5.1 (a) Calculate $V_{bi}$ in a silicon pn junction at $T = 300$ K for (i) $N_d = 10^{15}$ cm$^{-3}$ and $N_a = (i) 10^{15}$, (ii) $10^{16}$, (iii) $10^{17}$, (iv) $10^{18}$ cm$^{-3}$. (b) Repeat part (a) for $N_d = 10^{18}$ cm$^{-3}$.

5.3 (a) Plot the built-in potential barrier for a symmetrical ($N_a = N_d$) silicon pn junction at $T = 300$ K over the range $10^{14} \leq N_a = N_d \leq 10^{19}$ cm$^{-3}$. (b) Repeat part (a) for a GaAs pn junction.

5.14 We are assuming an abrupt depletion approximation for the space charge region. That is, no free carriers exist within the depletion region and the semiconductor abruptly changes to a neutral region outside the space charge region. This approximation is adequate for most applications, but the abrupt transition does not exist. The Debye length in the n region is given by

$$L_D = \left( \frac{\varepsilon kT}{e^2 N_d} \right)^{1/2}$$

Calculate $L_D$ and find the ratio of $L_D / x_n$ for the following conditions. The p-type doping concentration is $N_a = 8 \times 10^{17}$ cm$^{-3}$ and the n-type doping concentrations is (a) $N_d = 8 \times 10^{14}$ cm$^{-3}$, (b) $N_d = 2.2 \times 10^{16}$ cm$^{-3}$, and (c) $N_d = 8 \times 10^{17}$ cm$^{-3}$.

5.15 Examine how the electric field versus distance through a uniformly doped pn junction varies as the doping concentrations vary. For example, consider $N_d = 10^{18}$ cm$^{-3}$ and let $10^{14} \leq N_a \leq 10^{18}$ cm$^{-3}$, then consider $N_d = 10^{14}$ cm$^{-3}$ and let $10^{14} \leq N_a \leq 10^{18}$, and finally consider $N_d = 10^{16}$ cm$^{-3}$ and let $10^{14} \leq N_a \leq 10^{18}$ cm$^{-3}$. What can be said about the results for $N_a \geq 100 N_d$ or $N_d \geq 100 N_a$? Assume zero applied bias.

5.21 (a) The peak electric field in reverse-biased silicon pn junction is $|\varepsilon_{max}| = 3 \times 10^5$ V/cm. The doping concentrations are $N_d = 4 \times 10^{15}$ cm$^{-3}$ and $N_a = 4 \times 10^{17}$ cm$^{-3}$. Find the magnitude of the reverse-bias voltage. (b) Repeat part (a) for $N_d = 4 \times 10^{16}$ cm$^{-3}$ and $N_a = 4 \times 10^{17}$ cm$^{-3}$. (c) Repeat part (a) for $N_d = N_a = 4 \times 10^{17}$ cm$^{-3}$.

5.28 Consider a silicon pn junction with the doping profile shown in Figure P5.28. $T = 300$ K. (a) Calculate the applied reverse-bias voltage required so that the space charge region extends entirely through the p region. (b) Determine the space charge width into the n$^+$ region with the reverse-bias voltage calculated in part (a). (c) Calculate the peak electric field for this applied voltage.
A silicon PIN junction has the doping profile shown in Figure P5.33. The “I” corresponds to an ideal intrinsic region in which there is no impurity doping concentration. A reverse-bias voltage is applied to the PIN junction so that the total depletion width extends from $-2 \mu m$ to $+2 \mu m$. 

(a) Using Poisson’s equation, calculate the magnitude of the electric field at $x = 0$. (b) Sketch the electric field through the PIN junction. (c) Calculate the reverse-bias voltage that must be applied.

5.36 Consider a gold Schottky diode at $T = 300$ K formed on n-type GaAs doped at $N_d = 5 \times 10^{16}$ cm$^{-3}$. Determine (a) the theoretical barrier height, $\phi_b$, (b) $\phi_n$, (c) $V_{bi}$, (d) the space charge width, $x_n$, for $V_R = 5$ V, and (e) the electric field at the metal junction for $V_R = 5$ V.

5.42 A Schottky diode and a pn junction diode have cross-sectional areas of $A = 5 \times 10^{-4}$ cm$^2$. The reverse saturation current density of the Schottky diode is $3 \times 10^{-8}$ A/cm$^2$ and the reverse saturation current density of the pn junction diode is $3 \times$
10^{-12} \text{ A/cm}^2. \text{ The temperature is 300 K. Determine the forward-bias voltage in each diode required to yield diode currents of 1 mA.}

**5.44 (a)** The reverse-saturation currents of a Schottky diode and a pn junction diode at \( T = 300 \text{ K} \) are \( 5 \times 10^{-8} \text{ A} \) and \( 10^{-12} \text{ A} \), respectively. The diodes are connected in parallel and are driven by a constant current of 0.5 mA. (i) Determine the current in each diode. (ii) Determine the voltage across each diode. (b) Repeat part (a) if the diodes are connected in series.

**5.47** A metal-semiconductor junction is formed between a metal with a work function of 4.3 eV and p-type silicon with an electron affinity of 4.0 eV. The acceptor doping concentration in the silicon is \( N_a = 5 \times 10^{16} \text{ cm}^{-3} \). Assume \( T = 300 \text{ K} \). (a) Sketch the thermal-equilibrium energy-band diagram. (b) Determine the height of the Schottky barrier. (c) Sketch the energy-band diagram with an applied reverse-bias voltage of \( V_R = 3 \text{ V} \). (d) Sketch the energy-band diagram with an applied forward-bias voltage of \( V_a = 0.25 \text{ V} \).

**5.48** The built-in potential barrier of a linearly graded silicon pn junction at \( T = 300 \text{ K} \) is \( V_{bi} = 0.70 \text{ V} \). The junction capacitance measured at \( V_R = 3.5 \text{ V} \) is \( C' = 7.2 \times 10^{-9} \text{ F/cm}^2 \). Find the gradient, \( a \), of the net impurity concentration.

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