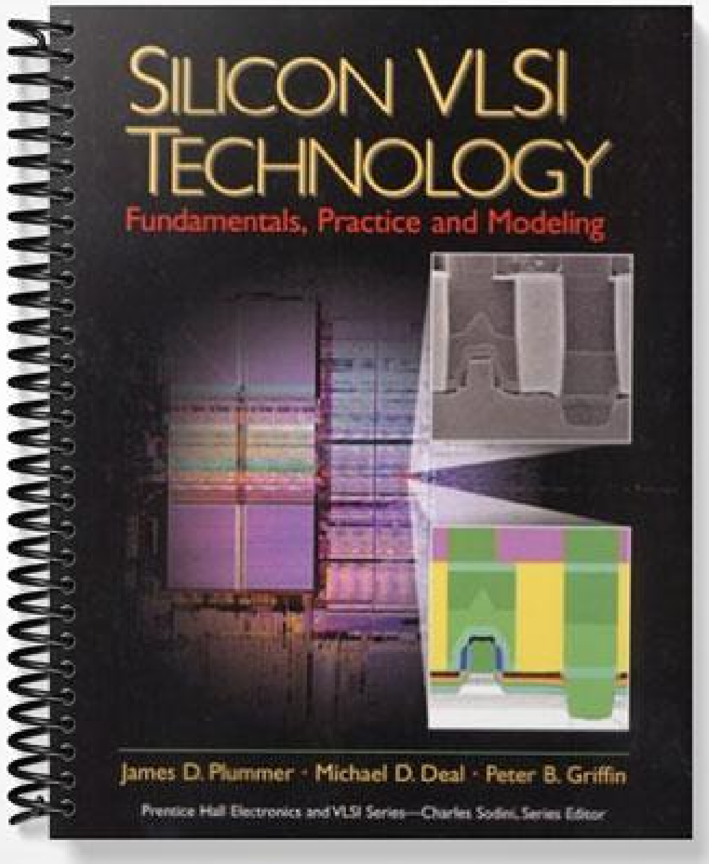
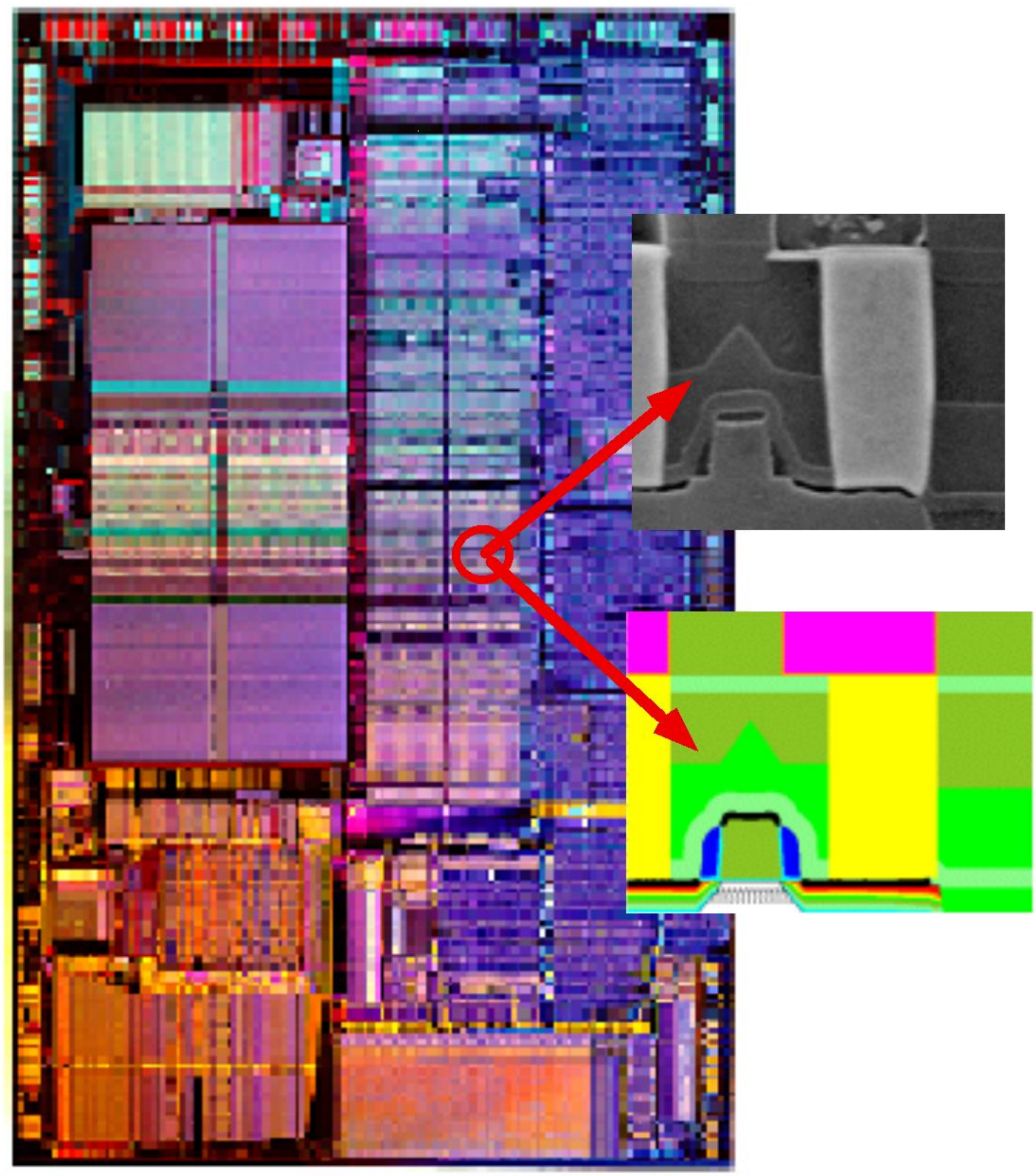
SOLUTIONS MANUAL



SILICON VLSI TECHNOLOGY
Fundamentals, Practice and Models

Solutions Manual for Instructors



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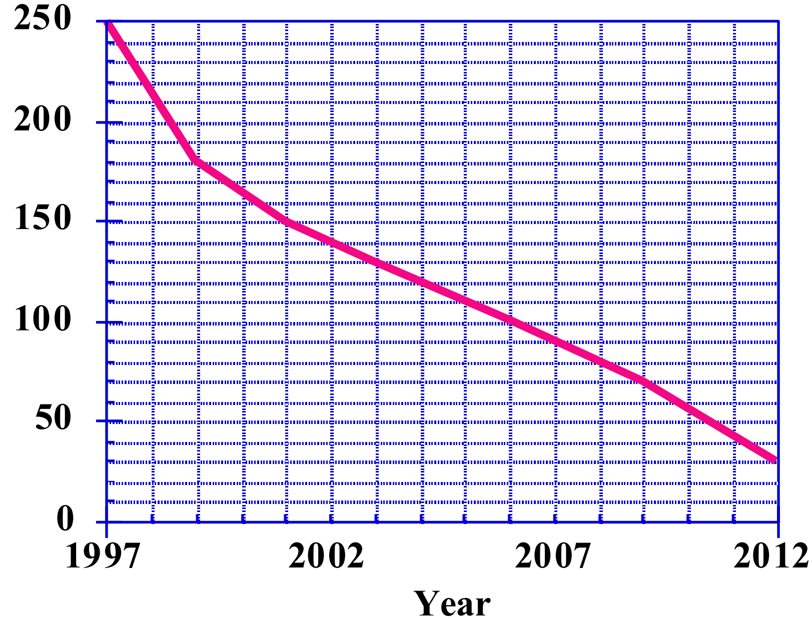
Chapter 1 Problems

1.1. Plot the NRTS roadmap data from Table 1.1 (feature size vs. time) on an expanded scale version of Fig. 1.2. Do all the points lie exactly on a straight line? If not what reasons can you suggest for any deviations you observe?

Answer:



Interestingly, the actual data seems to consist of two slopes, with a steeper slope for the first 2 years of the roadmap. Apparently the writers of the roadmap are more confident of the industry's ability to make progress in the short term as opposed to the long term.

1.2. Assuming dopant atoms are uniformly distributed in a silicon crystal, how far apart are these atoms when the doping concentration is a). 10^{15} cm^{-3}, b). 10^{18} cm^{-3}, c). $5\text{x}10^{20}$ cm^{-3}.

Answer:

The average distance between the dopant atoms would just be one over the cube root of the dopant concentration:

$$x = N_A^{-1/3}$$

a) $x = \left(1\text{x}10^{15}\,\text{cm}^{-3}\right)^{-1/3} = 1\text{x}10^{-5}\,\text{cm} = 0.1\mu\text{m} = 100\text{nm}$

b) $x = \left(1\text{x}10^{18}\,\text{cm}^{-3}\right)^{-1/3} = 1\text{x}10^{-6}\,\text{cm} = 0.01\mu\text{m} = 10\text{nm}$

c) $x = \left(5\text{x}10^{20}\,\text{cm}^{-3}\right)^{-1/3} = 1.3\text{x}10^{-7}\,\text{cm} = 0.0013\mu\text{m} = 1.3\text{nm}$

1.3. Consider a piece of pure silicon 100 μm long with a cross-sectional area of 1 μm². How much current would flow through this "resistor" at room temperature in response to an applied voltage of 1 volt?

Answer:

If the silicon is pure, then the carrier concentration will be simply n_i. At room temperature, $n_i \approx 1.45 \times 10^{10}\ cm^{-3}$. Under an applied field, the current will be due to drift and hence,

$$I = I_n + I_p = qAn_i\left(\mu_n + \mu_p\right)\varepsilon$$

$$= \left(1.6x10^{-19}\,\text{coul}\right)\left(10^{-8}\,\text{cm}^2\right)\left(1.45x10^{10}\,\text{carrierscm}^{-3}\right)\left(2000\,\text{cm}^2\,\text{volt}^{-1}\,\text{sec}^{-1}\right)\left(\frac{1\text{volt}}{10^{-2}\,\text{cm}}\right)$$

$$= 4.64x10^{-12}\,\text{amps or } 4.64\,\text{pA}$$

1.4. Estimate the resistivity of pure silicon in Ω ohm cm at a) room temperature, b) 77K, and c) 1000 ˚C. You may neglect the temperature dependence of the carrier mobility in making this estimate.

Answer:

The resistivity of pure silicon is given by Eqn. 1.1 as

$$\rho = \frac{1}{q\left(\mu_n n + \mu_p p\right)} = \frac{1}{qn_i\left(\mu_n + \mu_p\right)}$$

Thus the temperature dependence arises because of the change in n_i with T. Using Eqn. 1.4 in the text, we can calculate values for n_i at each of the temperatires of interest. Thus

$$n_i = 3.1x10^{16}T^{3/2}\exp\left(-\frac{0.603\text{eV}}{kT}\right)$$

which gives values of $\approx 1.45 \times 10^{10}\ cm^{-3}$ at room T, $7.34 \times 10^{-21}\ cm^{-3}$ at 77K and $5.8 \times 10^{18}\ cm^{-3}$ at 1000 ˚C. Taking room temperature values for the mobilities , $\mu_n = 1500\ cm^2\ volt^{-1}\ sec^{-1}$ and , $\mu_p = 500\ cm^2\ volt^{-1}\ sec^{-1}$, we have,

$$\begin{aligned}\rho &= 2.15x10^{5}\,\Omega\text{cm at room T}\\ &= 4.26x10^{35}\,\Omega\text{cm at 77K}\\ &= 5.39x10^{-4}\,\Omega\text{cm at 1000 ÞC}\end{aligned}$$

Note that the actual resistivity at 77K would be much lower than this value because trace amounts of donors or acceptors in the silicon would produce carrier concentrations much higher than the n_i value calculated above.

1.5. a). Show that the minimum conductivity of a semiconductor sample occurs when $n = n_i\sqrt{\dfrac{\mu_p}{\mu_n}}$.

b). What is the expression for the minimum conductivity?

c). Is this value greatly different than the value calculated in problem 1.2 for the intrinsic conductivity?

Answer:

a).

$$\sigma = \frac{1}{\rho} = q\left(\mu_n n + \mu_p p\right)$$

To find the minimum we set the derivative equal to zero.

$$\therefore \frac{\partial\sigma}{\partial n} = \frac{\partial}{\partial n}\left\{q\left(\mu_n n + \mu_p p\right)\right\} = \frac{\partial}{\partial n}\left\{q\left(\mu_n n + \mu_p \frac{n_i^2}{n}\right)\right\} = q\left(\mu_n + \mu_p \frac{n_i^2}{n^2}\right) = 0$$

$$\therefore n^2 = n_i^2 \frac{\mu_p}{\mu_n} \quad \text{or} \quad n = n_i\sqrt{\frac{\mu_p}{\mu_n}}$$

b). Using the value for n derived above, we have:

$$\sigma_{min} = q\left(\mu_n n_i\sqrt{\frac{\mu_p}{\mu_n}} + \mu_p \frac{n_i^2}{n_i\sqrt{\frac{\mu_p}{\mu_n}}}\right) = q\left(\mu_n n_i\sqrt{\frac{\mu_p}{\mu_n}} + \mu_p n_i\sqrt{\frac{\mu_n}{\mu_p}}\right) = 2qn_i\sqrt{\mu_n\mu_p}$$

c). The intrinsic conductivity is given by

$$\sigma_i = qn_i\left(\mu_n + \mu_p\right)$$

Taking values of $n_i = 1.45 \times 10^{10}$ cm^{-3}, $\mu_n = 1500$ cm^2 volt^{-1} sec^{-1} and , $\mu_p = 500$ cm^2 volt^{-1} sec^{-1}, we have:

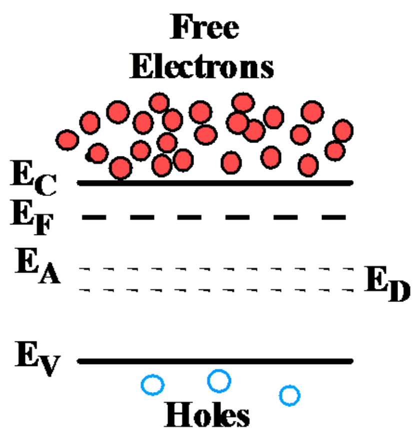
$$\sigma_i = 4.64\text{x}10^{-6}\,\Omega\text{cm} \quad \text{and} \quad \sigma_{min} = 4.02\text{x}10^{-6}\,\Omega\text{cm}$$

Thus there are not large differences between the two.

1.6. When a Au atom sits on a lattice site in a silicon crystal, it can act as either a donor or an acceptor. E_D and E_A levels both exist for the Au and both are close to the middle of the silicon bandgap. If a small concentration of Au is placed in an N type silicon crystal, will the Au behave as a donor or an acceptor? Explain.

Answer:

In N type material, the Fermi level will be in the upper half of the bandgap as shown in the band diagram below. Allowed energy levels below E_F will in general be occupied by electrons. Thus the E_D and E_A levels will have electrons filling them. This means the donor level will not have donated its electron whereas the acceptor level will have accepted an electron. Thus the Au atoms will act as acceptors in N type material.



1.7. Show that E_F is approximately in the middle of the bandgap for intrinsic silicon.

Answer:

Starting with Eqn. 1.9 and 1.10 in the text, we have

$$n \cong N_C \exp\left(-\frac{E_C - E_F}{kT}\right) \quad \text{and} \quad p \cong N_V \exp\left(-\frac{E_F - E_V}{kT}\right)$$

In intrinsic material, $n = p = n_I$, so we have