AL-Mustaqbal University College
Department of Medical Physics
The Second Stage
Semiconductors
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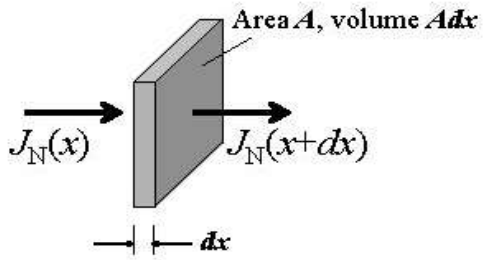
كلية المستقبل الجامعة
قسم الفيزياء الطبية
المرحلة الثانية
أشباه موصلات

Lecture 5

Derivation of Continuity Equation

- Consider carrier-flux into/out-of an infinitesimal volume:



$$A dx\left(\frac{\partial n}{\partial t}\right) = -\frac{1}{q}\left[J_N(x)A - J_N(x+dx)A\right] - \frac{\Delta n}{\tau_n} A dx$$

$$J_N(x+dx) = J_N(x) + \frac{\partial J_N(x)}{\partial x} dx$$

$$\Rightarrow \quad \frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_N(x)}{\partial x} - \frac{\Delta n}{\tau_n}$$

Continuity Equations:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_N(x)}{\partial x} - \frac{\Delta n}{\tau_n} + G_L$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_P(x)}{\partial x} - \frac{\Delta p}{\tau_p} + G_L$$

Derivation of Minority Carrier Diffusion Equation

- **The minority carrier diffusion equations are derived from the general continuity equations, and are applicable only for minority carriers.**
- **Simplifying assumptions:**
  - The electric field is small, such that

$$J_N = q\mu_n n\mathcal{E} + qD_N \frac{\partial n}{\partial x} \cong qD_N \frac{\partial n}{\partial x} \quad \text{in p-type material}$$

$$J_P = q\mu_p p\mathcal{E} + qD_P \frac{\partial p}{\partial x} \cong qD_P \frac{\partial p}{\partial x} \quad \text{in n-type material}$$

  - n_0 and p_0 are independent of x (uniform doping)
  - low-level injection conditions prevail

- Starting with the continuity equation for electrons:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_N(x)}{\partial x} - \frac{\Delta n}{\tau_n} + G_L$$

$$\frac{\partial(n_0 + \Delta n)}{\partial t} = \frac{1}{q}\frac{\partial}{\partial x}\left[qD_N \frac{\partial(n_0 + \Delta n)}{\partial x}\right] - \frac{\Delta n}{\tau_n} + G_L$$

$$\frac{\partial \Delta n}{\partial t} = D_N \frac{\partial^2 \Delta n}{\partial x^2} - \frac{\Delta n}{\tau_n} + G_L$$

Summary

- The ***continuity equations*** are established based on conservation of carriers, and therefore are general:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_N(x)}{\partial x} - \frac{\Delta n}{\tau_n} + G_L \qquad \frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_P(x)}{\partial x} - \frac{\Delta p}{\tau_p} + G_L$$

- The ***minority carrier diffusion equations*** are derived from the continuity equations, specifically for minority carriers under certain conditions (small *E*-field, low-level injection, uniform doping profile):

$$\frac{\partial \Delta n_p}{\partial t} = D_N \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L \qquad \frac{\partial \Delta p_n}{\partial t} = D_P \frac{\partial^2 \Delta p_n}{\partial x^2} - \frac{\Delta p_n}{\tau_p} + G_L$$

Quasi-Fermi Levels

- Whenever $\Delta n = \Delta p \neq 0$, $np \neq n_i^2$. However, we would like to preserve and use the relations:

$$n = n_i e^{(E_F - E_i)/kT} \qquad p = n_i e^{(E_i - E_F)/kT}$$

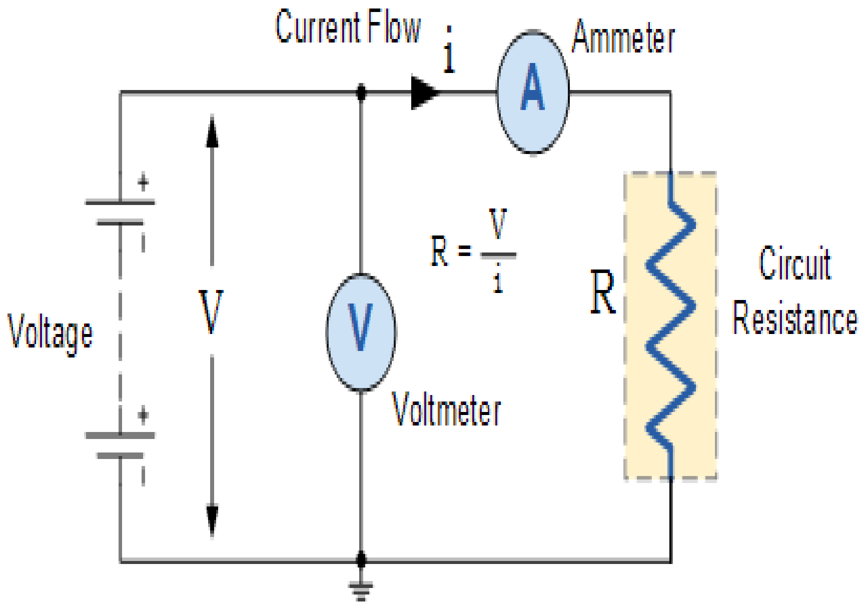
- These equations imply $np = n_i^2$, however. The solution is to introduce two ***quasi-Fermi levels*** F_N and F_P such that

$$n = n_i e^{(F_N - E_i)/kT} \qquad p = n_i e^{(E_i - F_P)/kT}$$

$$F_N \equiv E_i + kT \ln\left(\frac{n}{n_i}\right) \qquad F_P \equiv E_i - kT \ln\left(\frac{p}{n_i}\right)$$

I-V Characteristic Curves

The current-voltage, (I-V) Characteristics Curves define the operating characteristics of an electronic device



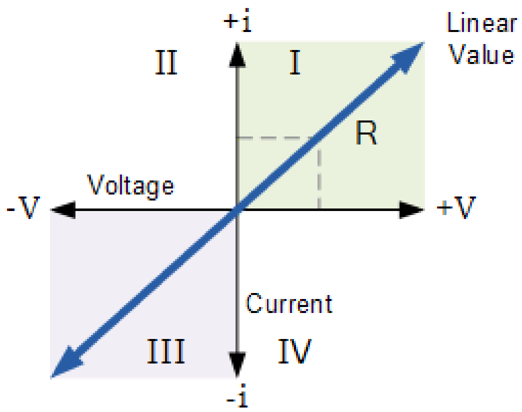
The **I-V Characteristic Curves**, which is short for **Current-Voltage Characteristic Curves** or simply **I-V curves** of an electrical device or component, are a set of graphical curves which are used to define its operation within an electrical circuit. As its name suggests, I-V characteristic curves show the relationship between the current flowing through an electronic device and the applied voltage across its terminals.

If the electrical supply voltage, V applied to the terminals of the resistive element R above was varied, and the resulting current, I measured, this current would be characterized as:

$$\mathbf{I = V/R}$$

being one of Ohm's Law equations.

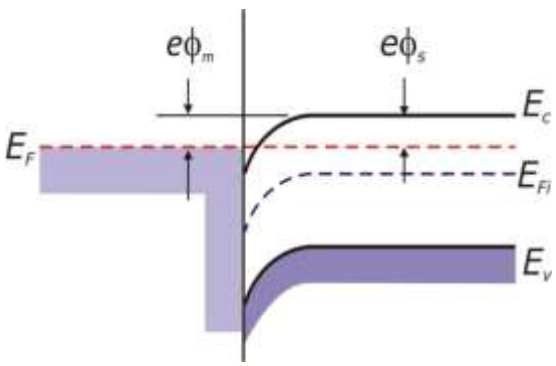
We know from Ohm's Law that as the voltage across the resistor increases so too does the current flowing through it, it would be possible to construct a graph to show the relationship between the voltage and current as shown with the graph representing the the volt-ampere characteristics .



Ohmic Contact

The Ohmic contact is a low resistance junction (non-rectifying) provides current conduction from metal to semiconductor and vice versa. Theoretically speaking the current should increase/ decrease linearly with the applied voltage. With an immediate response for the any small voltage. There are two types of the Ohmic contacts:

1. The Ideal Nonrectifying Barriers



2. The Tunneling Barriers