3.23 Electrical, Optical, and Magnetic Properties of Materials
Fall 2007

3.23 Fall 2007 – Lecture 24

LUMINESCENCE

Last time

- Optical processes, optical materials
- Complex dielectric constant, Kramers-Kronig relations
- Interband absorption, direct and indirect transitions
- Fermi's golden rule, perturbing Hamiltonian

$M_{if} = \langle f | H' | i \rangle$

Study

- Fox, Optical Properties of Solids: Chapter 5

Direct and indirect transitions

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Please see: Fig. 3.2 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Transition rates: perturbing Hamiltonian

$$H'(\vec{r}) = -\vec{d} \cdot \vec{E}(\vec{r}) = e\vec{r}\,\vec{E}(\vec{r})$$

$$= e E_0 \vec{r}\, e^{\pm i \vec{k}\vec{r}}$$

$$\delta(E_f - E_i - \hbar\omega)$$

$$M_{if} = e\langle f |\, e\vec{r} \cdot \vec{E}(\vec{r}) \,| i \rangle$$

Transition rate for direct absorption

$$\psi_i^{nk} = \frac{1}{\sqrt{V}} u_i(\vec{r}) e^{i\vec{k}_i \cdot \vec{r}} \qquad \psi_f(\vec{r}) = \dots$$

$$M = \frac{e}{V} \int u_f^*(r) e^{-i\vec{k}_f \cdot r} \left(\vec{r} \cdot \vec{E}_0 e^{\pm i \vec{k} \cdot r} \right) \cdot u_i(r) e^{i\vec{k}_i \cdot \vec{r}}$$

$$\Downarrow \qquad\qquad \Downarrow$$

$$\hbar k_f - \hbar k_i = \pm \hbar \vec{k} \qquad \int u_f^*(r)\, \vec{r}\, u_i(\vec{r})$$

Transition rate for direct absorption

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p-char

Please see: Fig. 3.5 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Please also see any diagram of GaAs energy bands, such as http://ecee.colorado.edu/~bart/book/book/chapter2/gif/fig2_3_6.gif.

Dipole-allowed selection rules

These are for atoms…

- Parity of initial and final state are opposite
- Δm=-1, 0 or 1
- Δl=-1 or 1
- Δm_s = 0

E.g. phosphorence involves dipole-forbidden transitions that are mediated by higher order terms (magnetic dipole, electronic quadrupole)

Joint Density of States

$$E_c(\vec{k}) = E_g + \frac{\hbar^2 k^2}{2 m_e^2}$$

$$E_{hh}(\vec{k}) = -\frac{\hbar^2 k^2}{2 m_{hh}^2}$$

$$g(\hbar\omega) \propto (\hbar\omega - E_g)^{1/2}$$

Frequency dependence of band edge absorption

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Please see: Fig. 3.6 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Indirect gap semiconductors

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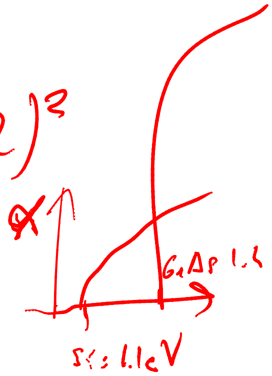
$(\Omega, \vec{q})$

$$E_f = E_i + \hbar\omega \pm \hbar\Omega$$

$$\hbar\vec{k}_f = \hbar\vec{k}_i \pm \hbar\vec{q}$$

$$g(\hbar\omega) \propto (\hbar\omega - E_g \mp \hbar\Omega)^2$$



Indirect gap semiconductors

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Please see: Fig. 3.10 in Fox, Mark. *Optical Properties of Solids*. Oxford, England: Oxford University Press, 2001.

Absorption above the band edge

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Please see: Fig. 3.11 and 3.12 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Excitons

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Please see: Fig. 4.1 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

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Excitons

$$E_n = -\frac{1}{n^2} Ry \qquad \left(\frac{1}{\varepsilon^2}\right)$$

$$r_n = n^2 \,(\text{Bohr}) \qquad (\varepsilon)$$

Excitons absorption

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Please see: Fig. 4.4 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Light emission in solids

$$I(\hbar\nu) \propto |M|^2 g(\hbar\nu).$$

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Please see: Fig. 5.1 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Interband luminescence

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Please see: Fig. 5.2 and 5.3 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Indirect band gap materials

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Please see: Fig. 5.4 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Photoluminescence: excitation, relaxation

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Please see Fig. 5.5 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Low-carrier density case

$$\frac{1}{1+e}$$

$$f(E) \propto \exp^{-\frac{E}{kT}}$$

$$I(h\nu) \propto (h\nu - E_g)^{1/2} \cdot$$

$$\cdot \exp\left(-\frac{h\nu - E_g}{kT}\right)$$

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Please see: Fig. 5.6 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Degeneracy

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Please see: Fig. 5.7 and 5.8 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.