Optoelectronics Devices & Circuits (MEC-166)

UNIT-II

By

Dr. POOJA LOHIA

Department of Electronics & Communication

Madan Mohan Malaviya University of Technology, Gorakhpur

SYLLABUS

Madan Mohan Malaviya University of Technology, Gorakhpur-273 010, India

M. Tech. (Digital Systems) Syllabus

MEC-166	**Optoelectronics Devices & Circuits**
Topics Covered	
UNIT-I	
Elements and compound Semiconductor, Electronic Properties of semiconductor, Carrier effective masses and band structure, effect of temperature and pressure on bandgap, Carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena.	9
UNIT-II	
Optical Properties of semiconductor, EHP formation and recombination, absorption in semiconductor, Effect of electric field on absorption, absorption in quantum wells, radiation in semiconductor, Deep level transitions, Augur recombination's.	9
UNIT-III	
Junction theory, Schottky barrier and ohmic contacts, semiconductor heterojunctions, LEDs, Photo Detectors, Solar cells.	9
UNIT-IV	
Optoelectronics modulation and switching devices: Analog and Digital modulation, Franz-Keldysh and stark effects modulators, Electro-optic modulators. Optoelectronics Integrated Circuits (OEICs): Need for hybrid and monolithic integration, OEIC transmitters and receivers.	9
Textbooks	
1. Semiconductor optoelectronic Devices By Pallab Bhattachrya, Prentice Hall Publications.	
2. Physics of Semiconductor Devices, By S.M. Sze, Wiley Publication.	

Key Points

- ❖ Electron-Hole Pair recombination Rate
- Low Level Injection
- High Level Injection

- ❖ Absorption in semiconductors
- Band to band Recombination
- Indirect intrinsic transitions
- Exciton absorption
- Donor Acceptor and impurity-band absorption
- Low energy(long Wavelength) absorption

- ❖ Effect of electric field on absorption:
- Franz-Keldysh Effect
- stark Effects

Electron-Hole Pair Recombination Rate

- All the processes occur at the same time in a material but at different rates.

- If we have device with **low field and non-degenerate** semiconductor then the recombination-generation mechanism **at room temperature** that dominates is-

1. **Band-to- Band Transition**
2. **R-G Center Transition**

- For example,

- In a **direct** band gap semiconductor, **band-to-band** transitions dominate.
- In **indirect** band gap semiconductors, **R-G center** transitions dominate.

Electron-Hole Pair Recombination Rate

- In general, the total recombination rate is given by the sum of recombination rate due to all the processes-

$$R = B_1 np + B_2 np + B_3 np + \ldots\ldots\ldots$$

- Not all of them will dominate so one can simplify the expression by looking at only the dominating recombination mechanism.

- **There are two special cases in device physics-**

1. **Low Level Injection**
2. **High Level Injection or Excitation**

Electron-Hole Pair Recombination Rate

Case I- Low Level Injection :

Let in equilibrium we have the equilibrium concentration of electrons and holes is $\boldsymbol{n_0}$ & $\boldsymbol{p_0}$ and $\boldsymbol{n_i}$ be the intrinsic carrier concentration then-

$$\boldsymbol{n_0 p_0 = n_i^2} \qquad \textbf{(1)}$$

Now, we create excess electrons and holes such that new carrier concentration be-

$$\boldsymbol{n = n_0 + \Delta n \ ; p = p_0 + \Delta p} \qquad \textbf{(2)}$$

Where $\boldsymbol{\Delta n \ and \ \Delta p}$ are the excess number of electrons and holes generated respectively.

Electron-Hole Pair Recombination Rate

- At t = 0, in optical and thermal generation,

$$\Delta n_0 = \Delta p_0 \; ; \; \Delta n = \Delta p \qquad (3)$$

- Low level injection means the excess carrier generated at any time must be much smaller than the majority carrier concentration of semiconductor.

$$\Delta p, \Delta n \ll n_0 \qquad \textbf{for n-type} \qquad (4)$$

$$\Delta p, \Delta n \ll p_0 \qquad \textbf{for p-type} \qquad (5)$$

Electron-Hole Pair Recombination Rate

- Now we want to see how the carrier concentration is changing with time at any time ‘t’-

$$\frac{dn}{dt} = \frac{dp}{dt} = Bnp - G_{th} \qquad (6)$$

Recombination Rate (Bnp)

Thermal Generation Rate (B $n_0 p_0$) (G_{th})

the carrier concentration at any time ‘t’ is-

$$\frac{d(n_0 + \Delta n)}{dt} = B(n_0 + \Delta n)(p_0 + \Delta p) - Bn_0p_0 \qquad (7)$$

Electron-Hole Pair Recombination Rate

$$\frac{d(n_0 + \Delta n)}{dt} = B(n_0 + \Delta n)(p_0 + \Delta p) - Bn_0p_0$$

$$\frac{d(\Delta n)}{dt} = B(n_0p_0 + p_0\Delta n + n_0\Delta p + \Delta n\Delta p) - Bn_0p_0 \qquad \textbf{(8)}$$

$\Delta n\Delta p$ is negligible at low level injection

$$\frac{d(\Delta n)}{dt} = B(p_0\Delta n + n_0\Delta p) \qquad \textbf{(9)}$$

Since $\Delta n = \Delta p$

Electron-Hole Pair Recombination Rate

$$\frac{d(\Delta n)}{dt} = B\Delta n(p_0 + n_0) \qquad (10)$$

At t=0 , $\Delta n = \Delta n_0$, therefore after solving above equation we get the equation for change in excess carrier concentration at any time t-

$$\Delta n = \Delta n_0 e^{-\frac{t}{\tau}} \qquad (11)$$

Where $'\tau'$ is the ***'carrier life time'*** which is defined as

$$\tau = \frac{1}{B(n_0 + p_0)} \qquad (12)$$

Electron-Hole Pair Recombination Rate

- From equation 10 and 12 we get, the recombination rate R is given by-

$$R = \frac{dn}{dt} = \frac{d(\Delta n)}{dt} = B\Delta n(p_0 + n_0) = \frac{\Delta n}{\tau} \quad (13)$$

Since $\tau = \frac{1}{B(n_0+p_0)}$

- In a **n-type device** majority carrier concentration is n_0 so, $\tau = \frac{1}{B(n_0)}$ **(14)**
- In a **p-type device** majority carrier concentration is p_0 so, $\tau = \frac{1}{B(p_0)}$ **(15)**

Electron-Hole Pair Recombination Rate

- For a single recombination process

$$R = \frac{\Delta n}{\tau}$$

- If more processes of recombination are involved then the recombination rate is given by-

$$R = \frac{\Delta n}{\tau_1} + \frac{\Delta n}{\tau_2} + \frac{\Delta n}{\tau_3} + \dots\dots\dots\dots \qquad (16)$$

- **This expression of recombination is for low level injecction**

Electron-Hole Pair Recombination Rate

Case I- High Level Injection :

The excess carrier generated in this case is very much larger than the total equilibrium concentration of electrons an holes-

$$\Delta n \gg n_0 + p_0 \tag{17}$$

Simillar to low level injection eq (8) is given by-

$$\frac{d(\Delta n)}{dt} = B(n_0 p_0 + p_0 \Delta n + n_0 \Delta p + \Delta n \Delta p) - B n_0 p_0 \tag{18}$$

Here, in this case $n_0 p_0$ is negligible as compared to other and $\Delta n = \Delta p$.

Electron-Hole Pair Recombination Rate

$$\frac{d(\Delta n)}{dt} = B\left(\Delta n(p_0 + n_0) + \Delta n^2\right) \tag{19}$$

After solving this gives change in carrier concentration,

$$\boxed{\Delta n(t) = \frac{1}{(Bt + \Delta n^{-1})}} \tag{20}$$

Thus, the rate of recombination **at high level injection** is given by-

$$\boxed{R = -\frac{dn}{dt} = -\frac{B}{\left(Bt + \Delta n_0^{-1}\right)^2}} \tag{21}$$

Summary Recombination Rate

Case I- Low Level Injection	Case II- High Level Injection
$\Delta n(t) = \Delta n_0 e^{-\frac{t}{\tau}}$	$\Delta n(t) = \frac{1}{(Bt + \Delta n^{-1})}$
$\tau = \frac{1}{B(n_0 + p_0)}$	$R = -\frac{dn}{dt} = -\frac{B}{\left(Bt + \Delta n_0^{-1}\right)^2}$
$R = \frac{dn}{dt} == B\Delta n\left(p_0 + n_0\right) = \frac{\Delta n}{\tau}$	


THANK YOU