

- 3.2. A boron-doped crystal pulled by the Czochralski technique is required to have a resistivity of  $10 \Omega \text{ cm}$  when half the crystal is grown. Assuming that a 100 gm pure silicon charge is used, how much  $0.01 \Omega \text{ cm}$  boron doped silicon must be added to the melt? For this crystal, plot resistivity as a function of the fraction of the melt solidified. Assume  $k_0 = 0.8$  and the hole mobility  $\mu_p = 550 \text{ cm}^2 \text{ volt}^{-1} \text{ sec}^{-1}$ .

Answer:

Using the mobility value given, and  $\rho = \frac{1}{q\mu N_A}$  we have:

$$10 \Omega \text{ cm} \Rightarrow N_A = 1.14 \times 10^{15} \text{ cm}^{-3} \text{ and } 0.01 \Omega \text{ cm} \Rightarrow N_A = 1.14 \times 10^{18} \text{ cm}^{-3}$$

From Eqn. 3.38,  $C_S = C_0 k_0 (1-f)^{k_0-1}$  and we want  $C_S = 1.14 \times 10^{15} \text{ cm}^{-3}$  when  $f = 0.5$ . Thus, solving for  $C_0$  the initial doping concentration in the melt, we have:

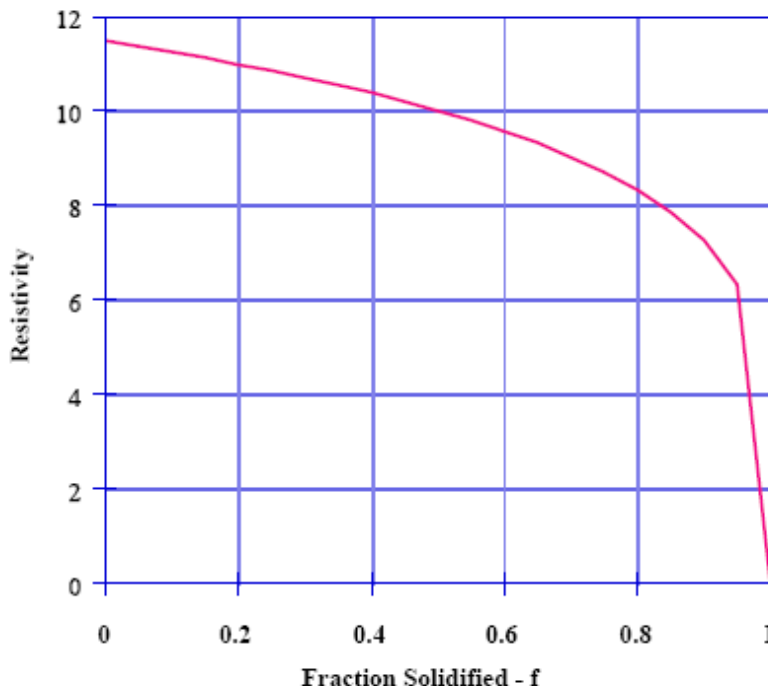
$$C_0 = \frac{1.14 \times 10^{15}}{0.8} (1-0.5)^{0.2} = 1.24 \times 10^{15} \text{ cm}^{-3}$$

$$\text{But } C_0 = \frac{I_0}{V_0} = \frac{\# \text{ of impurities}}{\text{unit vol of melt}} = \frac{(\text{Doping})(\text{Vol. of } 0.01 \Omega \text{ cm})}{\text{Vol } 100 \text{ gm Si}}$$

$$\therefore \text{Wgt added of } 0.01 \Omega \text{ cm Si} = \left( \frac{C_0}{\text{Doping}} \right) (100 \text{ gm}) = 0.109 \text{ gm}$$

The resistivity as a function of distance is plotted below and is given by

$$\rho(x) = \frac{1}{q\mu N_A(x)} = \frac{(1-f)^{1-k_0}}{q\mu C_0 k_0} = 11.5 \Omega \text{ cm} (1-f)^{0.2}$$



**3.3. A Czochralski crystal is pulled from a melt containing  $10^{15} \text{ cm}^{-3}$  boron and  $2 \times 10^{14} \text{ cm}^{-3}$  phosphorus. Initially the crystal will be P type but as it is pulled, more and more phosphorus will build up in the liquid because of segregation. At some point the crystal will become N type. Assuming  $k_0 = 0.32$  for phosphorus and 0.8 for boron, calculate the distance along the pulled crystal at which the transition from P to N type takes place.**

**Answer:**

We can calculate the point at which the crystal becomes N type from Eqn. 3.38 as follows:

$$C_S(\text{Phos}) = C_0 k_0 (1-f)^{k_0-1} = (2 \times 10^{14}) (0.32) (1-f)^{-0.68}$$

$$C_S(\text{Boron}) = C_0 k_0 (1-f)^{k_0-1} = (10^{15}) (0.8) (1-f)^{-0.2}$$

At the point where the cross-over occurs to N type, these two concentrations will be equal. Solving for  $f$ , we find

$$f \cong 0.995$$

Thus only the last 0.5% of the crystal is N type.

**4.1. An IC manufacturing plant produces 1000 wafers per week. Assume that each wafer contains 100 die, each of which can be sold for \$50 if it works. The yield on these chips is currently running at 50%. If the yield can be increased, the incremental income is almost pure profit because all 100 chips on each wafer are manufactured whether they work or not. How much would the yield have to be increased to produce an annual profit increase of \$10,000,000?**

**Answer:**

At 1000 wafers per week, the plant produces 52,000 wafers per year. If each wafer has 50 good die each of which sells for \$50, the plant gross income is simply

$$\text{Income} = (52,000)(50)(\$50) = \$130,000,000 \text{ per year.}$$

To increase this income by \$10,000,000 requires that the yield increase by

$$\frac{10}{130} \cong 7.7\%$$