponding thickness on the initial 0.2 µm oxide, we need to know the total oxide thickness first using

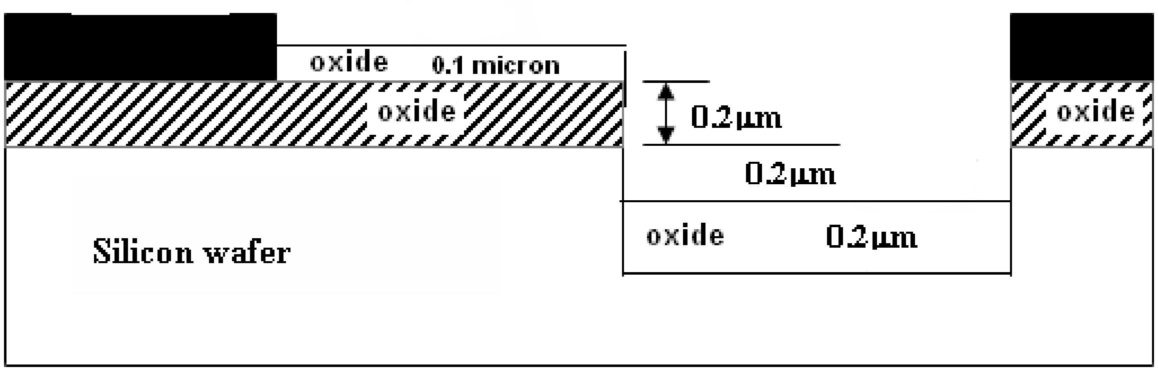
$$t_{ox}^2 + At_{ox} = B(t + \tau)$$

To find τ, we use t = 0 and t_{oxi} = 0.2 µm. This gives τ = 2.15 hr.

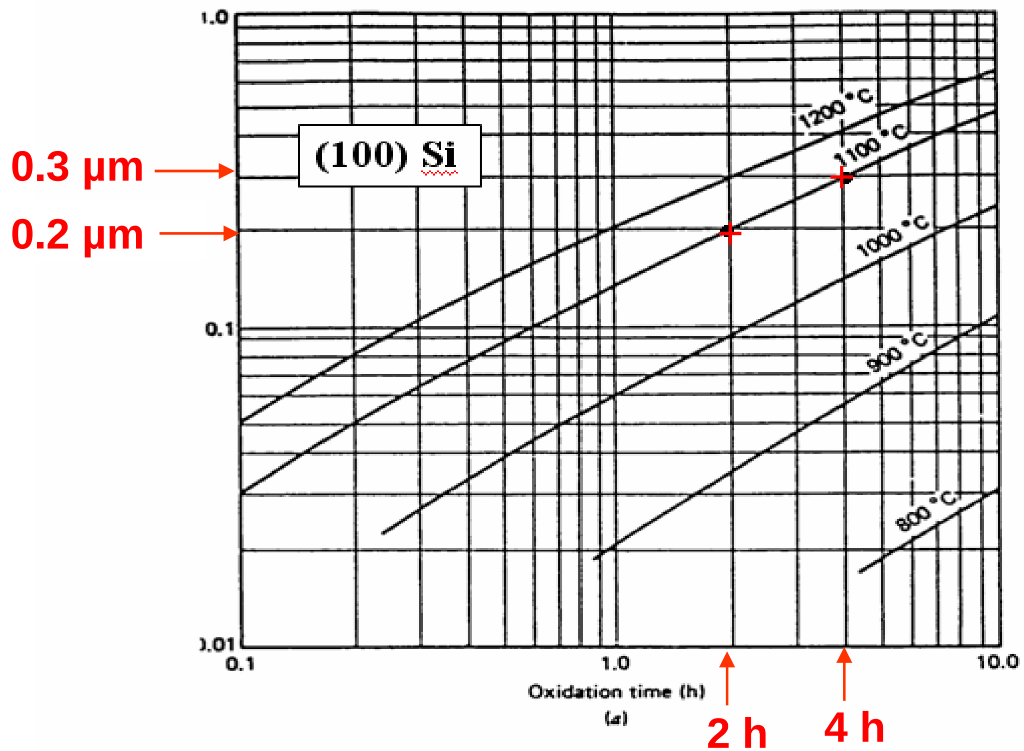
The total thickness of the oxide layer after another 2.15 hr dry oxidation will be:

$$t_{ox}^2 + 0.09t_{ox} = 0.027(2.15 + 2.15)$$ ➔ t_{ox} = 0.3 µm

Hence, the additional thickness of oxide grown on the initial 0.2 µm is = 0.3 – 0.2 = 0.1 µm.



By graph



Oxide Growth rate in (100) Silicon for dry Oxygen

From the chart, grow 0.2 micron oxide on bare (100) silicon at 1100°C will take 2 hours (+).

The total oxide thickness for (2 + 2) = 4 hours of growth, the total thickness = 0.3 µm (*)

Additional oxide thickness grown is 0.3-0.2 = 0.1 µm.