Week 3 Practice Assignment

Sanjeev Patil

PhD scholar

Dept. of Metallurgical and Materials Engineering

IIT – Madras

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Week 3 Practice Assignment

Poll Q1. What level of doping is reasonable?

A. 10^{-8} cm^{-3}
B. 1 cm^{-3}
C. 10^{6} cm^{-3}
D. 10^{9} cm^{-3}

Poll Q2. What happens upon addition of small amount of antimony to pure silicon? Assume 100% ionization of added antimony atoms.

A. 1 extra delocalized electron generated per antimony atom ionized
B. 1 extra delocalized hole generated
C. Room temperature is NOT enough to excite extra electron to CB
D. None of these

Poll Q3. What happens upon addition of small amount of silicon to pure gallium arsenide? Assume 100% ionization of added dopant.

A. n-type doping
B. p-type doping
C. amphoteric doping
D. degenerate semiconductor

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1) Consider the electrical conductivity of an **p-type** semiconductor at **low dopant concentrations**. Its conductivity is given by

$\sigma = en\mu_e + ep\mu_h$

At what **hole concentration** will the conductivity be **minimum**?

- ○ $n_i\sqrt{\mu_e/\mu_h}$
- ○ $n_i\sqrt{\mu_h/\mu_e}$
- ○ n_i
- ○ $n_i\sqrt{2\mu_h/\mu_e}$

$$\sigma = ne\mu_e + pe\mu_h$$

$$n_i^2 = np$$

$$\frac{d\sigma}{dp} = \frac{d(ne\mu_e)}{dp} + e\mu_h$$

$$\frac{d\sigma}{dp} = n_i^2 e\mu_e \frac{d(p^{-1})}{dp} + e\mu_h$$

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$$\frac{d\sigma}{dp} = -{n_i}^2 e\mu_e p^{-2} + e\mu_h$$

$$0 = -\left(\frac{n_i}{p}\right)^2 e\mu_e + e\mu_h$$

$$\left(\frac{n_i}{p}\right)^2 e\mu_e = e\mu_h$$

$$\left(\frac{n_i}{p}\right)^2 = \frac{\mu_h}{\mu_e}$$

$$\frac{n_i}{p} = \sqrt{\frac{\mu_h}{\mu_e}}$$

$$\boldsymbol{p = n_i\sqrt{\frac{\mu_e}{\mu_h}}}$$

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2) The intrinsic carrier concentration of Si at 300 K is $10^{10}\,\mathrm{cm}^{-3}$ and the electron and hole mobility are 1350 and 450 $\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$ respectively. *1 poi*

Si is doped with 10^{15} phosphorus atoms cm^{-3} and at 300 K the **dopants are completely ionized**. What is the electrical conductivity of this doped Si at this temperature? Give your answer in $\Omega^{-1}\mathrm{cm}^{-1}$

- 0.072
- 0.216
- 0.29
- 0.45

Given: n_i = 10^{10} cm^{-3}, N_D = 10^{15} cm^{-3}, μ_e = 1350 cm^{2}V^{-1}s^{-1}, μ_h = 450 cm^{2}V^{-1}s^{-1}

$$n_i{}^2 = np$$

Law of mass action $\quad 10^{20} = np$

$$n = N_D + p$$

Charge neutrality $\quad n = 10^{15} + p$

$$10^{20} = (10^{15} + p)np$$

$$p^2 + 10^{15}p - 10^{20} = 0$$

$p = 10^5$cm^{-3} $\qquad n = 10^{15}$cm^{-3}

$$\sigma = ne\mu_e + pe\mu_h$$

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$$\sigma = ne\mu_e + pe\mu_h$$

$$\sigma = 10^{15}e \times 1350 + 10^{5}e \times 450$$

$$\boldsymbol{\sigma = 0.216\ \Omega^{-1}\mathrm{cm}^{-1}}$$

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3) In an extrinsic semiconductor, the electron mobility due to **impurity scattering** is 300 $cm^2V^{-1}s^{-1}$ and mobility due to **lattice scattering** is 200 $cm^2V^{-1}s^{-1}$. What is the **net mobility** of electrons in this semiconductor? Give your answer in units of $cm^2V^{-1}s^{-1}$

- 120
- 200
- 300
- 500

Given: μ_I = 300 $cm^2V^{-1}s^{-1}$, μ_L = 200 $cm^2V^{-1}s^{-1}$

$$\frac{1}{\mu_{net}} = \frac{1}{\mu_I} + \frac{1}{\mu_L}$$

$$\frac{1}{\mu_{net}} = \frac{1}{300} + \frac{1}{200}$$

$$\frac{1}{\mu_{net}} = \frac{5}{600}$$

$$\mu_{net} = 120\ cm^2V^{-1}s^{-1}$$

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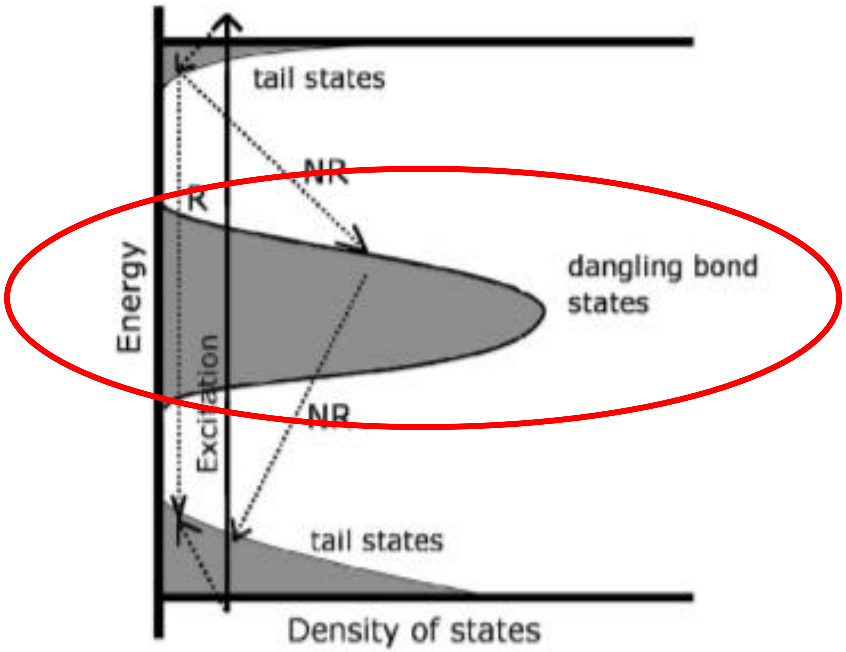
4) Which of the following is the **primary conduction mechanism** in an **amorphous semiconductor**?

- ○ intrinsic conduction
- ○ extrinsic conduction
- ○ metallic conduction
- ○ hopping conduction



Localized defect states

FIG. 2. Simplified depiction of the distribution of states for an amorphous Ge dot showing localized tail states extending beyond the limits of the nominal conduction and valence bands, together with dangling bond states of intermediate energies. Excited carriers can decay radiatively (R) from tail states or nonradiatively (NR) through dangling bond states.

Bhatti *et al*. Appl. Phys. Lett. 90, 011903 2007

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5) The intrinsic carrier concentration of Si, at 300 K, is $10^{10}\ \text{cm}^{-3}$. A sample of Si is doped with phosphorous atoms of concentration $10^{15}\ \text{cm}^{-3}$ **and** boron atoms of concentration $10^{16}\ \text{cm}^{-3}$. Assume complete ionization of all dopant atoms. Which of the following is **true** for this semiconductor? *1*

- ○ $n = 10^{15}\ \text{cm}^{-3}$ and $p = 10^{16}\ \text{cm}^{-3}$
- ○ $n = 10^{10}\ \text{cm}^{-3}$ and $p = 9 \times 10^{15}\ \text{cm}^{-3}$
- ○ $n = 1.1 \times 10^{4}\ \text{cm}^{-3}$ and $p = 9 \times 10^{15}\ \text{cm}^{-3}$
- ○ $n = 9 \times 10^{15}\ \text{cm}^{-3}$ and $p = 1.1 \times 10^{4}\ \text{cm}^{-3}$

Compensation doping

Given: $n_i = 10^{10}$ cm^{-3}, $N_D = 10^{15}$ cm^{-3}, $N_A = 10^{16}$ cm^{-3}

$$n_i^2 = np$$

Law of mass action $\quad 10^{20} = np$

$$n = N_D + p$$

Charge neutrality $\quad n = 10^{15} + p$

P doping

$$10^{20} = (10^{15} + p)np$$

$$p^2 + 10^{15}p - 10^{20} = 0$$

$p = 10^5$cm^{-3} $\qquad n = 10^{15}$cm^{-3}

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Compensation doping

$N_A > N_D \Longrightarrow p\ type$

$$p = N_A - N_D$$

Charge neutrality

$$p = 10^{16} - 10^{15}$$

$$\boldsymbol{p = 9 \times 10^{15}\mathrm{cm}^{-3}}$$

$${n_i}^2 = np$$

Law of mass action

$$10^{20} = n\,(9 \times 10^{15})$$

$$\boldsymbol{n = 1.1 \times 10^{4}\mathrm{cm}^{-3}}$$

B doping

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