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CHAPTER 2

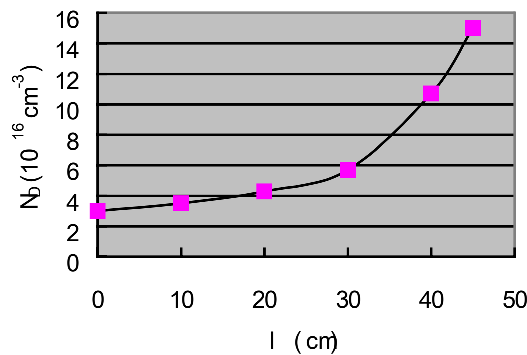
1. $C_0 = 10^{17}$ cm^{-3}

k_0(As in Si) = 0.3

$C_S = k_0 C_0 (1 - M/M_0)^{k0-1}$

$= 0.3\times10^{17}(1- x)^{-0.7} = 3\times10^{16}/(1 - l/50)^{0.7}$

x	0	0.2	0.4	0.6	0.8	0.9
l (cm)	0	10	20	30	40	45
C_S (cm-3)	3×10^{16}	3.5×10^{16}	4.28×10^{16}	5.68×10^{16}	1.07×10^{17}	1.5×10^{17}



2. (a) The radius of a silicon atom can be expressed as

$$r = \frac{\sqrt{3}}{8}a$$

so $r = \frac{\sqrt{3}}{8}\times 5.43 = 1.175\text{Å}$

(b) The numbers of Si atom in its diamond structure are 8.

So the density of silicon atoms is

$$n = \frac{8}{a^3} = \frac{8}{(5.43\text{Å})^3} = 5.0\times10^{22} \text{ atoms/cm}^3$$

(c) The density of Si is

$$\rho = \frac{M / 6.02\times10^{23}}{1/n} = \frac{28.09\times5\times10^{22}}{6.02\times10^{23}} \text{g / cm}^3 = 2.33 \text{ g / cm}^3.$$

3. $k_0 = 0.8$ for boron in silicon

$M / M_0 = 0.5$

The density of Si is 2.33 g / cm^3.

The acceptor concentration for $\rho = 0.01$ Ω–cm is 9×10^{18} cm^{-3}.

The doping concentration C_S is given by

$$C_s = k_0 C_0 (1 - \frac{M}{M_0})^{k_0 - 1}$$

Therefore

$$C_0 = \frac{C_s}{k_0 (1 - \frac{M}{M_0})^{k_0 - 1}} = \frac{9\times10^{18}}{0.8(1-0.5)^{-0.2}}$$

$$= 9.8\times10^{18}\,\text{cm}^{-3}$$

The amount of boron required for a 10 kg charge is

$$\frac{10{,}000}{2.338}\times 9.8\times10^{18} = 4.2\times10^{22} \text{ boron atoms}$$

So that

$$10.8\text{g/mole}\times\frac{4.2\times10^{22}\,\text{atoms}}{6.02\times10^{23}\,\text{atoms/mole}} = 0.75\text{g boron} .$$

4. (a) The molecular weight of boron is 10.81.

The boron concentration can be given as

$$\begin{aligned} n_b &= \frac{\text{number of boron atoms}}{\text{volume of silicon wafer}} \\ &= \frac{5.41\times10^{-3}\,\text{g}/10.81\text{g}\times 6.02\times10^{23}}{10.0^2\times3.14\times0.1} \\ &= 9.78\times10^{18}\,\text{atoms/cm}^3 \end{aligned}$$

(b) The average occupied volume of everyone boron atoms in the wafer is

$$V = \frac{1}{n_b} = \frac{1}{9.78 \times 10^{18}} \text{cm}^3$$

We assume the volume is a sphere, so the radius of the sphere (r) is the average distance between two boron atoms. Then

$$r = \sqrt{\frac{3V}{4\pi}} = 2.9 \times 10^{-7} \text{cm} .$$

5. The cross-sectional area of the seed is

$$\pi \left(\frac{0.55}{2} \right)^2 = 0.24 \text{cm}^2$$

The maximum weight that can be supported by the seed equals the product of the critical yield strength and the seed's cross-sectional area:

$$(2 \times 10^6) \times 0.24 = 4.8 \times 10^5 \text{g} = 480 \text{kg}$$

The corresponding weight of a 200-mm-diameter ingot with length l is

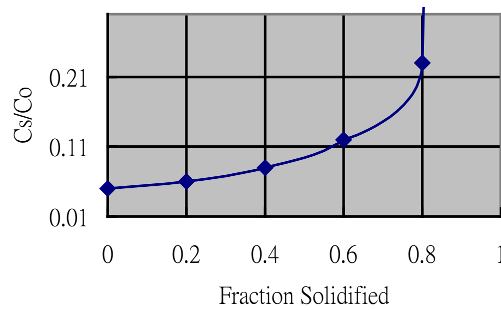
$$(2.33 \text{g/cm}^3) \pi \left(\frac{20.0}{2} \right)^2 l = 480000 \text{g}$$

$$\therefore \quad l = 656 \text{cm} = 6.56 \text{m}.$$

6. We have

$$C_s / C_0 = k_0 \left(1 - \frac{M}{M_0} \right)^{k_0 - 1}$$

Fractional solidified	0	0.2	0.4	0.6	0.8	1.0
C_S / C_0	0.05	0.06	0.08	0.12	0.23	∞



7. The segregation coefficient of boron in silicon is 0.72. It is smaller than unity, so the solubility of B in Si under solid phase is smaller than that of the melt. Therefore, the excess B atoms will be thrown-off into the melt, then the concentration of B in the melt will be increased. The tail-end of the crystal is the last to solidify. Therefore, the concentration of B in the tail-end of grown crystal will be higher than that of seed-end.

8. The reason is that the solubility in the melt is proportional to the temperature, and the temperature is higher in the center part than at the perimeter. Therefore, the solubility is higher in the center part, causing a higher impurity concentration there.

9. The segregation coefficient of Ga in Si is 8×10^{-3}

From Eq. 18

$$C_s / C_0 = 1 - (1-k)e^{-kx/L}$$

We have

$$\begin{aligned} x &= \frac{L}{k} \ln\left(\frac{1-k}{1-C_s/C_0}\right) \\ &= \frac{2}{8\times 10^{-3}} \ln\left(\frac{1-8\times 10^{-3}}{1-5\times 10^{15}/5\times 10^{16}}\right) \\ &= 250 \ln(1.102) \\ &= 24 \text{ cm.} \end{aligned}$$

10. We have from Eq.18

$$C_s = C_0[1-(1-k_e)\exp(-k_e x/L)]$$

So the ratio $C_s / C_0 = [1-(1-k_e)\exp(-k_e x/L)]$

$$= 1-(1-0.3)\bullet\exp(-0.3\times 1) = 0.52 \qquad \text{at } x/L = 1$$
$$= 0.38 \qquad \text{at } x/L = 2.$$

11. For the conventionally-doped silicon, the resistivity varies from 120 Ω-cm to 155 Ω-cm. The corresponding doping concentration varies from 2.5×10^{13} to 4×10^{13} cm^{-3}. Therefore the range of breakdown voltages of p^+ - n junctions is given by

$$V_B \cong \frac{\varepsilon_s \mathcal{E}_c^2}{2q}(N_B)^{-1}$$

$$= \frac{1.05\times10^{-12}\times(3\times10^5)^2}{2\times1.6\times10^{-19}}(N_B)^{-1} = 2.9\times10^{17}/N_B = 7250 \text{ to } 11600 \text{ V}$$

$$\Delta V_B = 11600 - 7250 = 4350 \text{ V}$$

$$\therefore \left(\frac{\Delta V_B}{2}\right)/7250 = \pm 30\%$$

For the neutron irradiated silicon, ρ = 148 ± 1.5 Ω-cm. The doping concentration is 3×10^{13} (±1%).

The range of breakdown voltage is

$$V_B = 1.3\times10^{17}/N_B = 2.9\times10^{17}/3\times10^{13}(\pm1\%)$$
$$= 9570 \text{ to } 9762 \text{ V}.$$

$$\Delta V_B = 9762 - 9570 = 192 \text{ V}$$

$$\therefore \left(\frac{\Delta V_B}{2}\right)/9570 = \pm 1\%.$$

12. We have

$$\frac{M_s}{M_l} = \frac{\text{weight of GaAs at T}_b}{\text{weight of liquid at T}_b} = \frac{C_m - C_l}{C_s - C_m} = \frac{s}{l}$$

Therefore, the fraction of liquid remained f can be obtained as following

$$f = \frac{M_l}{M_s + M_l} = \frac{l}{s+l} \approx \frac{30}{16+30} = 0.65 .$$

13. From the Fig.2.11, we find the vapor pressure of As is much higher than that of the Ga. Therefore, the As content will be lost when the temperature is increased. Thus the composition of liquid GaAs always becomes gallium rich.

14. $n_s = N\exp(-E_s / kT) = 5\times10^{22}\exp(2.3\,\text{eV}/kT) = 5\times10^{22}\exp\left[\frac{-88.8}{(T/300)}\right]$

$$= 1.23\times10^{-16}\,\text{cm}^{-3} \approx 0 \quad \text{at } 27^0\text{C} = 300\,\text{K}$$

$$= 6.7\times10^{12}\,\text{cm}^{-3} \quad \text{at } 900^0\text{C} = 1173\,\text{K}$$

$$= 6.7\times10^{14}\,\text{cm}^{-3} \quad \text{at } 1200^0\text{C} = 1473\,\text{K} .$$

15. $n_f = \sqrt{NN^`}\exp(-E_f / 2kT)$

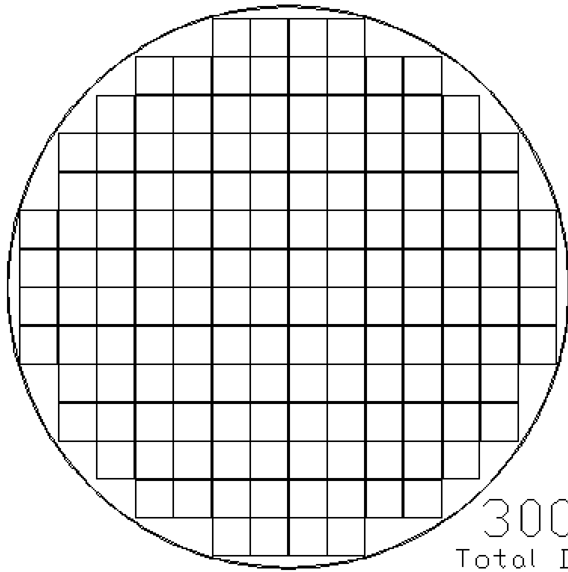
$$= \sqrt{5\times10^{22}\times1\times10^{27}e^{-3.8eV/kT}} \times e^{-1.1eV/2kT} = 7.07\times10^{24}\times e^{-94.7/(T/300)}$$

$=5.27\times10^{-17}$ at 27°C = 300 K

$=2.14\times10^{14}$ at 900°C = 1173 K.

16. 37 × 4 = 148 chips

In terms of litho-stepper considerations, there are 500 μm space tolerance between the mask boundary of two dice. We divide the wafer into four symmetrical parts for convenient dicing, and discard the perimeter parts of the wafer. Usually the quality of the perimeter parts is the worst due to the edge effects.


300 mm
Total Dies: 148