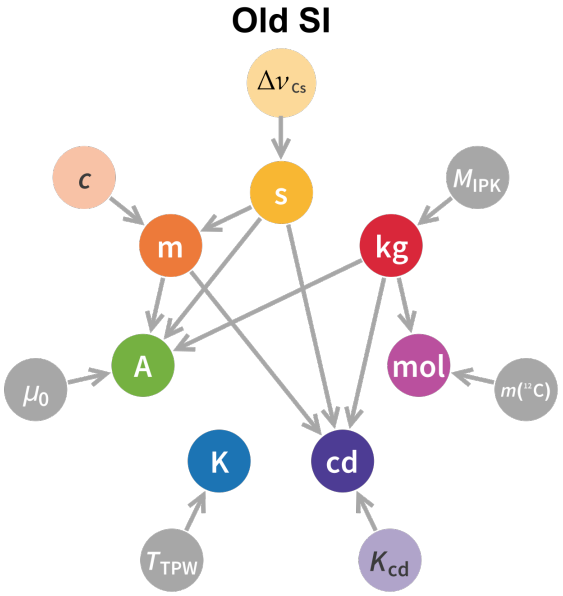
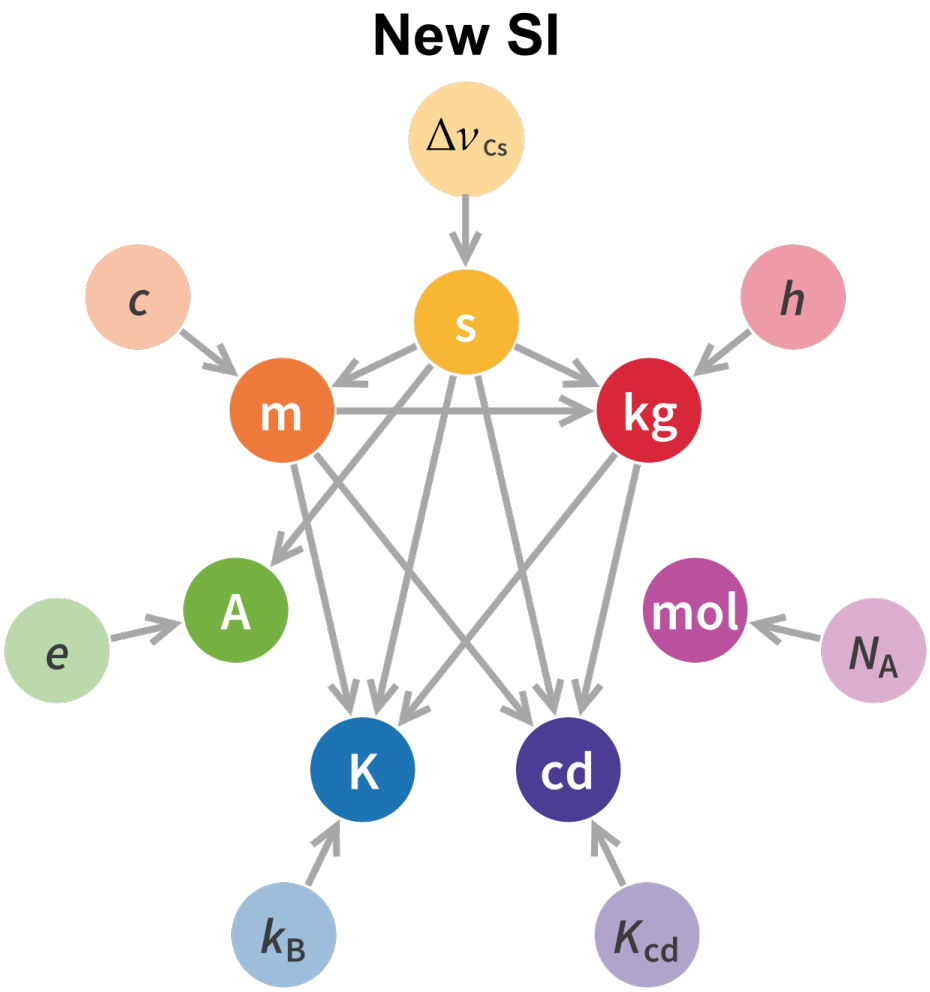
PH575 Spring 2019

World Metrology Day!
20 May 2019

http://www.worldmetrologyday.org/

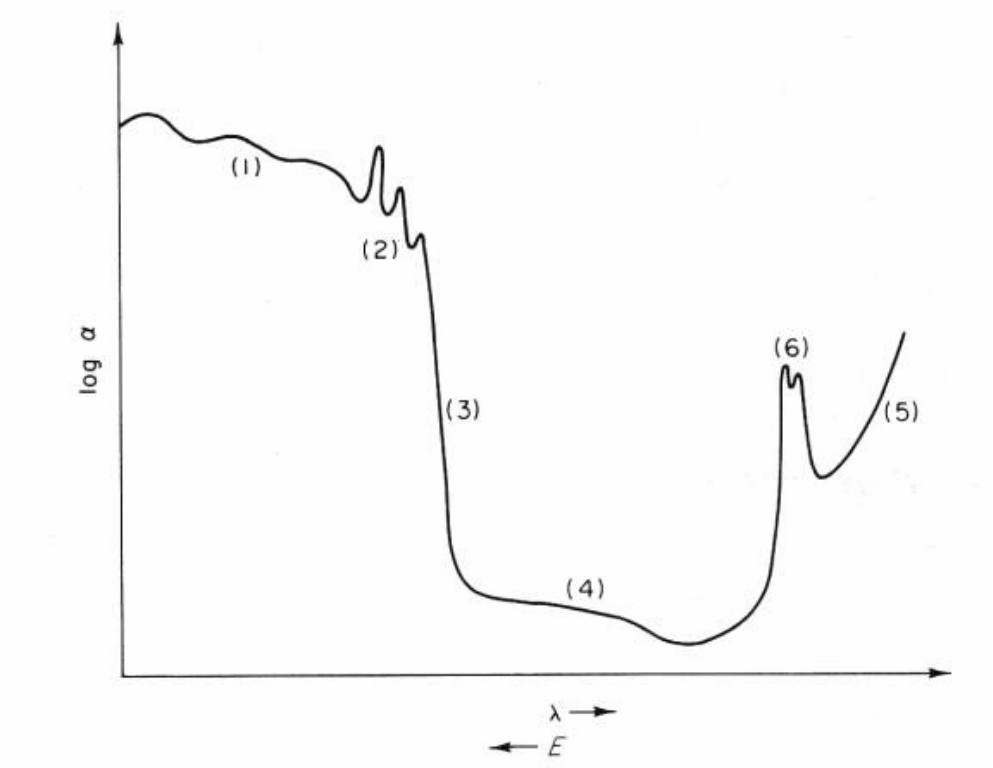
- SI units underlie global science, trade
- Connected to fundamental constants





PH575 Spring 2019

Lecture #21
Semiconductors: optical properties: Kittel Ch. 8 pp. 187-191; Ch 15 pp. 435-444



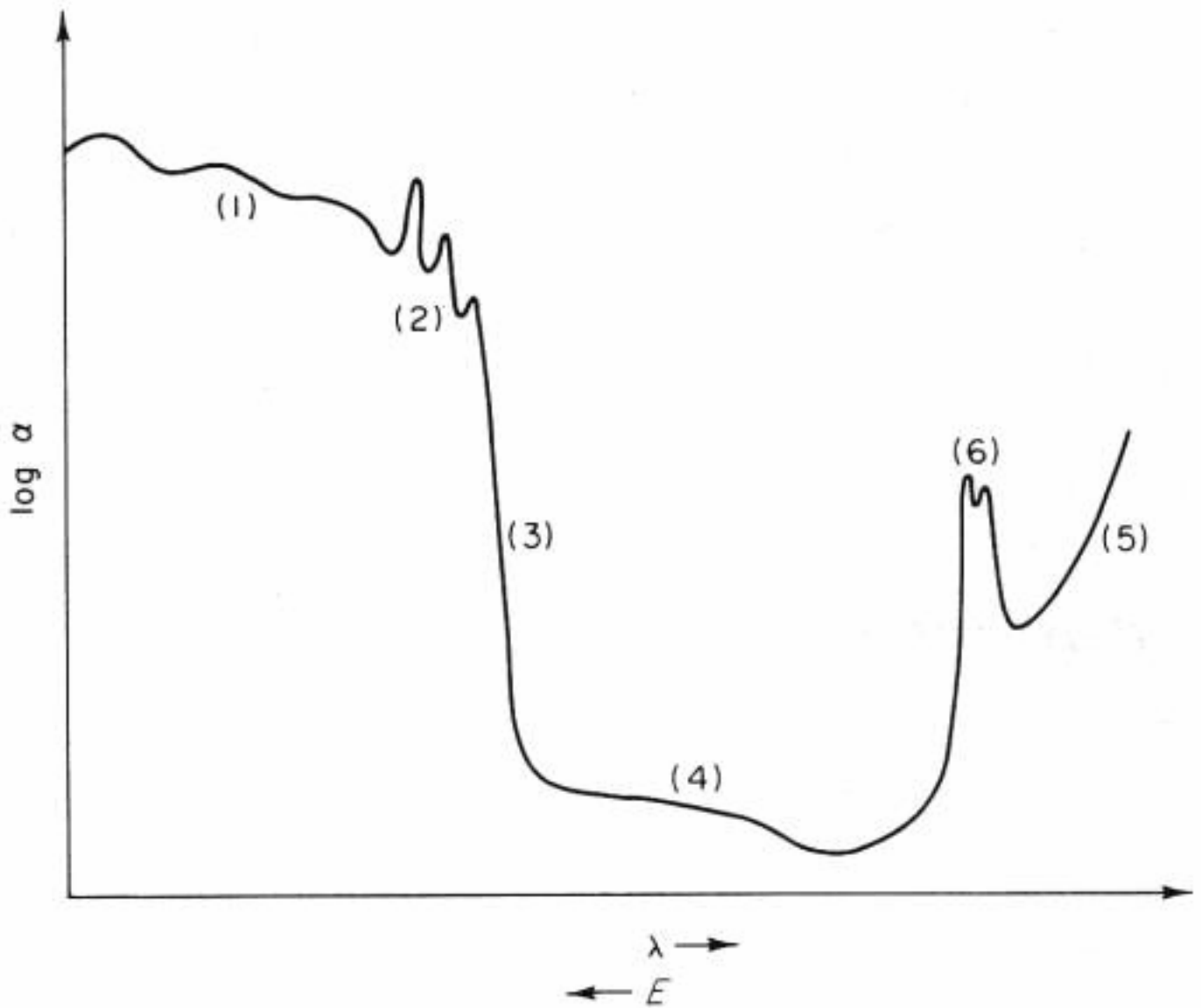
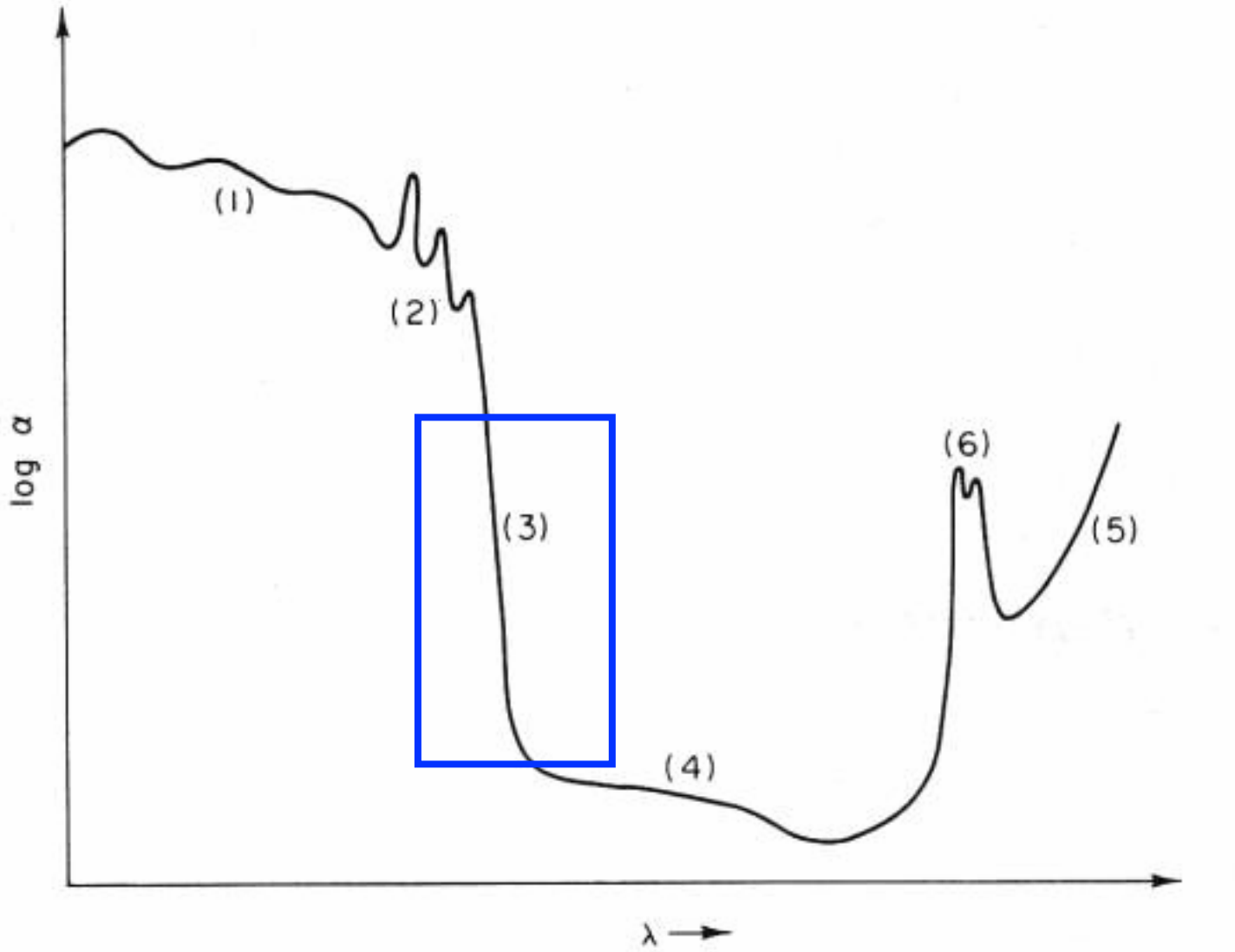


Figure VI-1-1: Different types of optical absorption phenomena; (1) transitions of high-lying bands, (2) excitons, (3) fundamental absorption (VB-to-CB transition and Urbach-tail), (4) impurity absorption, (5) free-carrier absorption and (6) Reststrahlen absorption.

http://kottan-labs.bgsu.edu/teaching/workshop2001/chapter6.htm



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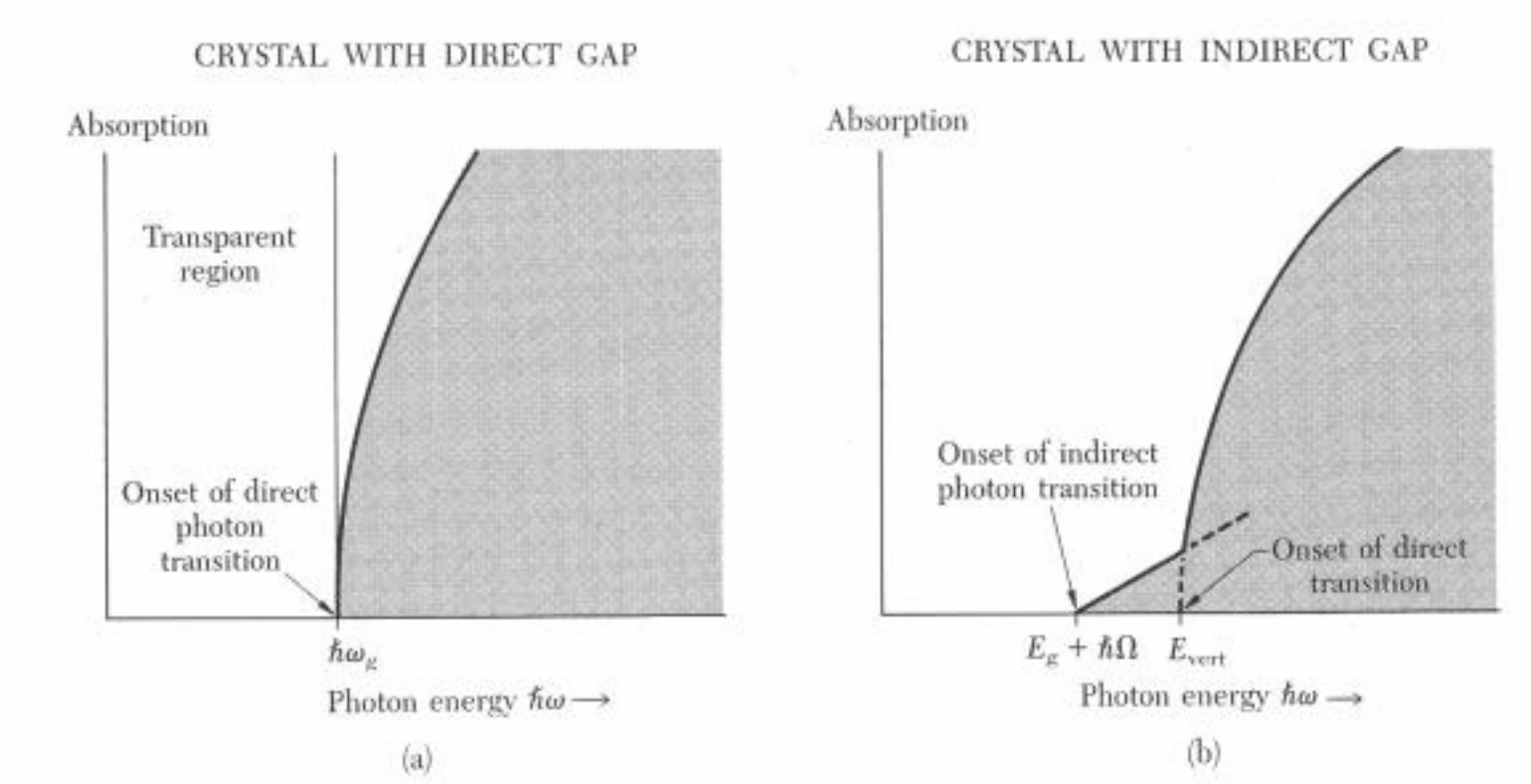


Figure VI-3-1: The absorption edge of (a) a direct semiconductor and (b) indirect semiconductor. The energy E_{vert} marks the threshold for the vertical transition.

http://kottan-labs.bgsu.edu/teaching/workshop2001/chapter6.htm

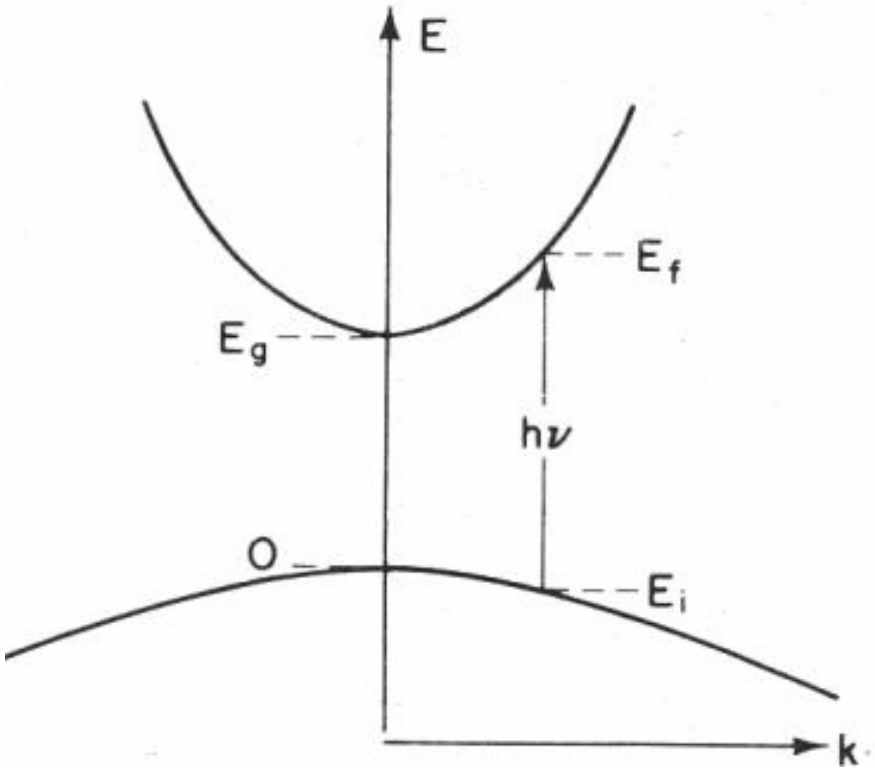


Figure VI-2-1: Direct absorption in a semiconductor.

Parabolic bands:

$$\hbar\omega_{photon} = E_g + \frac{\hbar^2 k^2}{2m_e^*} + \frac{\hbar^2 k^2}{2m_h^*}$$

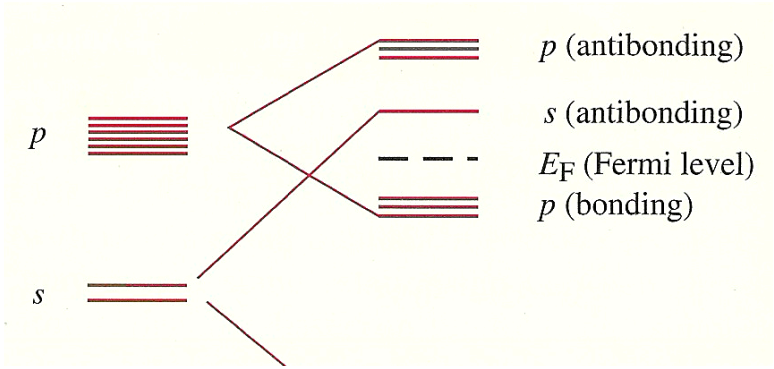
$$\hbar\omega_{photon} = E_g + \frac{\hbar^2 k^2}{2\mu}; \quad \frac{1}{\mu} = \frac{1}{m_e^*} + \frac{1}{m_h^*}$$

Joint density of states:

$$D(E) = 0; \quad \hbar\omega < E_g$$

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2\mu}{\hbar^2}\right)^{3/2}\left(\hbar\omega - E_g\right)^{1/2}; \quad \hbar\omega > E_g$$

Matrix element:



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Calculating band gap from absorption and transmission spectra:

In very clean samples at very low temperatures, onset of absorption is sharp and BG identification is trivial, but under other conditions, extraction is harder.

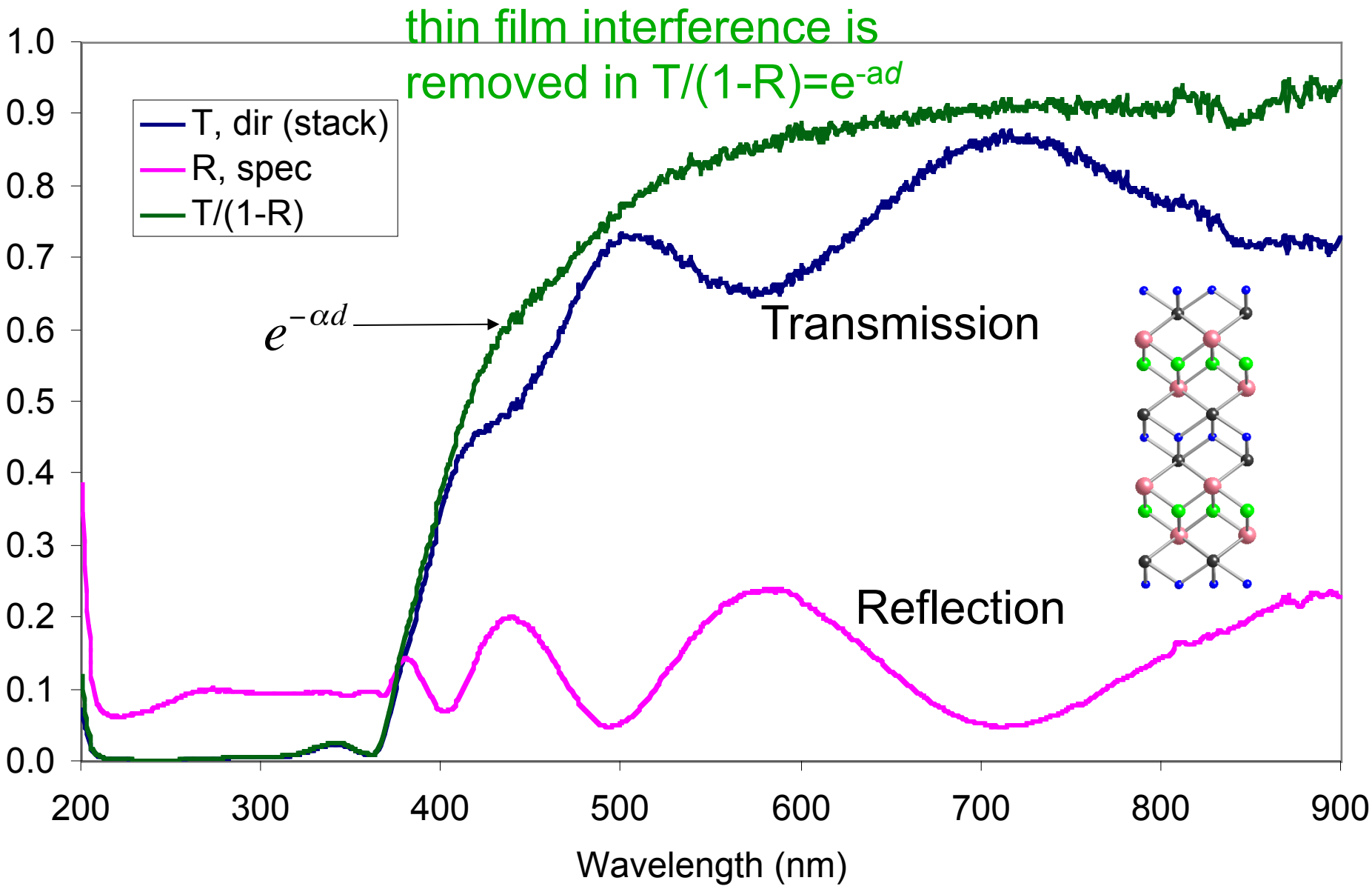
It can be shown (*e.g.* Cardona and Yu) that the imaginary part of the dielectric constant (proportional to absorption coefficient α, remember) for a DIRECT GAP semiconductor is

$$\varepsilon''(\omega) = A\left(\frac{E_g}{E}\right)^2 \left(\frac{E}{E_g} - 1\right)^{1/2} \propto \alpha$$

Comes from matrix element

Comes from density of states

Optical Spectrum of BaCuSF film



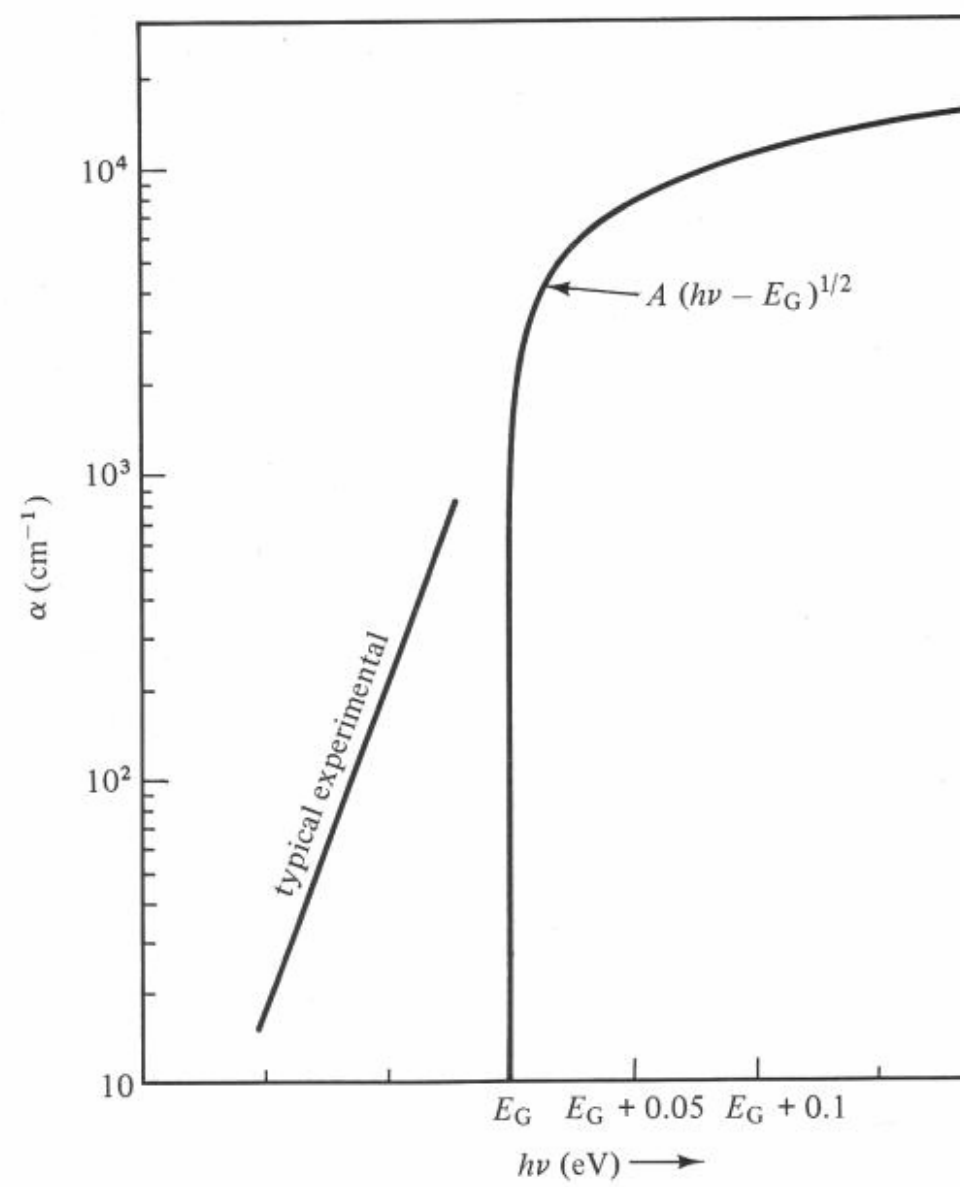
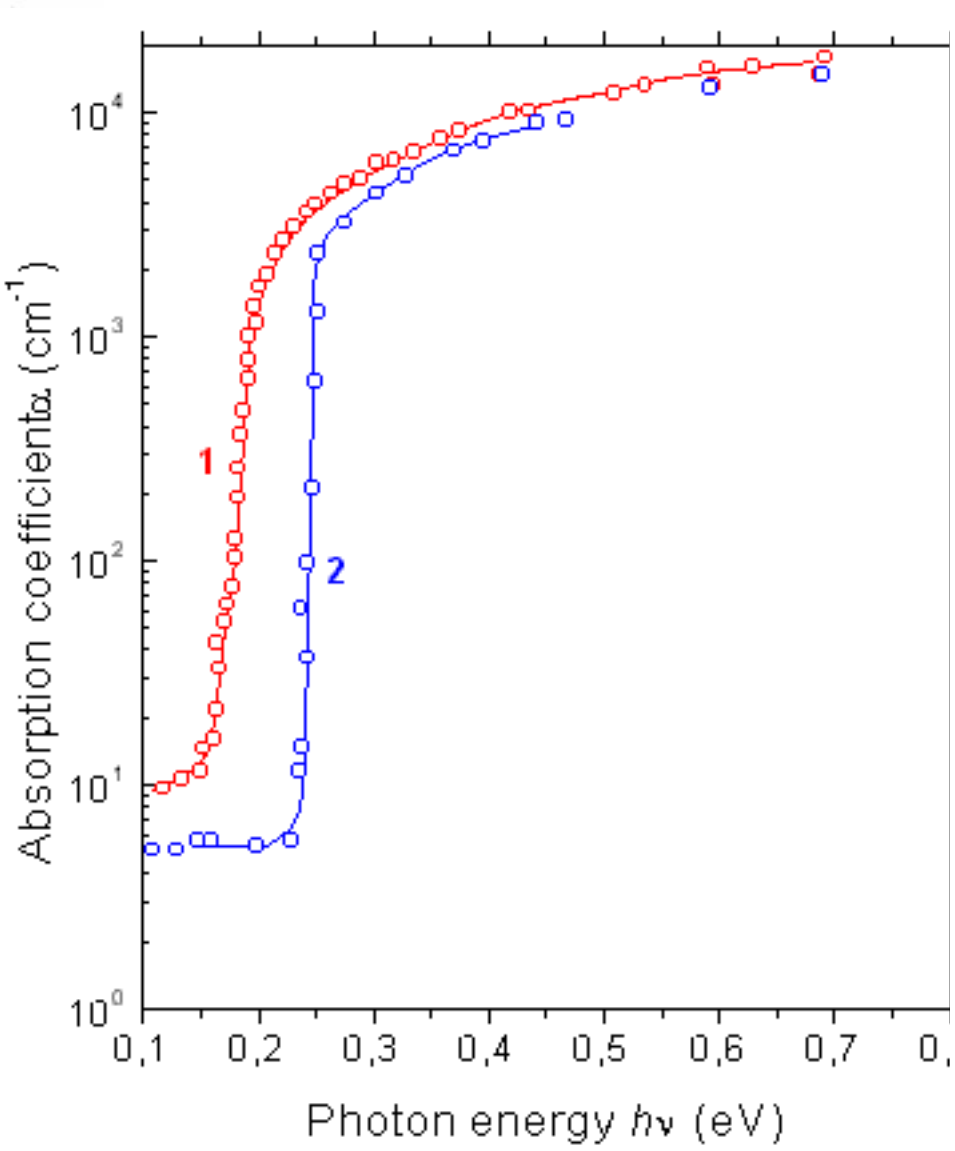


Figure VI-2-8: Qualitative plot of an absorption edge.



Absorption edge of pure InSb. T (K):
1. 298;
2. 5K;
(Johnson [1967]), *(Gobeli and Fan [1956])*

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Calculating band gap from absorption and transmission spectra:

Close to the gap energy, E-E_g is small, and $E \approx E_g$ so

$$\alpha^2 \propto \left(E - E_g \right)$$

A plot of the square of the absorption coefficient against the photon energy is a straight line, and intersects the energy axis at $E = E_g$

Some real data follows, and illustrates that the real world is not like the text book at all!

Calculating band gap from absorption and transmission spectra:

It can be shown (e.g. Cardona and Yu) that the imaginary part of the dielectric constant (proportional to absorption coefficient a, remember) for a INDIRECT GAP semiconductor is

$$\varepsilon''(\omega) \propto \alpha \propto \left(E \pm E_{phonon} - E_g\right)^2$$

$$\alpha^{1/2} \propto \left(E + E_{ph} - E_g\right)$$

A plot of the square root of the absorption coefficient against the photon energy is a straight line, and intersects the energy axis at $E = E_g - E_{ph}$

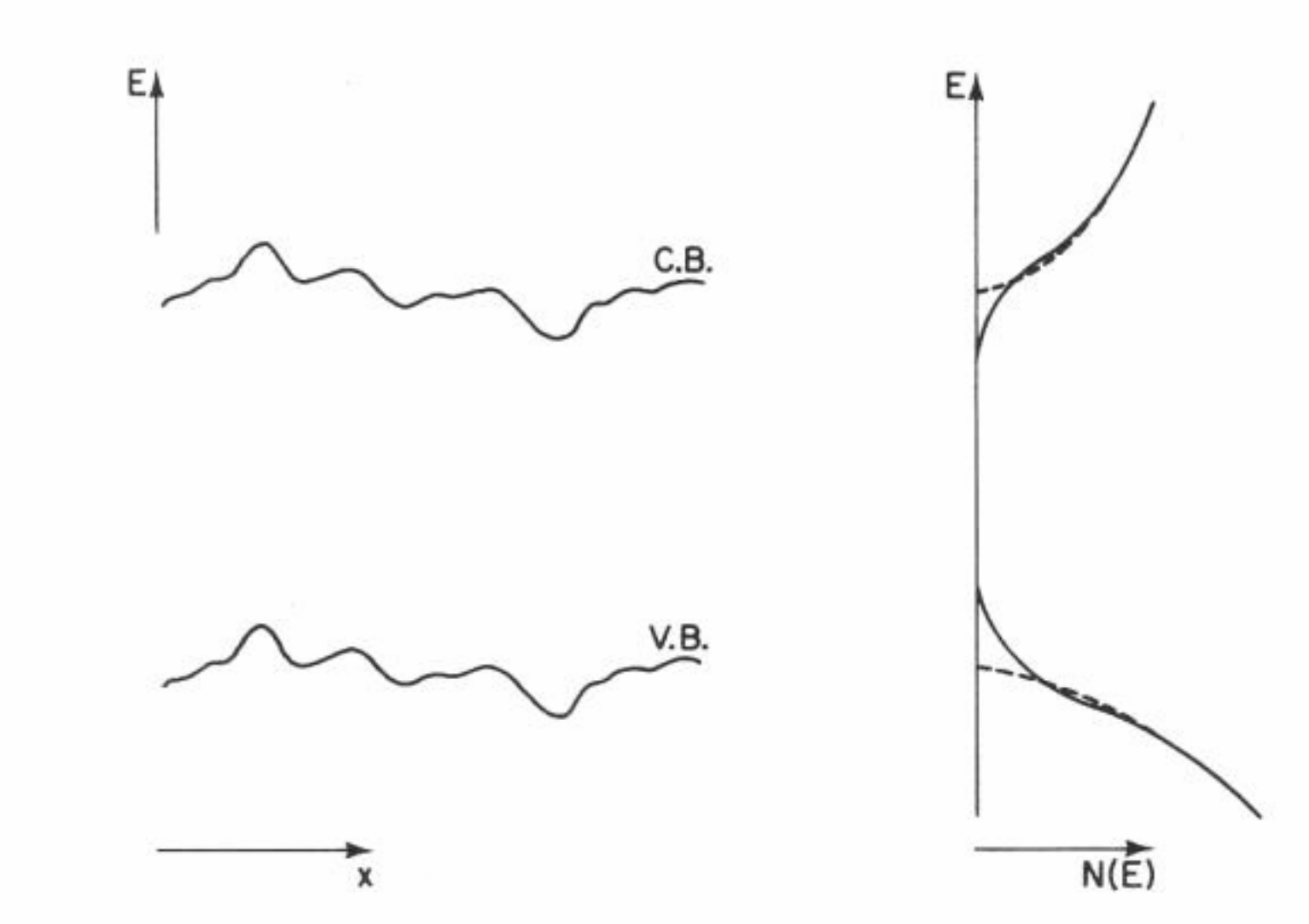

Figure VI-2-6: The left diagram shows the perturbation of the band edges by Coulomb interaction with inhomogeneously distributed impurities. This leads to the formation of tails of states shown on the right side. The dashed lines show the distribution of states in the unperturbed case.

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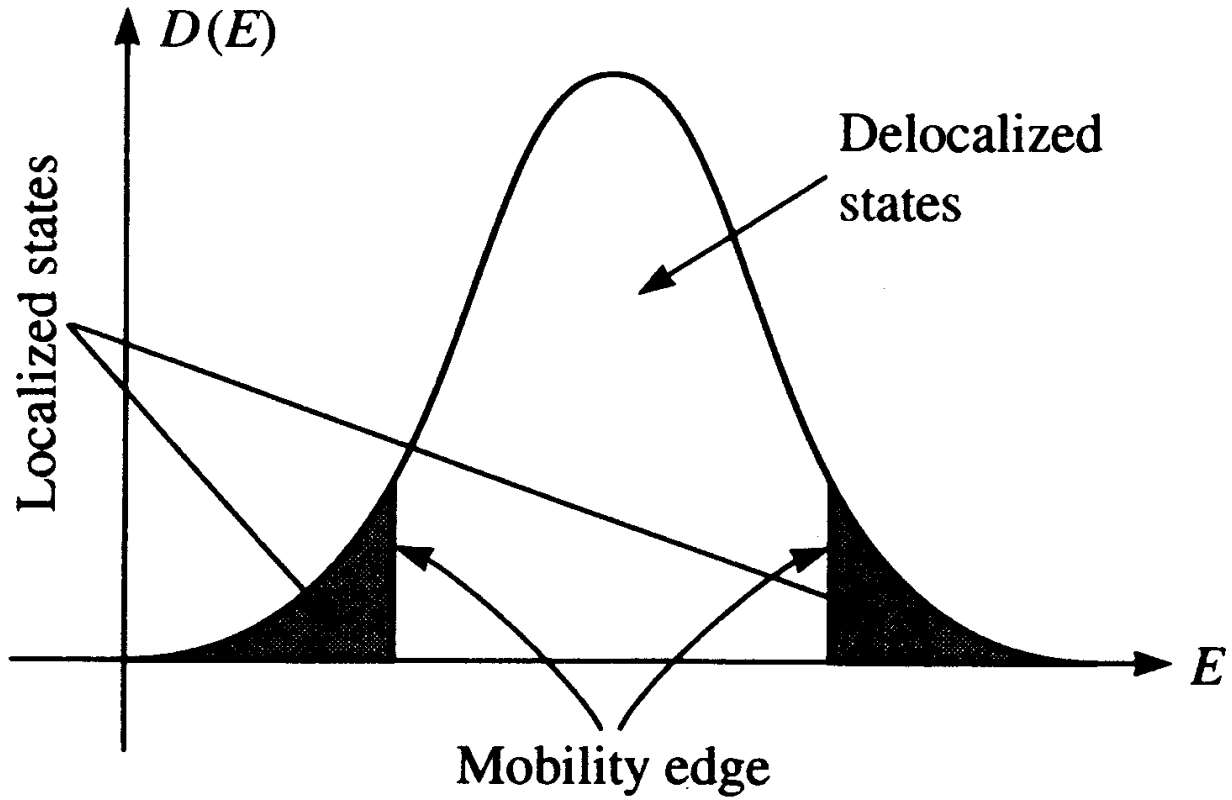
Mobility Edges/ Minimum Metallic Conductivity



Effect of Disorder: "Urbach Tails"

States near band edge $\Rightarrow$ extra absorption:

$$\alpha \propto \exp\left[-\frac{\left(E_g - E\right)}{k_B T}\right]$$

Exponential, not power law!

Band gap absorption is important for ….

Optical detection devices. Light with energy greater than the band gap energy excites electrons and holes in a semiconductor. By application of a voltage, the charged electrons and holes can be collected and measured. Light sensor! (This is the basis of a solar cell; not only is light sensed - it is used to generate electricity.)

Optical emission: The reverse process occurs too. Excited electrons and holes recombine, emitting light, primarily at the energy corresponding to the gap. Light emitter! Non radiative recombination processes (phonon emission for example), can hinder the process.

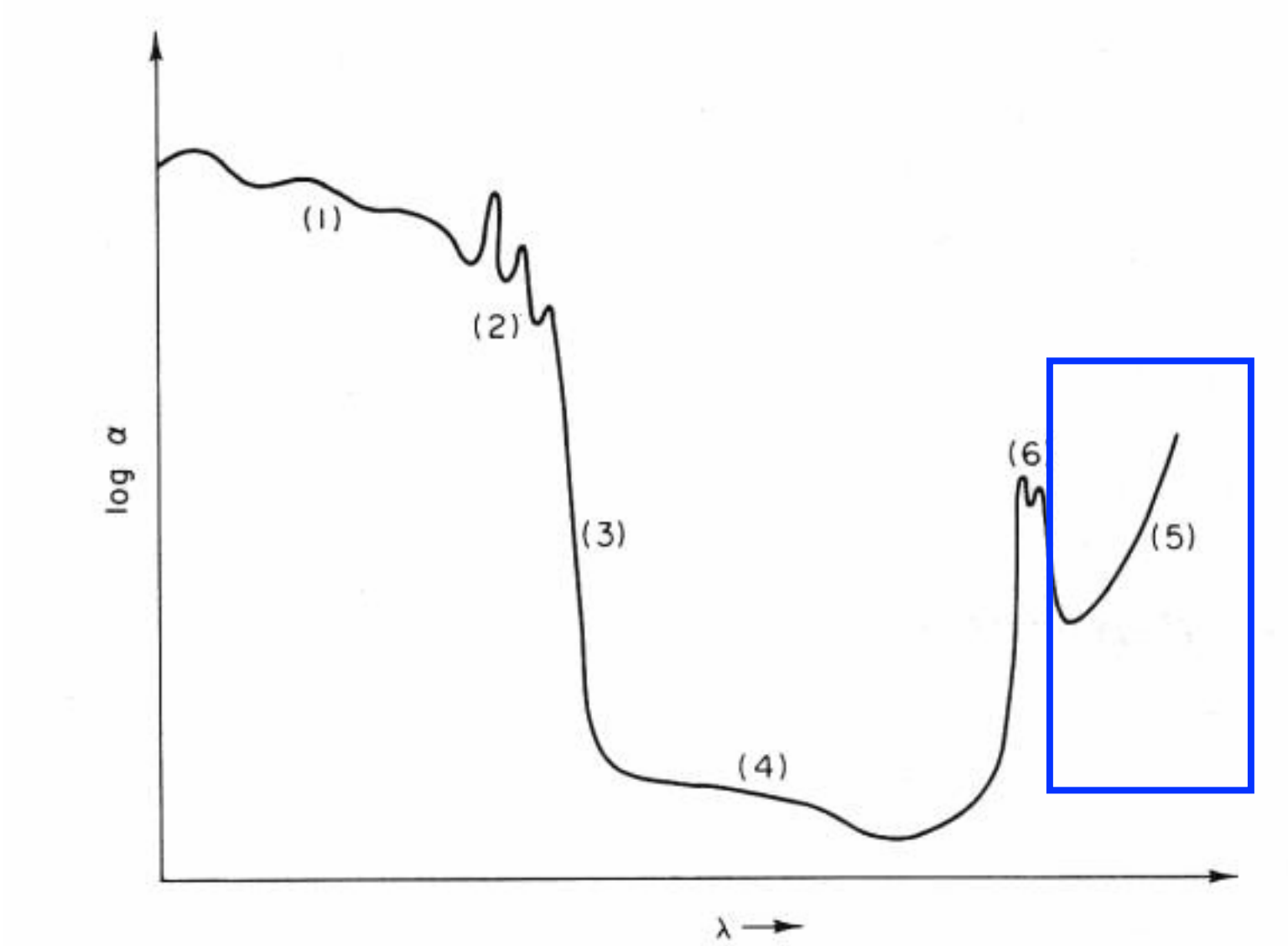
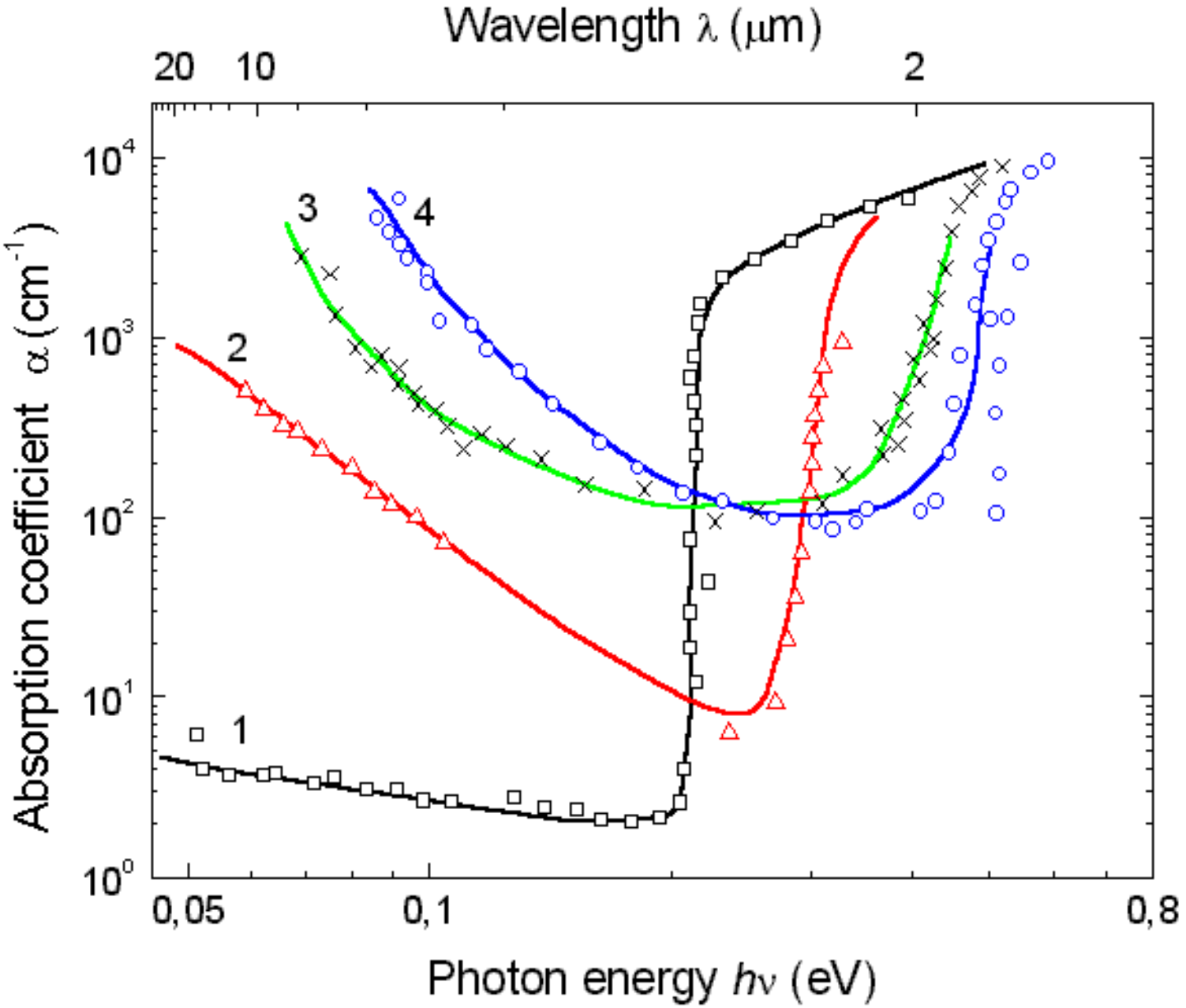
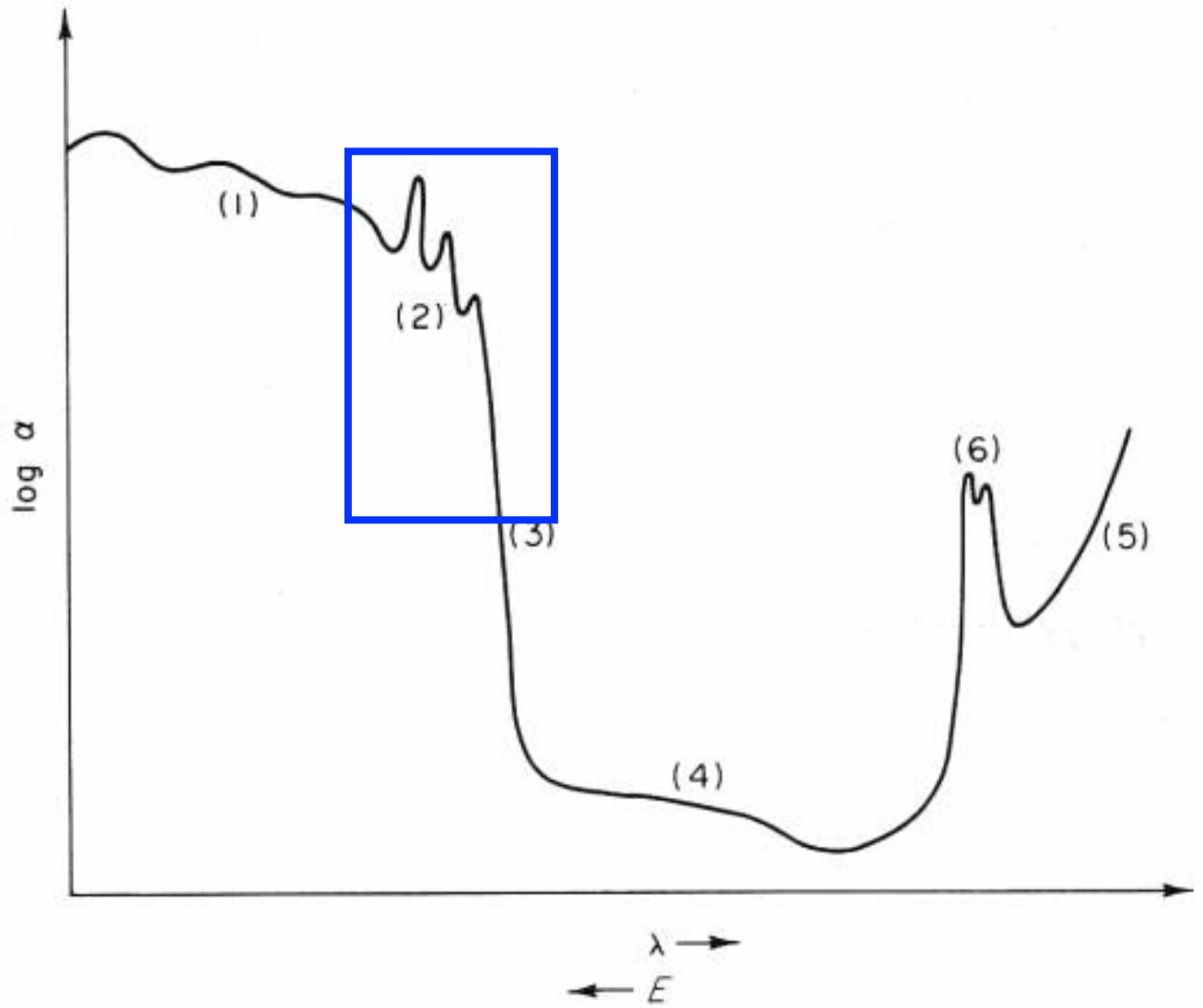


Figure VI-1-1: Different types of optical absorption phenomena; (1) transitions of high-lying bands, (2) excitons, (3) fundamental absorption (VB-to-CB transition and Urbach-tail), (4) impurity absorption, (5) free-carrier absorption and (6) Reststrahlen absorption.



Absorption coeff. *vs*. photon energy at different doping levels, *n*-InSb, T = 130K:
1. $6.6 \cdot 10^{13}$ cm^{-3}; **2**. $7.5 \cdot 10^{17}$ cm^{-3}; **3**. $2.6 \cdot 10^{18}$ cm^{-3}; **4**. $6 \cdot 10^{18}$ cm^{-3}; *(Ukhanov [1977])*.



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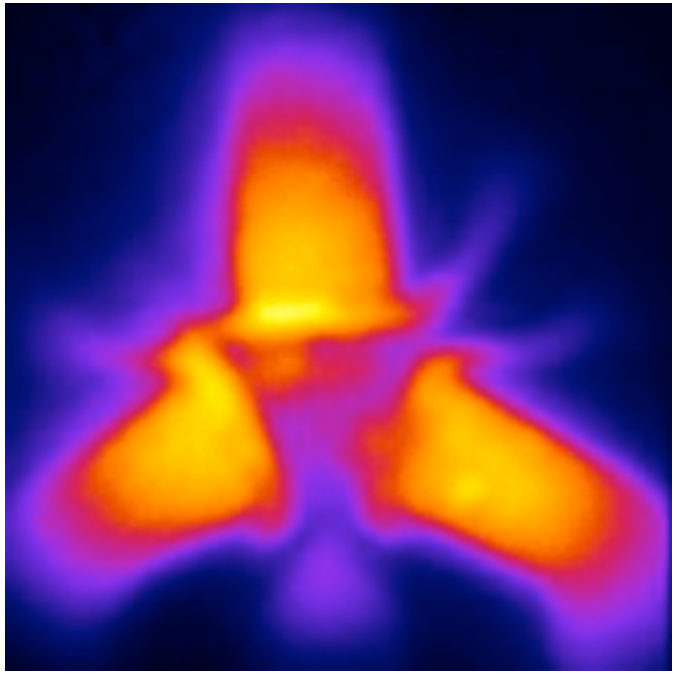
Will Excitonic Circuits Change Our Lives?

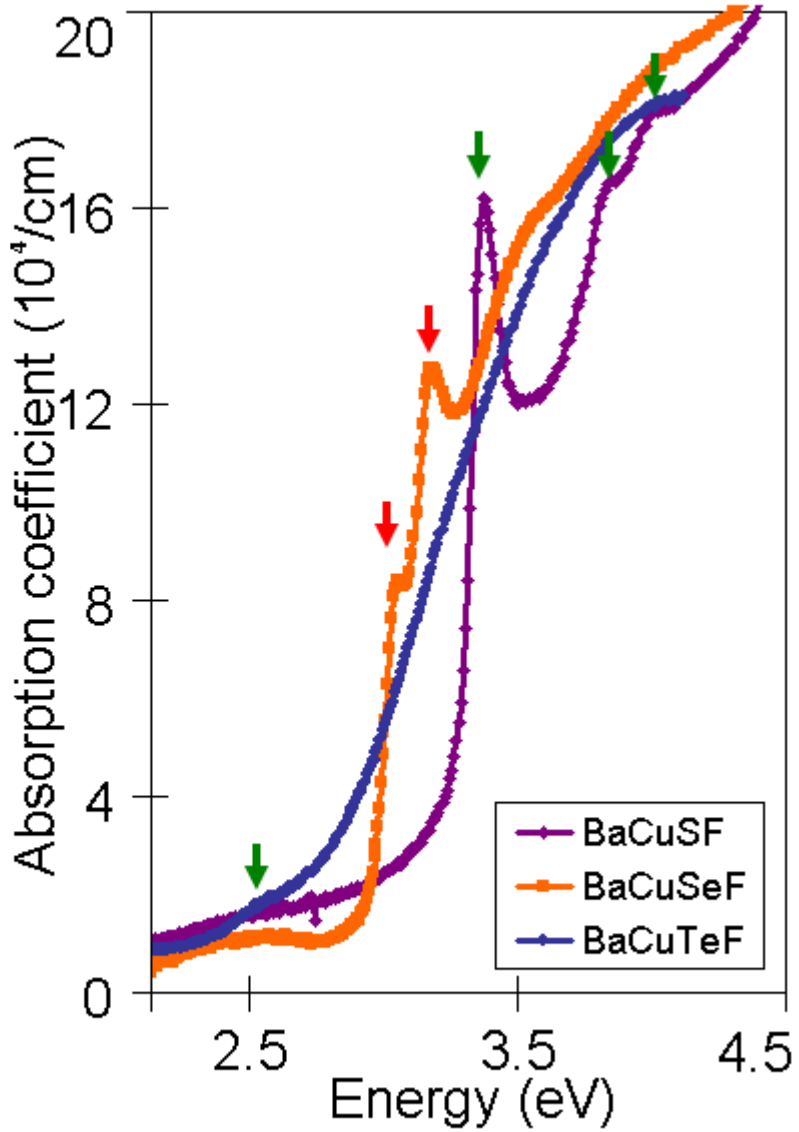
http://opfocus.org/index.php?topic=story&v=2&s=3

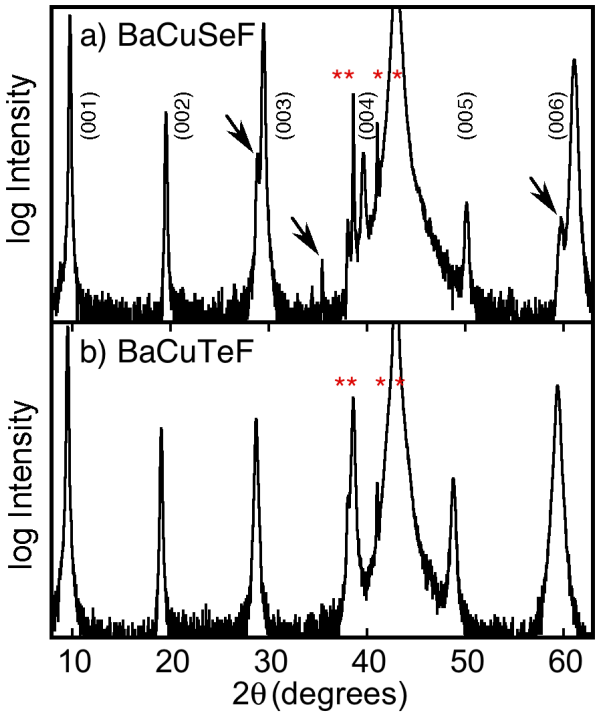
18/8/2008

The direct use of light, both for communication and computation, could speed things up. "Our gallium arsenide transistors process signals using indirect excitons instead of electrons," Butov explains. "They are controlled by gate electrodes exactly like electrons in silicon transistors, but, unlike electrons, they are directly coupled with photons, thus bridging the gap between processing and communication." While computation itself may not be faster than electron-based circuits, signal transmission to other devices or parts of the same chip connected by an optical link will definitely be.



Excitonic absorption in BaCuChF (Ch= S, Se, Te)





XRD shows epitaxial quality of BaCuSeF and BaCuTeF films. BaCuSF is polycrystalline

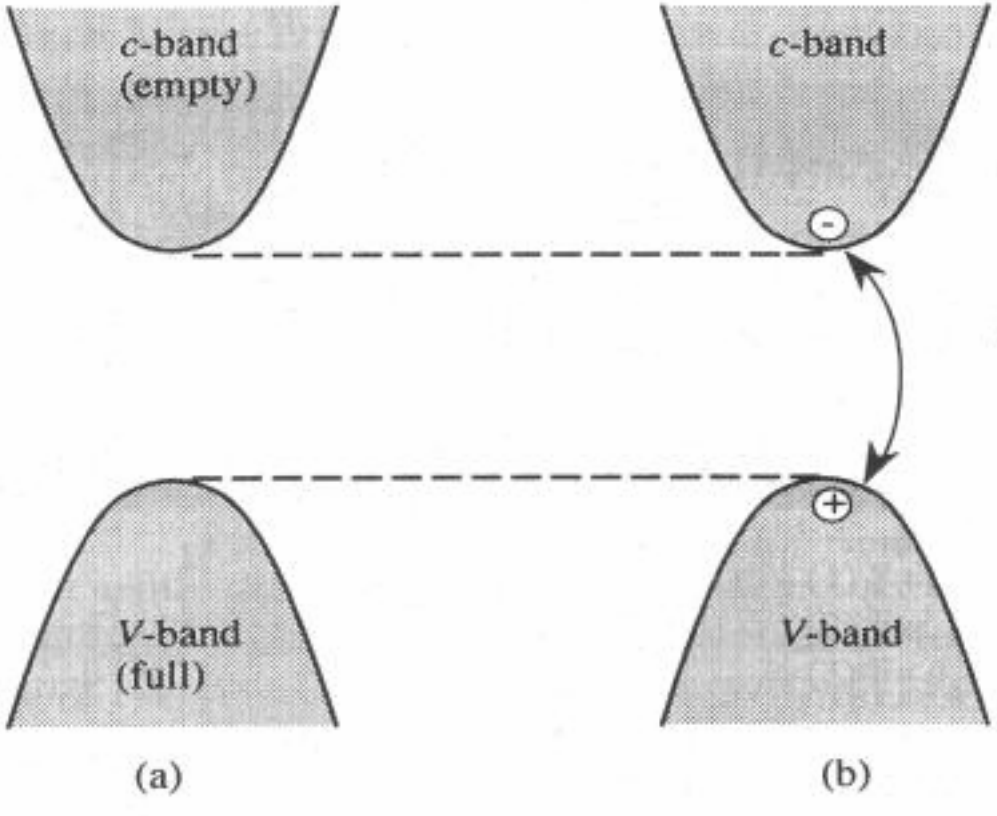
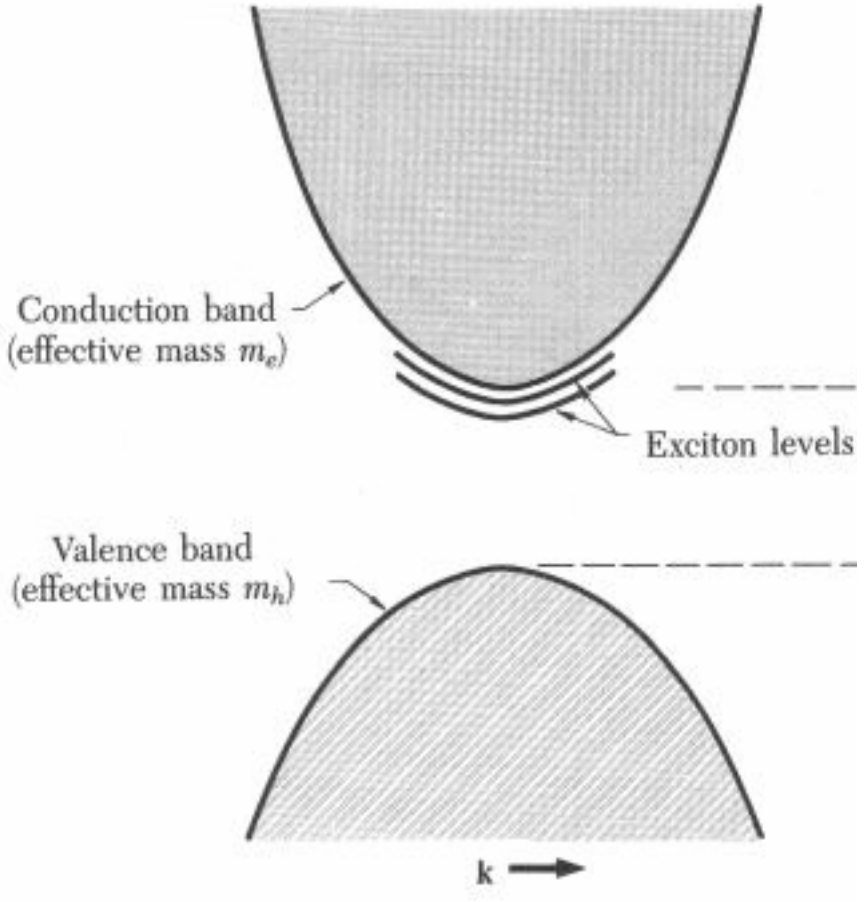


Figure VI-4-1: (a) The band structure in the independent electron picture and (b) the Coulombic interaction between electron and hole, which modifies the band structure.

Figure VI-4-2: Band structure including the exciton levels.



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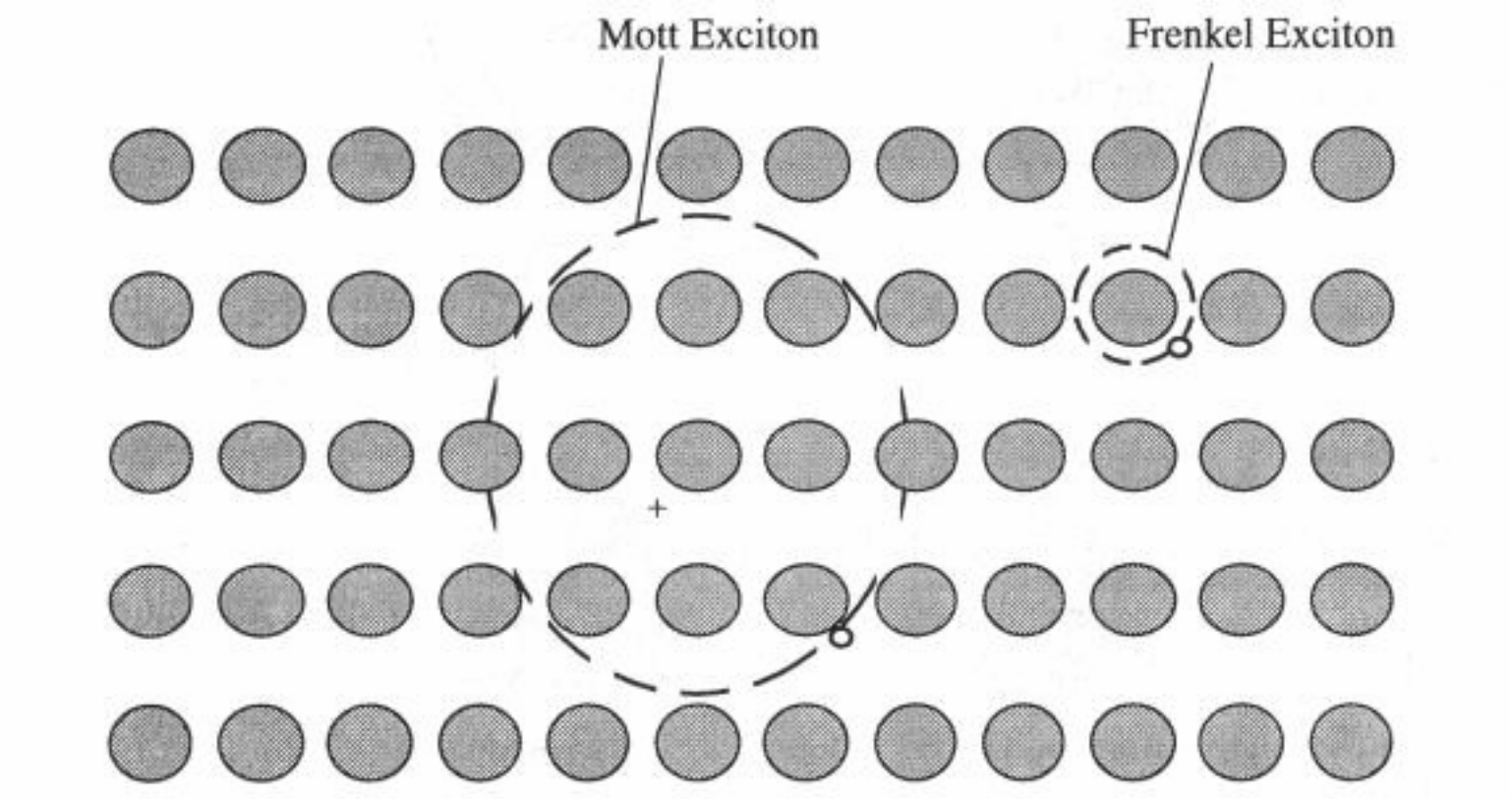
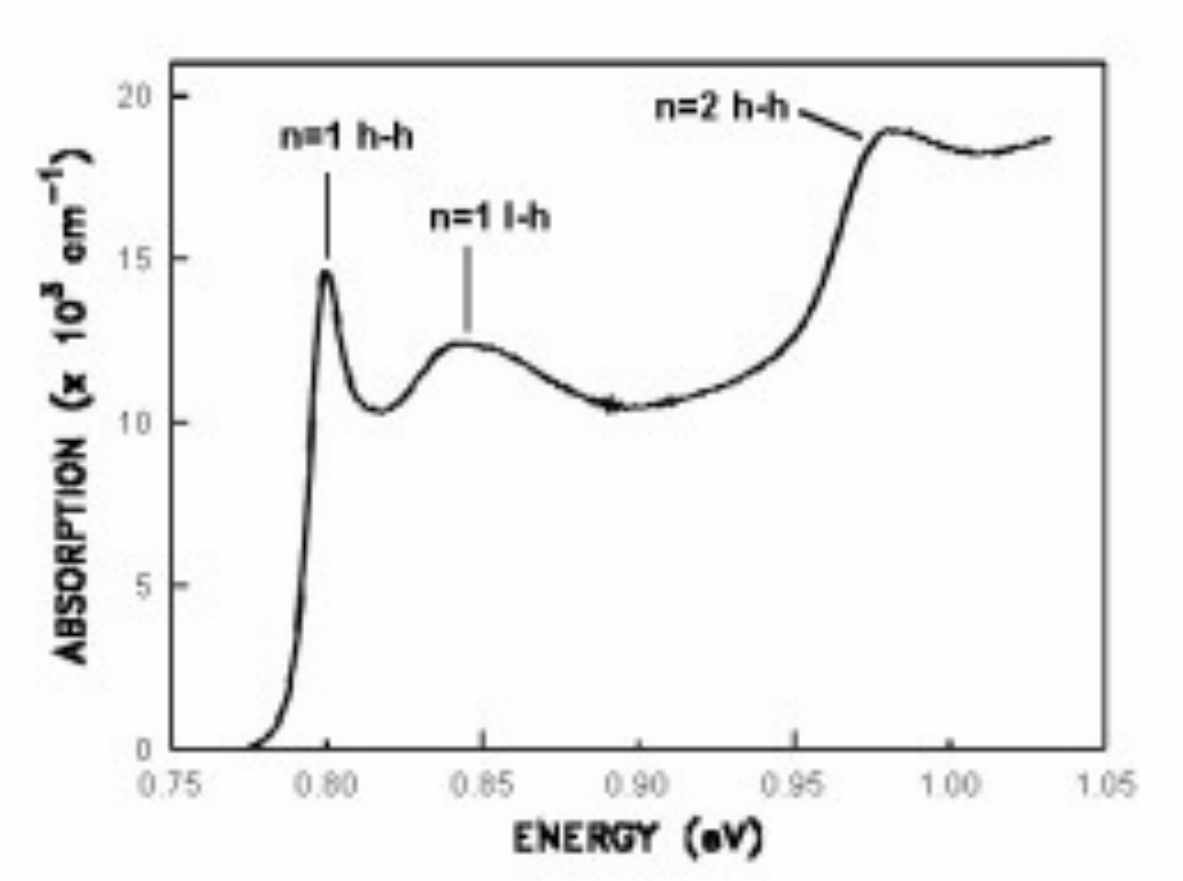


$$E_n = -\frac{\mu_{red}}{m_0}\frac{1}{\varepsilon_r^2}\frac{R_H}{n^2} = \frac{R_X}{n^2}$$

$$r_n = \frac{m_0}{\mu_{red}}\varepsilon_r n^2 a_H = n^2 a_X$$

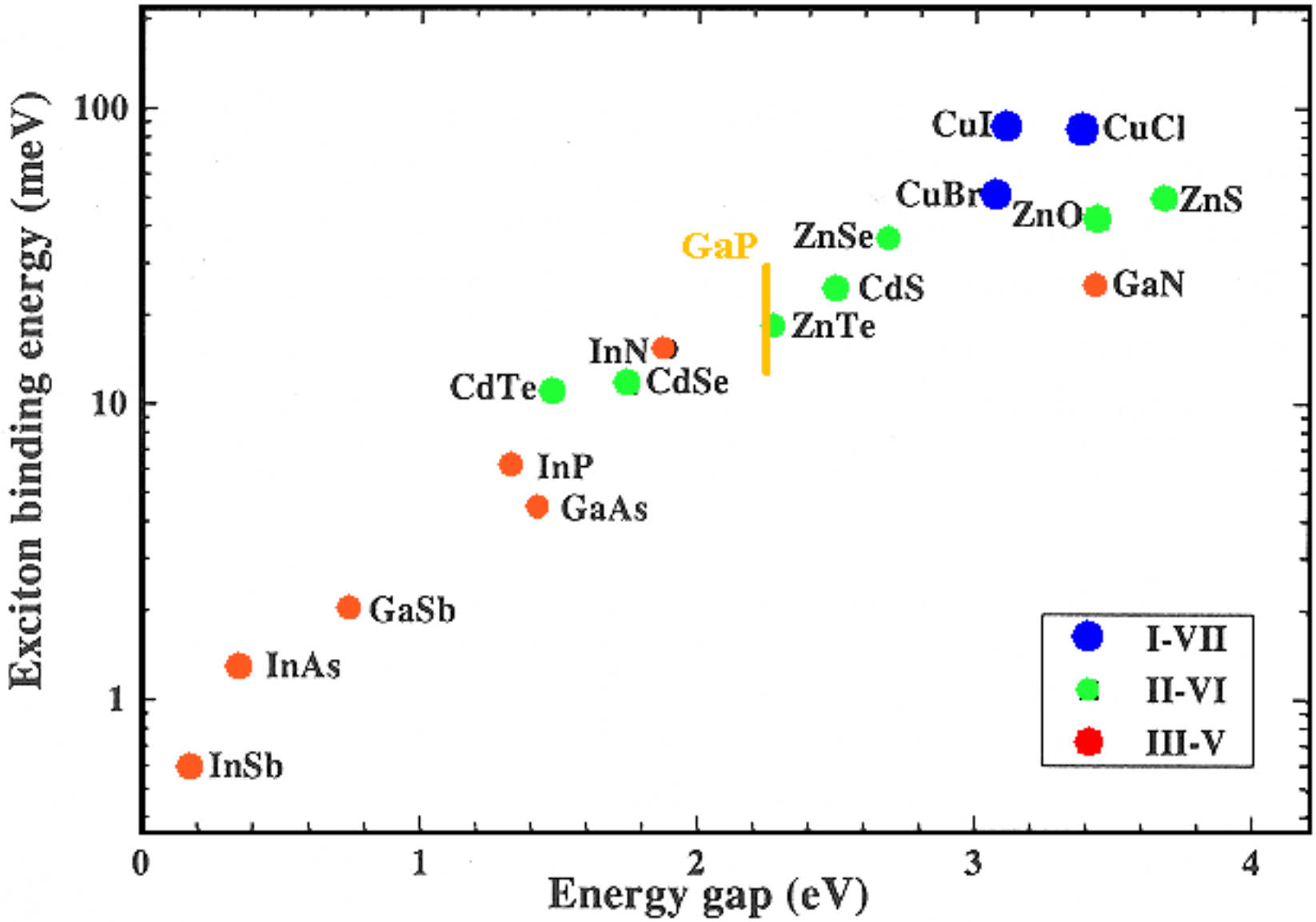
Figure VI-4-3: A conceptual picture of the periodic envelope function extent of Frenkel and Mott excitons.

http://kottan-labs.bgsu.edu/teaching/workshop2001/chapter6.htm



We have performed investigation of optical nonlinearities induced by exciton or carrier photogeneration in InGaAs/InP QW structures by using the infrared femtosecond optical parametric amplifier. The absorption spectrum shows clearly visible heavy and light hole exciton peaks

http://www.cusbo.polimi.it/us/research/quantum.html



http://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_5/advanced/t5_1_3.html