Explanation of carrier generation & recombination process :-

Carrier Generation (free e- and holes)

Process by which free e- and holes are generated in pair is called carrier generation
In other words, when the e- in the valence band get enough energy, they absorb the energy and jumps to conduction band. The jumped e- is called free e- & the place from where e- is left is called hole. Similarly, two type of charge carriers (e-& holes) are generated.

Recombination (free e- and holes)

The process by which free e- and holes gets eliminated is called recombination of carriers. When free e- in the conduction band falls into hole in the valence band, the free e- and hole gets eliminated.

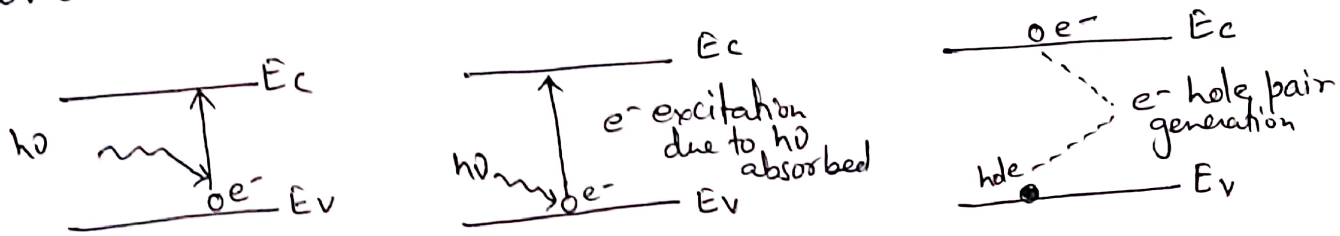
e- hole pair is the fundamental unit of generation and recombination corresponding to an e- transitioning between valence band and conduction band where generation of e- is a transition from the valence band to the conduction band and recombination is a reverse process.

Recombination and generation are regularly happening in semiconductors. With the change (sudden) in temperature, will increase the rate at which e- and holes are thermally generated so that their concentrations will change with time until new equilibrium values are reached. An external excitation such as light can also generate e- & holes, creating non-equilibrium condition. let us first consider the band-to-band generation and recombination and then later on effect of allowed electronic energy states within the band-gap referred as trap / recombination ~~ce~~ centres.

In equilibrium state e- and holes are independent of time. However e- ~~and~~ are continually thermally excited from valence to conduction band. At the same time, e- randomly moving through the crystal in the conduction band may come near to hole & fall into the empty states in the valence band. This rate of generation & recombination should be equal.

Explanation of Carrier Generation – With the absorption of ligh energy ~~of~~ or increase in temperature, e^- & holes when generated in pairs is known as generation process.

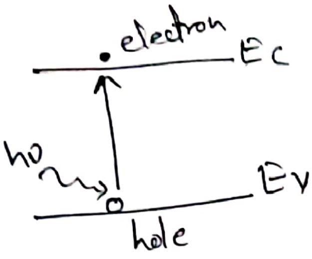
In the optical absorption process in semiconductors, if $h\nu \geq E_g$, then photon energy is absorbed as it has enough energy to break the covalent bond & ~~er~~ creates e^--hole pair.



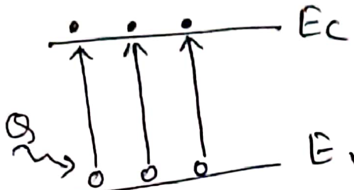
(i) Generation due to light absorption – Occurs when $h\nu$ is high to excite e^- from valence band till the conduction band giving e^--hole pair. For this photon of energy $E \geq E_g$ & $E - E_g$ is given to e^- & hole in the form of kinetic energy.

(ii) Generation due to High Energy beam – Occurs when $E >> E_g$ (E is much greater than E_g) which gives multiple e^--hole pairs. Applicable for nuclear particle counters depending on semiconductors.

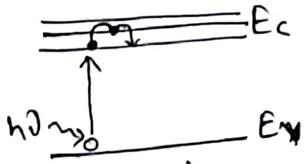
(iii) Generation due to impact ionization – due to e/hole with energy much larger/smaller than conduction band/valence band ~~b~~ edge.



Generation - Due to light absorption



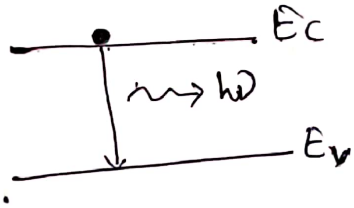
Generation - Due to high energy beam



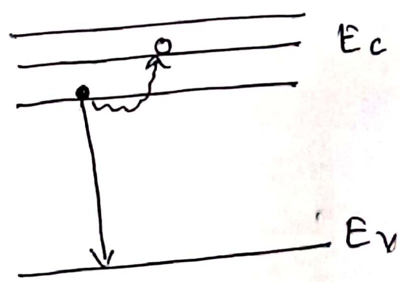
Generation - Due to impact ionization.

Explanation of Recombination Process- Process due to which both carriers annihilates each other.. Electrons are occupied by one or multiple steps - at the empty state associated with hole.

Radiative Recombination



Non-Radiative Recombination.



RECOMBINATION PROCESS → With the base of all previous theories -

Till now, we have come to know about the e⁻ hole pair generation. Now we will come to know about the recapturing of e with a hole.

Classification :-

(i) Band-to-Band recombination giving a photon (radiative)

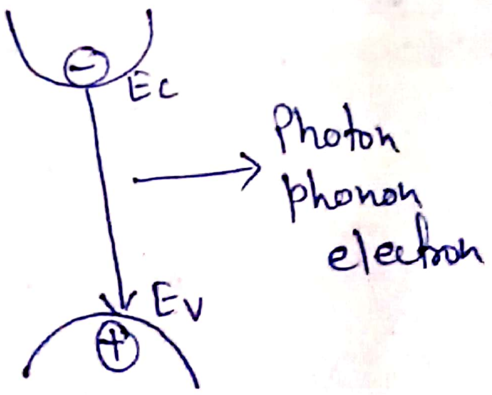
(ii) recombination by means of simply giving away energy to the phonons. (SRH-recombination)

(iii) recombination by transferring kinetic energy to another e⁻ and knocking out into higher energy levels. (Auger recombination)

Recombination Channels

Radiative:
Direct band gap:
Photon = Eg
Indirect Band gap
photon = Eg + phonon

Non radiative
Phonon trap assisted,
Shockley-read-hall
Electron-Auger

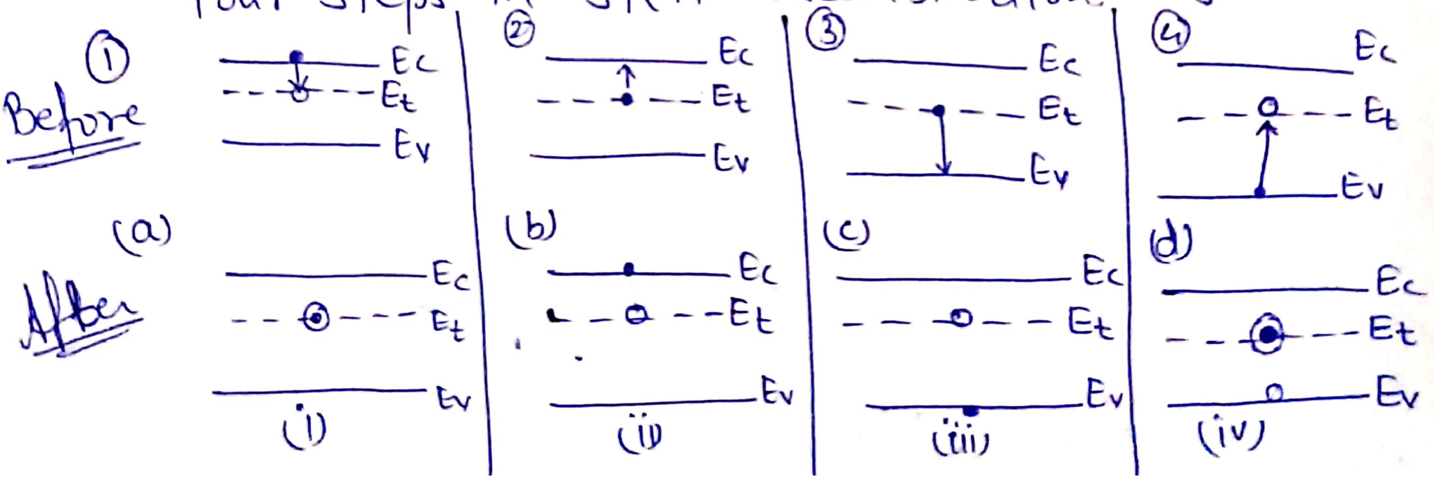


Shockley-Read-Hall Recombination (SRH)

An indirect recombination process in which the electrons from the lower level of conduction band moves to a defect level (E_t) which is an intermediate or transition level, lying between lower level of conduction band (E_c) and higher level of valence band (E_v). This is followed with the photon or phonon emission. From the intermediate level they move to upper level of valence band. It shows that the flaws/defects are essential for this ~~xx~~ "SRH recombination".

This recombination process mechanism is named as SRH recombination as it was explained Shockley, Read & Hall. The defects are deep in the crystal structure. Here, we will discuss the single level recombination.

Four steps in SRH - recombination - Fig-I



In the fig I, under the before category and after category, the four steps are depicted.

fig (a), (b), (c), (d) are the consequences after the steps of fig 1, 2, 3, 4 are taking place.

In fig (1), ~~see~~ ~~if~~ when the e^- from E_c moves towards E_t which after trapping due to to deep level defect, e^- is placed as shown in fig (a). This is step-(i).

In second step (ii), e^- from E_t when goes to E_c leaves hole in E_t as shown in fig (b). In step-(iii) e^- from E_t may also move to E_v, creating hole in E_t and e^--hole is annihilated (destroyed) in E_v. In fourth step (iv) e^- from E_v may also move to E_t creating ~~e~~ hole in E_v and e^- will be there in E_t.

Step-1 is named as capturing of e^-. Step-2 is known for emission of e^-. In step-3 capturing of hole and in step-4 emission of hole is taking place. In all the figures, the arrows represents the direction of transition (fig 1, 2, 3, 4)

Step(i) - represents the e- capture proces from Ec to the centre at Et. In step (ii) there is inverse of emission of e- from the centre at Et to the Ec. Step (iii) shows the capturing of hole from the valence band by the centre ~~pts~~ found in Et. In step (iii) the Et releases out ~~the~~ the e- captured at that point to the valence band (Ev). This step is equal to the process of transferring hole (o) from Ev to Et.

Process (iv), ~~capt~~ shows the capturing of e- from Ev creating hole in Ev. This process is equivalent to centres (Et) as if it has ~~emi~~ emitted a hole in the valence band (Ev).

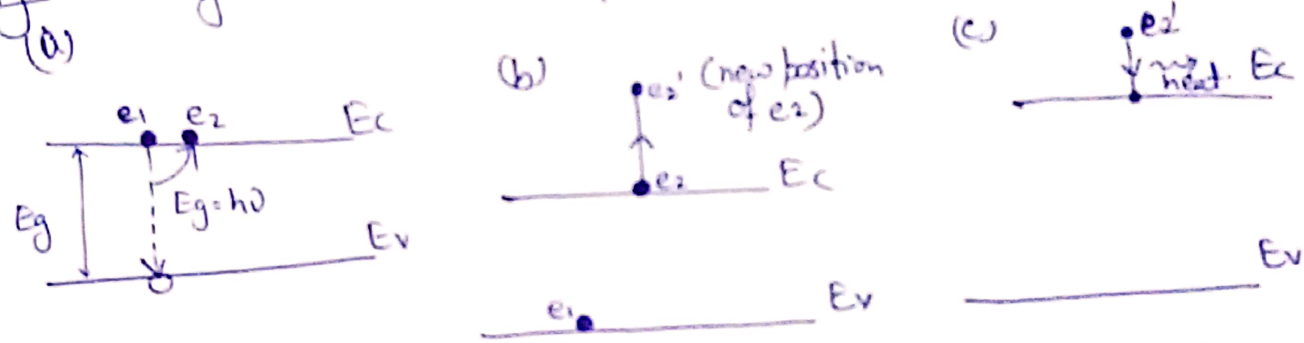
Thus, it is ~~infere~~ inferred that if Et is to act as an important recombination centre ~~then~~ then ~~proce~~ step (i) - e- capture must be followed by step (iii) hole capture and they should have same probability, which will result in going of e- from Ec to Ev.

On the other hand if e- capture ie step (i) is followed by step (ii) which is e- emission the Et centre acts as e- trap. Similarly if step (iii) is soon followed by step (iv) then the Et centre is a hole trap. Or else the impurity level will acts as recombination centre..

x———x——x

Auger Recombination - Recombination with three charge carriers. In this, during the e- hole pair recombination but does not emitt photon or phonons, but energy is transferred to the third free e- in the conduction band. The excited e- comes back to the conduction band minimum with the release of energy in the form of heat. (4)

Fig 2- Auger recombination process (A non-radiative process)



Process is not applicable for light doped materials.

Types -

① Direct (Band-to-Band) (II) Indirect Auger recombination

(I) Direct (Band-to-Band) Auger recombination (e-e-h recombination)

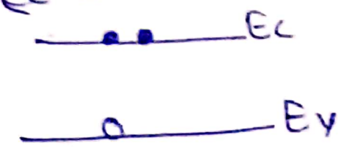


fig (a)

Two e- and one hole (eeh) process as shown in fig (a)

In this one e- in conduction band makes transition to the empty state hole in the valence band. The energy of e-hole pair ~~is~~ is transferred to the nearly present e- and this e- is excited to ~~an~~ a higher energy level in conduction band. Later on, the excited e- comes back to thermal equilibrium with the emission of its kinetic energy ~~as~~ (lattice phonons). Also possible for (e-h-h) in & which e- from conduction band recombines with hole in valence and their recombining energy is given to nearly present hole making it move to lower energy of valence band. Auger recombination is 3rd order process. (eqn contd. from previous notes).

x—— x —— x