Example 1

Determine the time needed to grow 0.35 μm of oxide on a bare silicon wafer (i.e. no initial oxide) if the oxidation temperature is 1000°C. The wafer has (100) orientation. Find the times for both wet and dry oxidations.

Do the wet case first. The first step is to find the linear and parabolic coefficients at 1000°C = 1273 K.

$$\left(\frac{B}{A}\right)_{wet} = \left(9.7 \times 10^{7} \frac{\mu m}{hr}\right) \exp\left(-\frac{2.05eV}{kT}\right)$$

$$= \left(9.7 \times 10^{7} \frac{\mu m}{hr}\right) \exp\left(-\frac{2.05eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1273K)}\right) = 0.742 \frac{\mu m}{hr}$$

$$B_{wet} = \left(386 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{0.78eV}{kT}\right)$$

$$= \left(386 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{0.78eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1273K)}\right) = 0.315 \frac{\mu m^2}{hr}$$

Now calculate the required oxidation time. Note that since there was no initial oxide, $\tau = 0$.

$$t = \frac{t_{ox}}{{}^{B}/_{A}} + \frac{t_{ox}^2}{B}$$

$$= \frac{0.35\mu m}{0.74\frac{\mu m}{hr}} + \frac{(0.35\mu m)^2}{0.32\frac{\mu m^2}{hr}} = 0.86hr$$

The wet oxidation should last 51 min, 36 sec.

The dry oxidation time is calculated in a similar manner.

$$\left(\frac{B}{A}\right)_{dry} = \left(3.71 \times 10^6 \frac{\mu m}{hr}\right) \exp\left(-\frac{2.00eV}{\left(8.617 \times 10^{-5}\frac{eV}{K}\right)(1273K)}\right) = 0.045\frac{\mu m}{hr}$$

$$B_{dry} = \left(772\frac{\mu m^2}{hr}\right) \exp\left(-\frac{1.23eV}{\left(8.617 \times 10^{-5}\frac{eV}{K}\right)(1273K)}\right) = 0.0104\frac{\mu m^2}{hr}$$

$$t = \frac{0.35\mu m}{0.045\frac{\mu m}{hr}} + \frac{(0.35\mu m)^2}{0.0104\frac{\mu m^2}{hr}} = 19.57hr$$ → significantly longer

Example 2

A (100)-oriented silicon wafer has 250 nm of oxide on it. It is run through a wet oxidation process at a temperature of 1100°C for 60 minutes. What is the oxide thickness at the end of the oxidation?

As in the previous example, we need the linear and parabolic coefficients first. For a wet oxidation at 1100°C (=1373 K):

$$\left(\frac{B}{A}\right)_{wet} = \left(9.7 \times 10^7 \frac{\mu m}{hr}\right) \exp\left(-\frac{2.05eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1373K)}\right) = 2.90 \frac{\mu m}{hr}$$

$$B_{wet} = \left(386 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{0.78eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1373K)}\right) = 0.529 \frac{\mu m^2}{hr}$$

Because there is an initial oxide, we need to include that in the form of the equivalent time.

$$\tau = \frac{t_{oxi}}{{}^{B}/_{A}} + \frac{t_{oxi}^2}{B} = \frac{0.25\mu m}{2.9 \frac{\mu m}{hr}} + \frac{(0.25\mu m)^2}{0.53 \frac{\mu m^2}{hr}} = 0.20hr$$

Then we can use the thickness equation to get the final thickness.

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

$$= \frac{0.53\frac{\mu m^2}{hr}}{2\left(2.90\frac{\mu m}{hr}\right)}\left[\sqrt{1+\frac{4\left(2.90\frac{\mu m}{hr}\right)^2}{0.53\frac{\mu m^2}{hr}}(1hr+0.2hr)}-1\right]$$

$$= 0.71\mu m$$

Example 3

A (100) silicon wafer has 0.375 μm of oxide. Determine the time needed to grow an additional 0.375 μm of oxide using wet oxidation at temperature of 1050°C. (The wafer will have a total of 0.75 μm of oxide when finished.)

Find the linear and parabolic coefficients for wet oxidation at 1050°C (= 1323K).

$$\left(\frac{B}{A}\right)_{wet} = \left(9.7 \times 10^7 \frac{\mu m}{hr}\right) \exp\left(-\frac{2.05eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1323K)}\right) = 1.50 \frac{\mu m}{hr}$$

$$B_{wet} = \left(386 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{0.78eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1323K)}\right) = 0.41 \frac{\mu m^2}{hr}$$

The time corresponding to the initial oxide is

$$\tau = \frac{t_{oxi}}{{}^{B}/_{A}} + \frac{t_{oxi}^2}{B} = \frac{0.375\mu m}{1.50\,\frac{\mu m}{hr}} + \frac{(0.375\mu m)^2}{0.41\,\frac{\mu m^2}{hr}} = 0.59hr$$

Then, the time to grow the extra 0.375 μm is

$$t = \frac{t_{ox}}{{}^{B}/_{A}} + \frac{t_{ox}^2}{B} - \tau$$

$$= \frac{0.75\mu m}{1.50\,\frac{\mu m}{hr}} + \frac{(0.75\mu m)^2}{0.41\,\frac{\mu m^2}{hr}} - 0.59hr = 1.28hr$$

Example 4

An initially bare (100) silicon wafer is oxidized in two steps. The first step uses dry oxidation at 1150°C for 120 min. The second step uses wet oxidation at 1000°C for 30 min. Find the final thickness of the oxide.

Find the linear and parabolic coefficients for dry oxidation at 1150°C (= 1423K).

$$\left(\frac{B}{A}\right)_{dry} = \left(3.71 \times 10^6 \frac{\mu m}{hr}\right) \exp\left(-\frac{2.00eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1423K)}\right) = 0.306 \frac{\mu m}{hr}$$

$$B_{dry} = \left(772 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{1.23eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1423K)}\right) = 0.034 \frac{\mu m^2}{hr}$$

The oxide thickness at the end of the dry step is

$$t_{ox1} = \frac{0.034 \frac{\mu m^2}{hr}}{2\left(0.306 \frac{\mu m}{hr}\right)} \left[\sqrt{1 + \frac{4\left(0.306 \frac{\mu m}{hr}\right)^2}{0.034 \frac{\mu m^2}{hr}}(2hr)} - 1\right] = 0.21 \mu m$$

Now find the coefficients for wet oxidation at 1000°C (=1273K). (Same as in Example 1.)

$$\left(\frac{B}{A}\right)_{wet} = \left(9.7 \times 10^7 \frac{\mu m}{hr}\right) \exp\left(-\frac{2.05eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1273K)}\right) = 0.742 \frac{\mu m}{hr}$$

$$B_{wet} = \left(386 \frac{\mu m^2}{hr}\right) \exp\left(-\frac{0.78eV}{\left(8.617 \times 10^{-5} \frac{eV}{K}\right)(1273K)}\right) = 0.315 \frac{\mu m^2}{hr}$$

Now find the *wet oxidation time* corresponding to the thickness grown in the dry step.

$$\tau = \frac{t_{oxi}}{{}^{B}/_{A}} + \frac{t_{oxi}^2}{B} = \frac{0.21\mu m}{0.742 \frac{\mu m}{hr}} + \frac{(0.21\mu m)^2}{0.315 \frac{\mu m^2}{hr}} = 0.42hr$$

To finish up, find the final thickness after the wet oxidation step.

$$t_{ox2} = \frac{0.315 \frac{\mu m^2}{hr}}{2\left(0.742 \frac{\mu m}{hr}\right)} \left[\sqrt{1 + \frac{4\left(0.742 \frac{\mu m}{hr}\right)^2}{0.315 \frac{\mu m^2}{hr}}(0.5hr + 0.42hr)} - 1\right] = 0.367\mu m$$