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Activity 1

A coworker has been working on doping silicon crystals with boron atoms to control the conductivity of silicon. They have used doping levels ranging from 10^{16} cm^{-3} to 10^{19} cm^{-3}. Your coworker's manager suggests increasing the boron concentration to 10^{21} cm^{-3}, but your coworker has been concerned about the possibility of boron aggregation during the rapid thermal anneal (~1 second at 1000 ºC) used for dopant activation.

Boron aggregation means that implanted boron atoms could diffuse into each other and form clusters. To help your coworker, you decide to calculate the diffusion lengths for boron in silicon and compare the diffusion lengths to the average distance between boron atoms, which is given by

$$d_{ave} = (n)^{-1/3} ,$$

where n is the dopant concentration.

You know that the diffusion coefficient of boron atoms in single crystal Si has been measured to be 1.5×10^{-18} m^2 s^{-1} at 1000 ºC and 1.1×10^{-16} m^2 s^{-1} at 1200 ºC. → Don't need this unless we need D at other temps or L at 1200C.

Also, given that the solubility limit of boron is 0.2 at.%, you calculate an upper limit for the boron concentration in silicon and compare that to the boron diffusion length during annealing. Note, the density of silicon is 2.33 g cm^{-3}.

Should your coworker increase the boron concentration?

Start with the rms diffusion length $L = \sqrt{2Dt}$. We have D at 1000°C (= 1273.15 K) and t is given as 1 second.

$$L = \sqrt{2(1.5\times10^{-18}\,m^2/s)(1\,s)} = 1.7\times10^{-9}\,m = 1.7\,nm$$

Is 1.7 nm too far? Depends on the concentration of B.

At $10^{16}\ \frac{Boron}{cm^3} \Rightarrow$ average B separation of $d_{ave} = (10^{22}\,m^{-3})^{-1/3} \approx 46\,nm$

If B moves 1.7 nm and average separation is 46 nm, they aren't likely to meet in 1 second of annealing.

At $10^{21}\ B/cm^3 \Rightarrow d_{ave} = (10^{27}\,m^{-3})^{-1/3} = 1\,nm$ ← Too close!

Solubility limit for B is 0.2 at.%

$$n_{Si} = \frac{N_A\,\rho_{Si}}{M_{Si}} = \frac{(6.022\times10^{23}/mol)(2.33\,g/cm^3)}{28.085\,g/mol} = 5\times10^{22}\ \frac{Si}{cm^3}$$

} $10^{20}\ \frac{B}{cm^3}$ = max conc. of B

↳ $d_{ave} \approx 2.2\,nm$