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SPRING COLLEGE ON AMORPHOUS SOLIDS
AND THE LIQUID STATE

14 April - 18 June 1982

LUMINESCENCE AND SPIN RESONANCE IN AMORPHOUS SILICON

(Lecture I)

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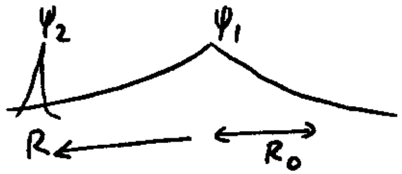
1) Radiative Transition Rate

$$\tau^{-1} = \frac{2\pi}{\hbar}\sum\left|\langle f\,|\,P\,|\,i\rangle\right|^2 \delta(E) \qquad \text{Golden Rule}$$

for typical semiconductor min ~~max~~. $\underline{\underline{\tau \simeq 10^{-8}\ \text{sec}}}$

Distant localized states



$$M = \int \psi_1 P \psi_2 \, d^3r$$

$$M \approx M_0\, \psi_1(R)$$

For a hydrogenic state $\psi \sim \exp(-R/R_0)$

so $$\underline{\underline{\tau = \underset{(10^{-8}\,\text{sec})}{\tau_0} \exp(2R/R_0)}}$$

Detailed Balance

radiative rate $\Longleftrightarrow$ absorption coefficient

$$\tau_{RAD}^{-1} = \frac{8\pi n^2}{\lambda^2}\left(\frac{g_1}{g_2}\right) N^{-1} \int \alpha \, d\nu$$

degeneracy — No. of states — ↑ integrated absorption strength

Electron-Phonon Interactions

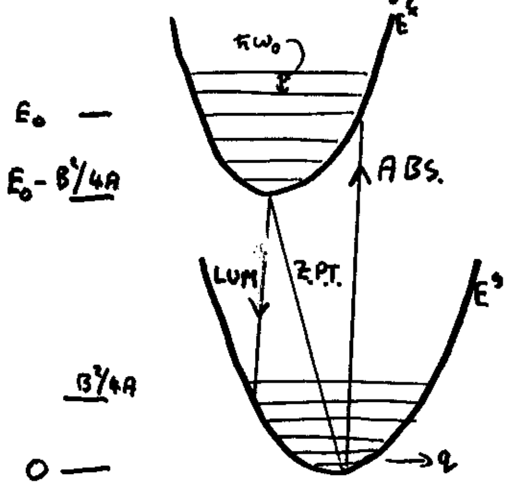
ground state $E^g = Aq^2$ — lattice energy ; q configurational coordinate

$A \Rightarrow$ force constant $\Rightarrow$ 1 phonon mode

min. of E^g at $q = 0$

excited state $E^x = E_0 - Bq + Aq^2$

electronic energy — electron-phonon coupling

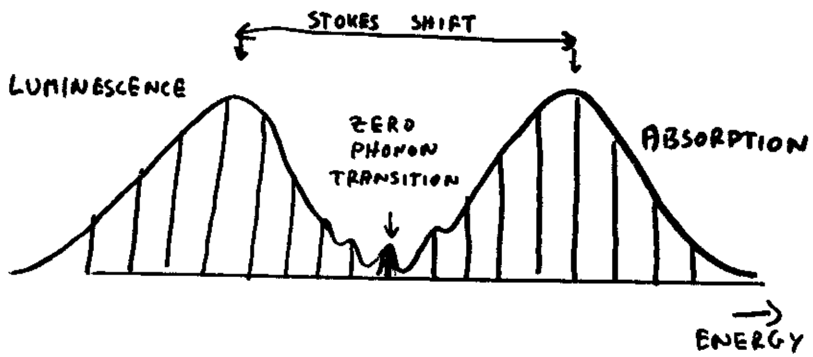


$$\frac{dE^x}{dq} = 0 = -B + 2Aq_{min}$$

$$q_{min} = -B/2A$$

$$E^x_{min} = E_0 - B^2/4A$$

FRANCK-CONDON: Lattice cannot follow electronic transition, so optical transitions are vertical

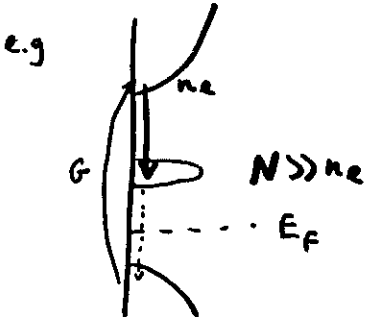


Recombination Kinetics

1) Monomolecular

Generation rate

$$\frac{dn_e}{dt} = G - \beta n_e N$$



decay $\qquad \dfrac{n_e(t)}{n_0} = \exp(-\beta N t)$

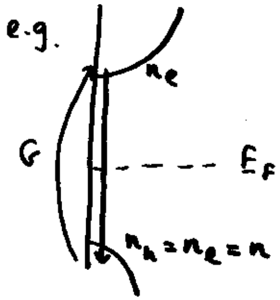
$n_0 = G/\beta N$

Decay Independent of G

2) Bimolecular

$$\frac{dn}{dt} = G - \gamma n^2$$

$$\frac{n(t)}{n_0} = \frac{1}{1+(G\gamma)^{1/2}\, t}$$



Decay varies with G

$\left(\frac{n(t)}{n_0} = \frac{1}{2} \text{ when } t = (G\gamma)^{-1} \ : \text{ so } G\uparrow,\ \tau\downarrow \right)$

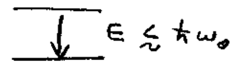
Non-Radiative Transitions
– Phonon Assisted Processes

A) Single Phonon Emission

Def. Pot; no. of phonons

$$\text{Rate} \quad p = \frac{q^3 E_1 |M|^2 n_q}{2\pi \hbar \rho_0 s^2}$$

density; vel. sound

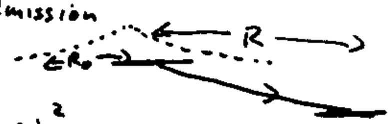


(Mott & Davis)

But $\quad$ p cannot be greater than $\omega_0 \simeq 10^{13}\,\text{sec}^{-1}$

so $\quad$ assume $p = \omega_0$

B) Tunnelling & Single Phonon Emission



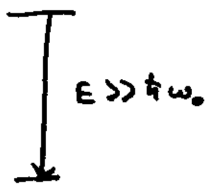
$$\text{Rate} \quad p = \omega_0 \times (\text{overlap})^2$$

$$p = \omega_0 \exp(-2R/R_0)$$

c) Thermal Excitation to Band

$$\text{Rate} \quad p = \omega_0 \exp(-E/kT)$$

D) Multiphonon Transitions

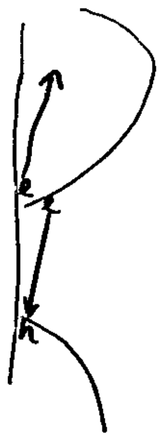


$$\text{Rate} \quad p = 10^{9-13} \exp(-\gamma n) \quad \text{sec}^{-1}$$

$\gamma = 1\text{-}2 \qquad n = E/\hbar\omega_0$

very slow if > 10 phonons $\quad (\Rightarrow 0.5\,\text{eV})$

Non-Radiative Transitions



– Auger

– 3 (or more) particles

– rate depends on many details (primarily momentum conservation, except in a-solids)

– For bound excitons in GaP

$p \sim 10^{10} \times \text{overlap} \ (\text{sec}^{-1})$

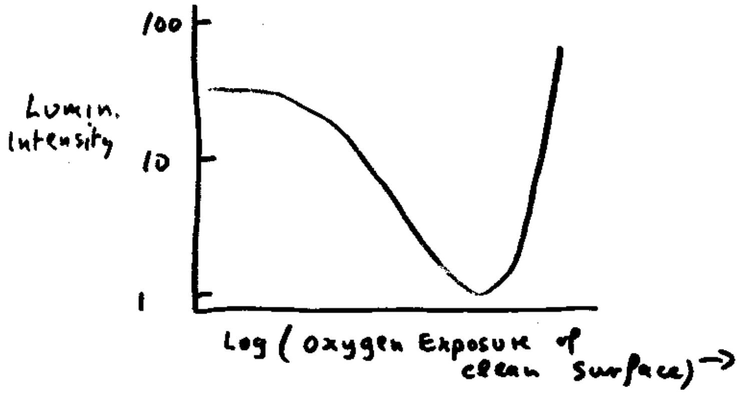
– Surface Recombination

– occurs when diffusion length > absorption depth

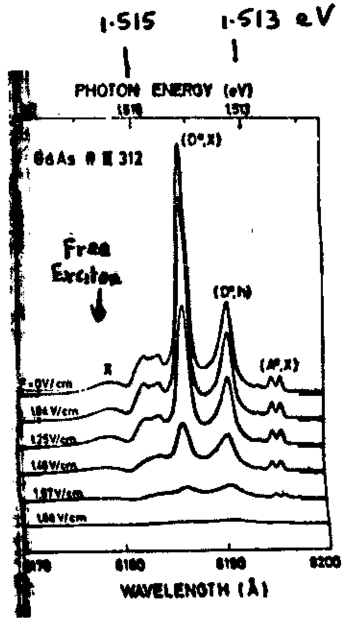
– requires surface states (usually present)

– helped by band bending

E.G. UHV cleaved xtal InP

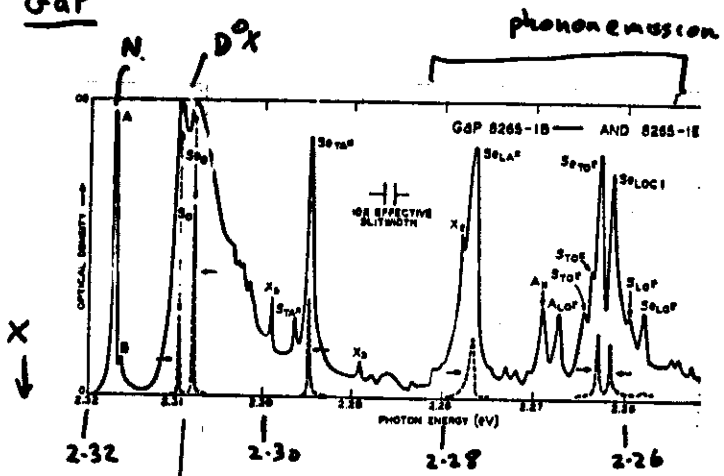


Xtal. GaAs



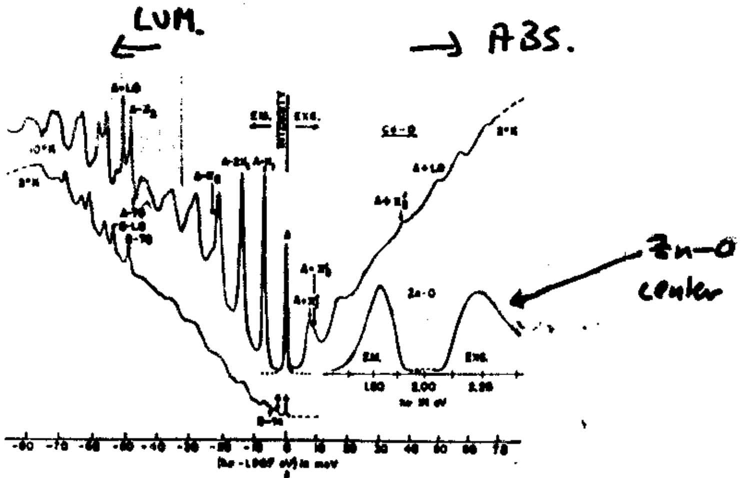
very small phonon coupling

GaP



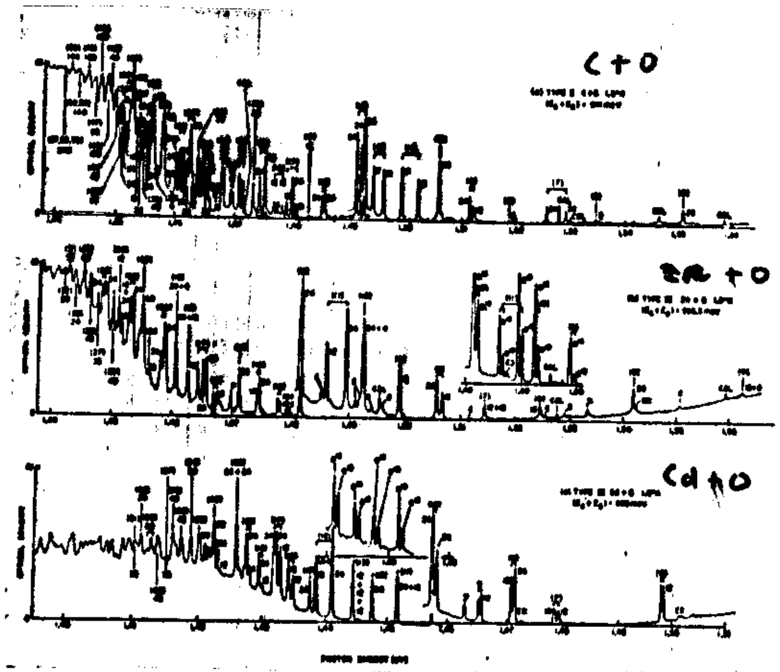
Auger Recombination too

GaP Cd-O center strong phonon coupling



1.907eV
Zero Phonon
Transition

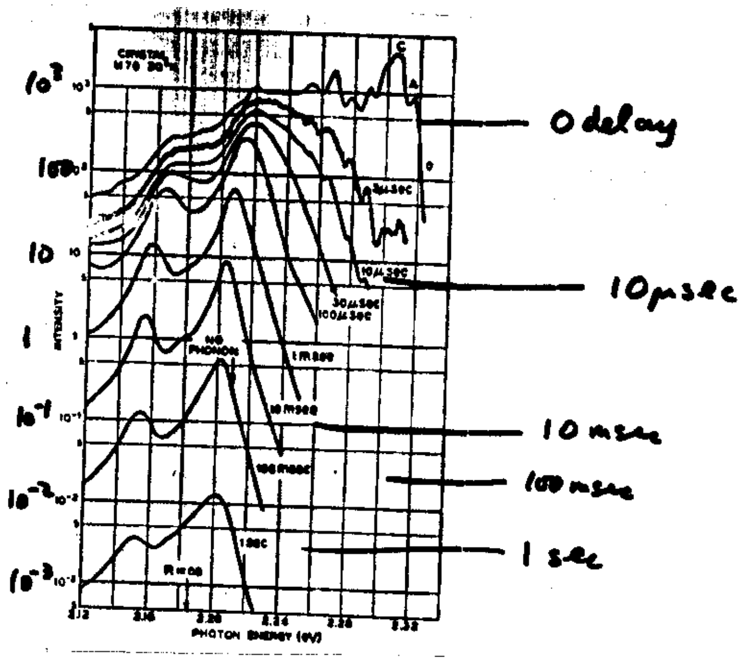
GaP Donor-Acceptor Pairs

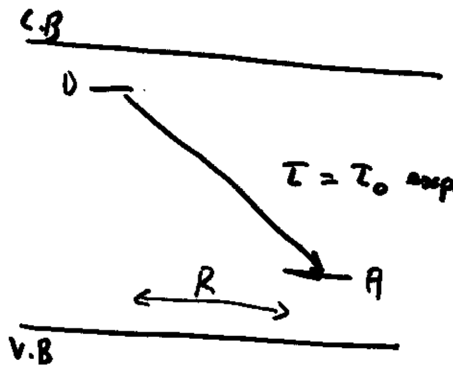


$$E_{LUM} = E_g - E_D - E_A + e^2/\epsilon\epsilon_0 R$$

GaP

Decay of D-A pair spectrum





$\tau = \tau_0 \exp(2R/R_0)$