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

3.23 Fall 2007 – Lecture 25

LAST LECTURE !

Exam

- Monday 17, 9am-12noon
- 2 questions on electronics, 1 on optics, 1 on magnetic

PEN(S), CALCULATOR (THAT WORKS)
1 SHEET

- BAND STRUCTURE (Si, Ge, GaAs)

Syllabus

- *From particles to waves: the Schrödinger equation*
- *The mechanics of quantum mechanics: operators, expectation values*
- *Measurements and probabilities. The harmonic oscillator.*
- *The hydrogen atom and the periodic table*
- *Periodicity and phonons*
- *Electrons in a lattice: Bloch's theorem*
- *The nearly-free electron model*
- *The tight-binding model. Band structures*
- *Metals, semiconductors and insulators*
- *Intrinsic and extrinsic semiconductors*
- *Transport of heat and electricity*
- *The p-n diode*

Syllabus

- *Electromagnetism in dielectric media*
- *Classic propagation of waves*
- *Optical materials and refractive index*
- *Interband absorption*
- *Excitons and luminescence*
- *Fundamental of ferromagnetic materials*
- *Hysteresis loop and driving energies*
- *Hard materials and permanent magnets*
- *Soft materials: thin films and nanoparticles. Spintronics and GMR*
- *Spin valves, spin switches, and spin tunneling*

Last time

- Fermi's golden rule, joint density of states
- Perturbing Hamiltonian, selection rules
- Frequency-dependence of band adsorption in direct or indirect band gap SC. Absorption above the band edge
- Excitons and exciton absorption
- Luminescence: low-carrier density; degeneracy.

Study

- Fox, Optical Properties of Solids, Chap. 7.5, 9.4, 10.4

Photoluminescence spectroscopy

Image removed due to copyright restrictions.

Please see: Fig. 5.9 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

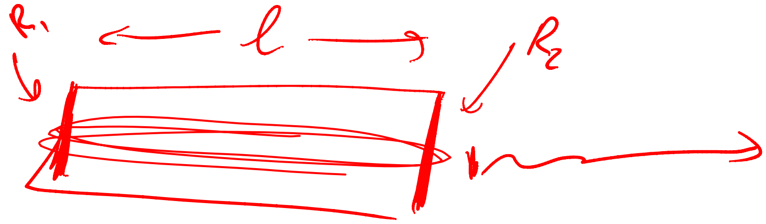
Electroluminescence: LED

Image removed due to copyright restrictions.

Please see: Fig. 5.12 and 5.13 in Fox, Mark. *Optical Properties of Solids*. Oxford, England: Oxford University Press, 2001.

3.23 Electronic, Optical and Magnetic Properties of Materials - Nicola Marzari (MIT, Fall 2007)

Diode laser: resonant longitudinal modes



$\lambda' = \frac{\lambda}{n}$ $\quad l = \frac{\lambda'}{2}$ INTEGER $\quad \nu = \text{INT} \cdot \frac{c}{2nl}$

$dI = \gamma_\nu \, dx \, I(x) \quad I(x) = I_0 e^{\gamma_\nu x}$

↑ INCREMENTAL GAIN

Injection current, threshold gain, slope efficiency

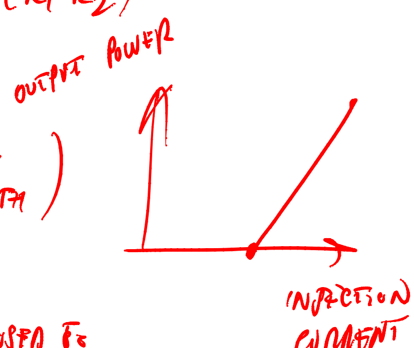
$R_1 R_2 \, e^{2\gamma_\nu \cdot l} \, e^{-2\alpha_\beta \cdot l} = 1$

$\gamma_{TH} = \alpha_\beta - \frac{1}{2l} \ln (R_1 R_2)$

↑ THRESHOLD GAIN

$P_{OUT} = \eta \frac{h\nu}{e} (I_{IN} - I_{TH})$

↑ FRACTION OF ELECTRON-HOLES EXCITATION THAT ARE USED TO GENERATE COHERENT PHOTONS



Electroluminescence: diode laser

Image removed due to copyright restrictions.

Please see: Fig. 5.16 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Solid state lasers

Image removed due to copyright restrictions.

Please see: Fig. 9.12 in Fox, Mark. *Optical Properties of Solids*. Oxford, England: Oxford University Press, 2001.

Plasmons

$N \rightarrow$ # electrons x unit volume

$\mathcal{E} = \frac{Neu}{\varepsilon_0}$

Image removed due to copyright restrictions.

Please see: Fig. 7.12 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

$$Nm \frac{d^2u}{dt^2} = -Ne\mathcal{E} = -\left(\frac{N^2e^2}{\varepsilon_0}\right)u$$

$$\omega_p = \left(\frac{Ne^2}{\varepsilon_0 m}\right)^{1/2}$$

Plasmonics

Images removed due to copyright restrictions. Please see: The Cover, *Nature Materials* 2 (April 2003). Please see: http://www.webexhibits.org/causesofcolor/images/content/plate-VIII-01.jpg.

Polarons

Image removed due to copyright restrictions.

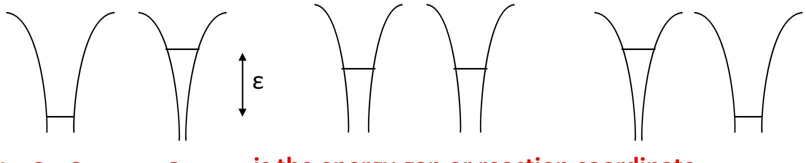
Please see: Fig. 10.8 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.

Electron Transfer

- **Electron transfer mediated by polar solvent fluctuations.**
- **Tunneling can occur when reactant and product are degenerate**

Image removed due to copyright restrictions.

Please see Fig. 2 in Sit, P. H.-L., et al. "Realistic, Quantitative Descriptions of Electron-tranfer Reactions: Diabatic Free-energy Surfaces from First-principles Molecular Dynamics." arXiv:cond-mat/0606310v1 [cond-mat.mtrl-sci], 2006.



- **$\varepsilon = \varepsilon_{product} - \varepsilon_{reactant}$ is the energy gap or reaction coordinate**

R. A. Marcus, J. Chem. Phys. 43, 679 (1965)
A. Warshel, J. Chem. Phys. 86, 2218 (1982)
D. Chandler, Classical and Quantum Dynamics in Condensed Phase Simulations, pp. 25-49 (1998)

Ferrous-ferric self-exchange

Image removed due to copyright restrictions.

Please see: Fig. 1 in Sit, P. H.-L., et al. "Realistic, Quantitative Descriptions of Electron-tranfer Reactions: Diabatic Free-energy Surfaces from First-principles Molecular Dynamics." arXiv:cond-mat/0606310v1 [cond-mat.mtrl-sci], 2006.

- ΔG is the free-energy barrier of the reaction
- λ (reorganization energy) is the difference in free energy between product and reactant in the optimum atomic configuration for the reactant

The colour of gems

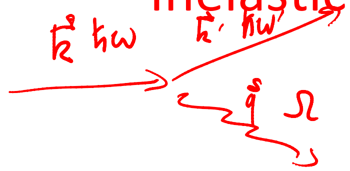
Fe^{2+}

Ti^{4+}

Image from Wikimedia Commons, http://commons.wikimedia.org

3.23 Electronic, Optical and Magnetic Properties of Materials - Nicola Marzari (MIT, Fall 2007)

Inelastic light scattering



Images removed due to copyright restrictions.

Please see: Fig. 10.10 and 10.11 in Fox, Mark. *Optical Properties of Solids.* Oxford, England: Oxford University Press, 2001.