HW 1 Solution Problem 4-7 Revised

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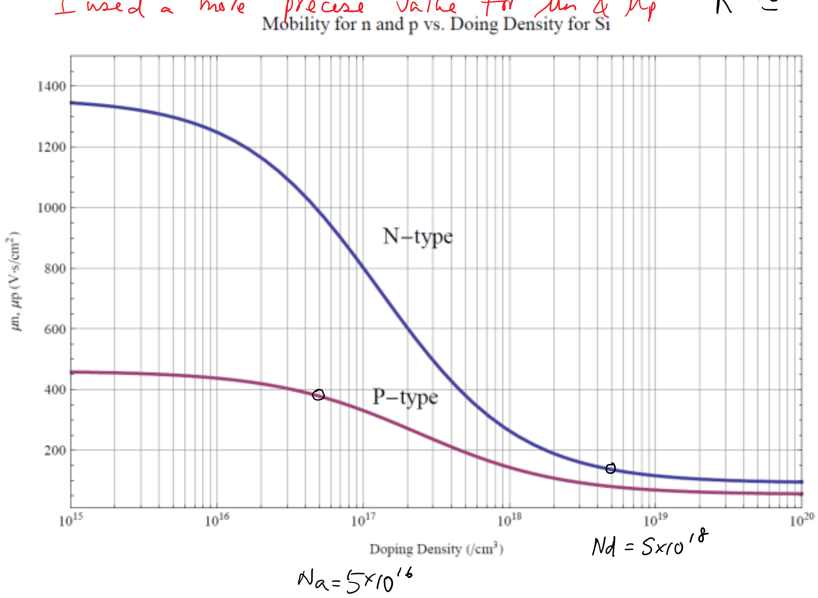
Section 3.3: Current Flow in Semiconductors

3.6 A young designer, aiming to develop intuition concerning conducting paths within an integrated circuit, examines the end-to-end resistance of a connecting bar 10-μm long, 3-μm wide, and 1 μm thick, made of various materials. The designer considers:

(a) intrinsic silicon
(b) n-doped silicon with $N_D = 5 \times 10^{16}/\text{cm}^3$
(c) n-doped silicon with $N_D = 5 \times 10^{18}/\text{cm}^3$
(d) p-doped silicon with $N_A = 5 \times 10^{16}/\text{cm}^3$
(e) aluminum with resistivity of 2.8 μΩ·cm

Find the resistance in each case. For intrinsic silicon, use the data in Table 3.1. For doped silicon, assume $\mu_n = 3\mu_p = 1200\ \text{cm}^2/\text{V}\cdot\text{s}$. (Recall that $R = \rho L/A$.)

I used a more precise value for μ_n & μ_p



(a) $R = \frac{1}{\sigma} \cdot \frac{L}{W \cdot t}$

$\sigma = q\mu_p p + q\mu_n n$

$R = \frac{1}{q\mu_p p + q\mu_n n}\left(\frac{L}{Wt}\right)$

$\frac{L}{Wt} = \frac{10}{3 \times 10^{-4}} = \frac{10}{3} \times 10^4\ \text{cm}, \quad q = 1.6 \times 10^{-19}\ C$

(a) intrinsic Si, $\mu_p \simeq 450\ \frac{\text{cm}^2}{V \cdot S}$ V: Volt

$\mu_n \simeq 1350\ \frac{\text{cm}^2}{V \cdot S}$

$R = \boxed{7.72 \times 10^9\ \Omega}$ or $7.72\ G\Omega$

(b) $N_d = 5 \times 10^{18}$, $n = 5 \times 10^{18}$, $p = 4.5 \times 10^2/\text{cm}^3$, $\mu_n \simeq 125\ \frac{\text{cm}^2}{V \cdot S}$

$R \simeq \frac{1}{\cancel{q\mu_p p} + q\mu_n n}\left(\frac{L}{Wt}\right) = \boxed{333\ \Omega}$

≈ 0

(c) $N_a = 5 \times 10^{16}$, $p \simeq 5 \times 10^{16}$, $\mu_p \simeq 375\ \frac{\text{cm}^2}{V \cdot S}$

$R \simeq \frac{1}{q\mu_p p}\left(\frac{L}{Wt}\right) = \boxed{1.1 \times 10^4\ \Omega}$

or $11\ k\Omega$

(d) $R = 2.8 \times 10^{-6} \times \left(\frac{10}{3} \times 10^4\right) = \boxed{9.3 \times 10^{-2}\ \Omega}$

3.7 Contrast the electron and hole drift velocities through a 10-μm layer of intrinsic silicon across which a voltage of 3 V is imposed. Let $\mu_n = 1350\ \text{cm}^2/\text{V}\cdot\text{s}$ and $\mu_p = 480\ \text{cm}^2/\text{V}\cdot\text{s}$.

```
Efield = Volt/L;
vdn = μn * Efield /. {μn → 1350.0, Volt → 3, L → 10 * 10^-4};
Print["Vd for electron = ", vdn // ScientificForm // Framed, "cm/s"]
vdn = μp * Efield /. {μp → 480.0, Volt → 3, L → 10 * 10^-4};
Print["Vd for hole = ", vdn // ScientificForm // Framed, "cm/s"]
```

Vd for electron = $\boxed{4.05 \times 10^6}$ cm/s

Vd for hole = $\boxed{1.44 \times 10^6}$ cm/s

3.8 Find the current that flows in a silicon bar of 10-µm length having a 5-µm × 4-µm cross-section and having free-electron and hole densities of $10^4/\text{cm}^3$ and $10^{16}/\text{cm}^3$, respectively, when a 1 V is applied end-to-end. Use $\mu_n = 1200\ \text{cm}^2/\text{V}\cdot\text{s}$ and $\mu_p = 500\ \text{cm}^2/\text{V}\cdot\text{s}$.

```
Clear["Global`*"]
q = 1.6 * 10^-19
Efield = Volt/L;
σ = q * μn * n + q * μp * p /. {μn → 1200, μp → 500, n → 10^4, p → 10^16, Volt → 1, L → 10 * 10^-4, W → 5 * 10^-4, t → 4 * 10^-4}
J = σ * Efield;
current = J * W * t /. {μn → 1200, μp → 500, n → 10^4, p → 10^16, Volt → 1, L → 10 * 10^-4, W → 5 * 10^-4, t → 4 * 10^-4};
Print["Current = ", current, " A"]
R = 1/σ * L/(W * t) /. {μn → 1200, μp → 500, n → 10^16, p → 10^4, Volt → 1, L → 10 * 10^-4, W → 5 * 10^-4, t → 4 * 10^-4};
1/R;
Print["Alternatively, R= ", R, " Ω; current = V/R=1/R= ", 1/R, " A"]
```

```
1.6 × 10^-19

0.8

Current = 0.00016 A

Alternatively, R= 6250. Ω; current = V/R=1/R= 0.00016. A
```

3.9 In a 10-µm-long bar of donor-doped silicon, what donor concentration is needed to realize a current density of $2\ \text{mA}/\mu\text{m}^2$ in response to an applied voltage of 1 V? (*Note*: Although the carrier mobilities change with doping concentration, as a first approximation you may assume μ_n to be constant and use $1350\ \text{cm}^2/\text{V}\cdot\text{s}$, the value for intrinsic silicon.)

```
q = 1.6 * 10^-19;
ni = 1.5 * 10^10;
Currentdensity = 2 * 10^-3/(10^-4)^2; (* converting the unit to A/cm^2 *)
NSolve[Currentdensity == (Nd * q * 1350 + q * ni^2/Nd * μp) * Volt/L /. {Volt → 1, L → 10 * 10^-4, μp → 450}, Nd]
NSolve[Currentdensity == (Nd * q * 1350) * Volt/L /. {Volt → 1, L → 10 * 10^-4}, Nd]
(* neglecting minorty carrers for σ calculaton *)
```

```
{{Nd → 9.25926 × 10^17}, {Nd → 81.}}

{{Nd → 9.25926 × 10^17}}
```

n

p

previously missing

from μ_p vs N_a graph

w/out considering the role of the minority carriers