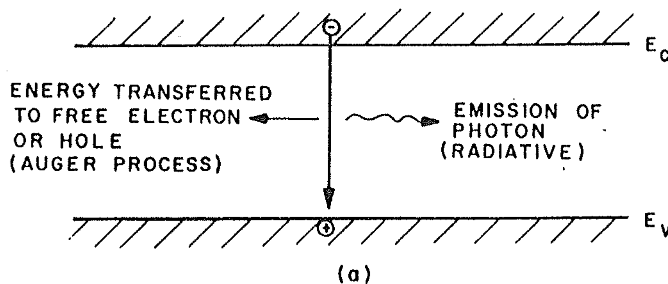
RICOMBINAZIONE

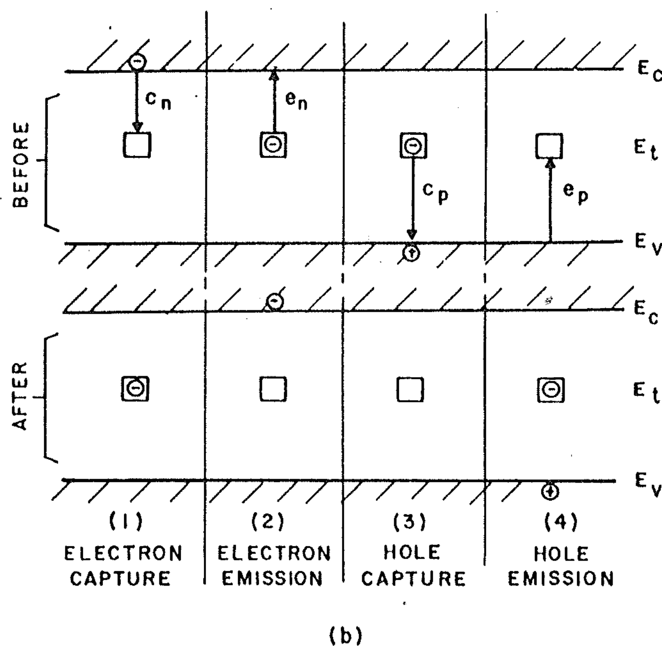
Ricombinazione diretta



$$R(\nu)d\nu = \frac{8\pi}{c^2}\frac{\nu^2 n^2 \alpha}{e^{h\nu/kT}-1}d\nu$$

$$R = \int_0^\infty R(\nu)d\nu$$

Effetto delle trappole



All'equilibrio $pn = n_i^2 \to U = 0$

σ_p, σ_n = sez. d'urto di cattura di e, h.

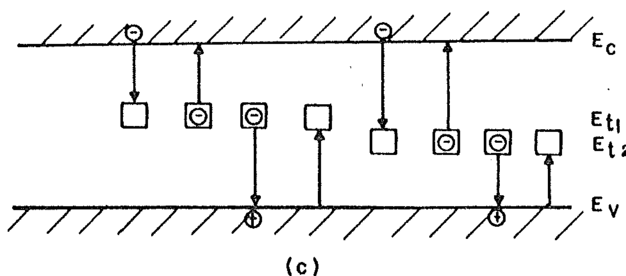


Fig. 24 Recombination processes. (*a*) Band-to-band recombination (radiative or Auger process). (*b*) Single-level recombination. (*c*) Multiple-level recombination. (After Sah, Noyce, and Shockley, Ref. 43.)

velocità di ricombinazione U (cm^{-3}/s) per trappole

N_t = densità trappole, E_t = energia trappole

$$U = \frac{\sigma_p \sigma_n v_{th} (pn - n_i^2) N_t}{\sigma_n \left[n + n_i \exp\left(\frac{E_t - E_i}{kT}\right)\right] + \sigma_p \left[p + n_i \exp\left(-\frac{E_t - E_i}{kT}\right)\right]} \quad (cm^{-3}/s)$$

i = intrinseco E_i = E_F intrinseco

Effetto delle impurezze nella ricombinazione

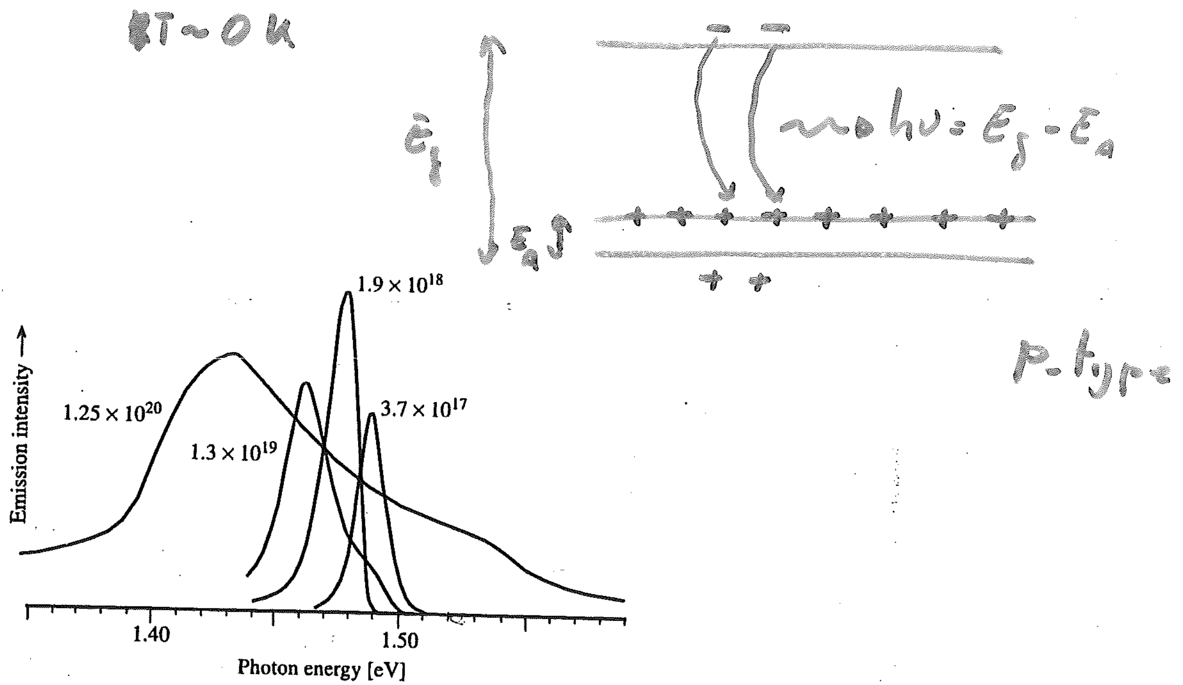


Fig. 7.4. Electroluminescence of p-type (Zn-doped) GaAs at 4.2K for increasing dopant

GaAs $E_g = 1.42$ eV (300 K) → 1.52 eV (0 K)

$3.7 \cdot 10^{17}$
$1.9 \cdot 10^{18}$ → transizioni CB → accettori con buche intrappolate

$1.3 \cdot 10^{19}$
$1.25 \cdot 10^{20}$] → ad alte concentrazioni di accettori, i livelli degli accettori "continui" → "banda delle impurezze"

Free-to-bound transitions

EMISSIONE

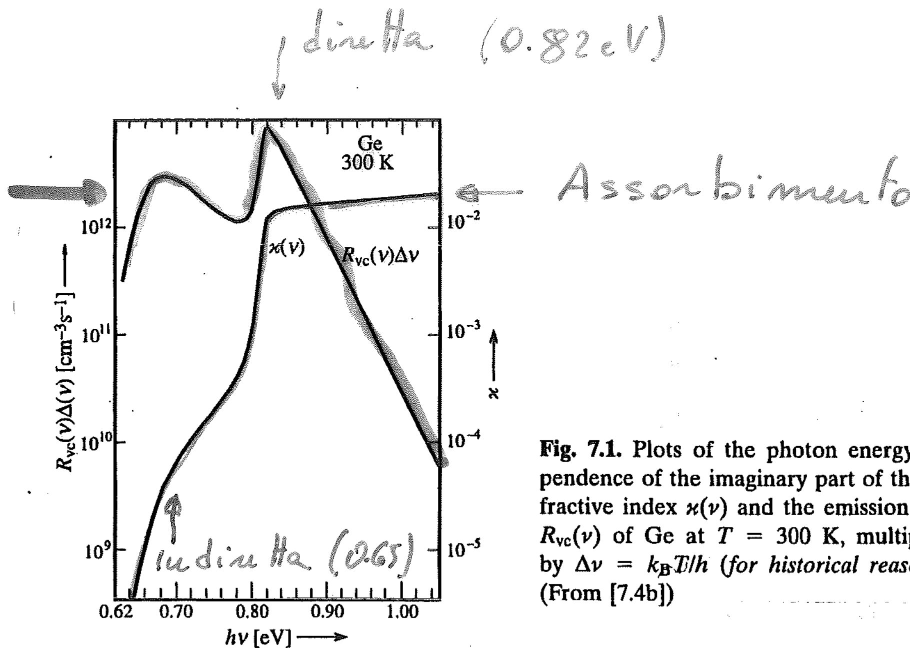


Fig. 7.1. Plots of the photon energy dependence of the imaginary part of the refractive index $\varkappa(\nu)$ and the emission rate $R_{vc}(\nu)$ of Ge at $T = 300$ K, multiplied by $\Delta\nu = k_B T/h$ *(for historical reasons).* (From [7.4b])

- Assorbimento diretto >> Assorbimento indiretto

- In emissione sono ~ uguali perché:

$$R(\nu)d\nu = \frac{8\pi}{c^2}\frac{\nu^2 n^2 \alpha}{e^{h\nu/kT}-1}\,d\nu$$

per $h\nu < h\nu' \rightarrow (e^{h\nu/kT}-1)^{-1} > (e^{h\nu'/kT}-1)^{-1}$

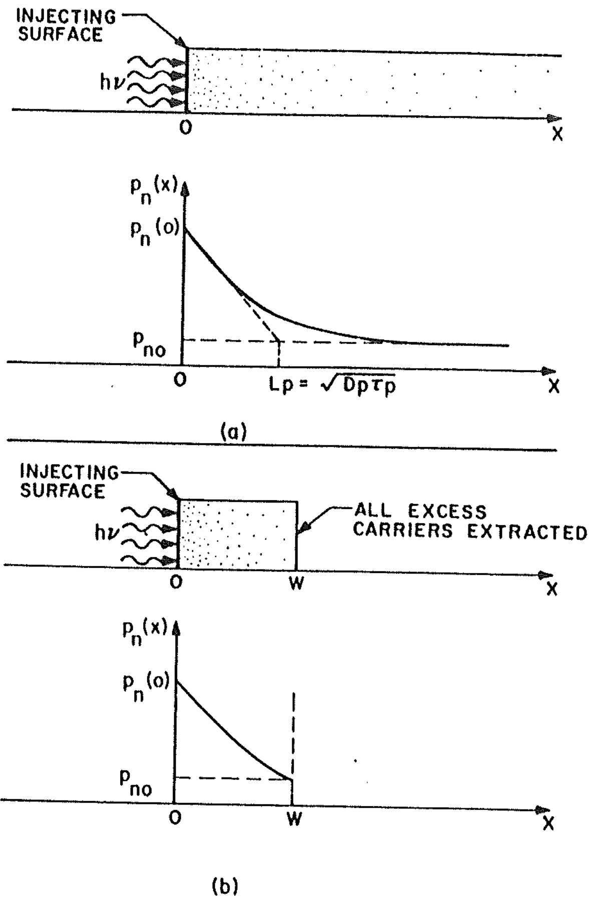


Fig. 34 Steady-state carrier injection from one side. (*a*) Semiinfinite sample. (*b*) Sample with length *W*.

ESEMPIO di MISURA DI τ_p

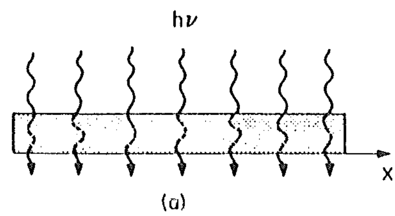
a) n-type

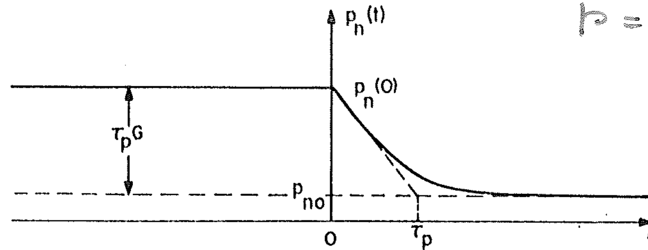
b) eccitazione con luce:

$p = p_0 + g\tau_p$ all'equilibrio

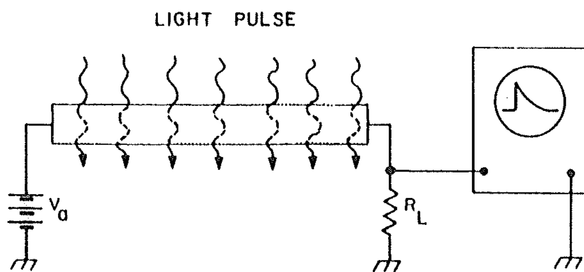
c) Per $t=0$ si spegne "la luce"

$p = p_0 + g\tau_p e^{-t/\tau_p}$





(b)



← impulso di luce

$\tau(\text{photon}) << \tau_p$

(c)

Fig. 33 Decay of photoexcited carriers. (*a*) *n*-type sample under constant illumination. (*b*) Decay of minority carriers (holes) with time. (*c*) Schematic experimental setup to measure minority carrier lifetime. (After Stevenson and Keyes, Ref. 46.)

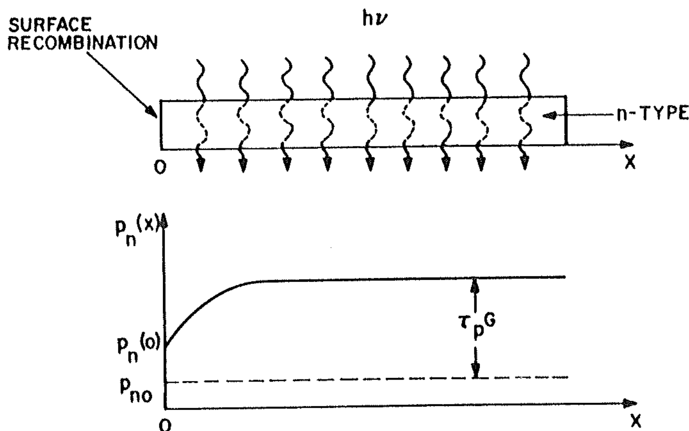


Fig. 36 Surface recombination at $x = 0$. The minority-carrier distribution near the surface is affected by the surface recombination velocity.