Absorption coefficients of semiconductor thin films

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The University of Toledo
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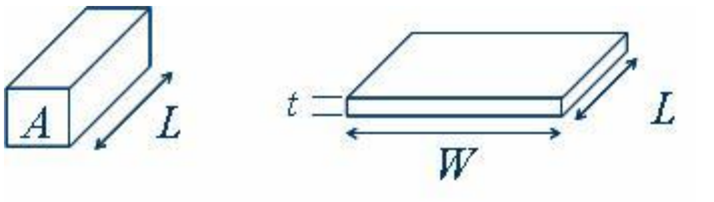
Sheet Resistance (revisited)



Regular 3-D conductor, resistance *R* is:

$$R = \rho \frac{L}{A} = \rho \frac{L}{Wt}$$

where ρis the resistivity (Ω-cm), *A* is the cross-section area, and *L* is the length. For *A* in terms of *W* and *t*,

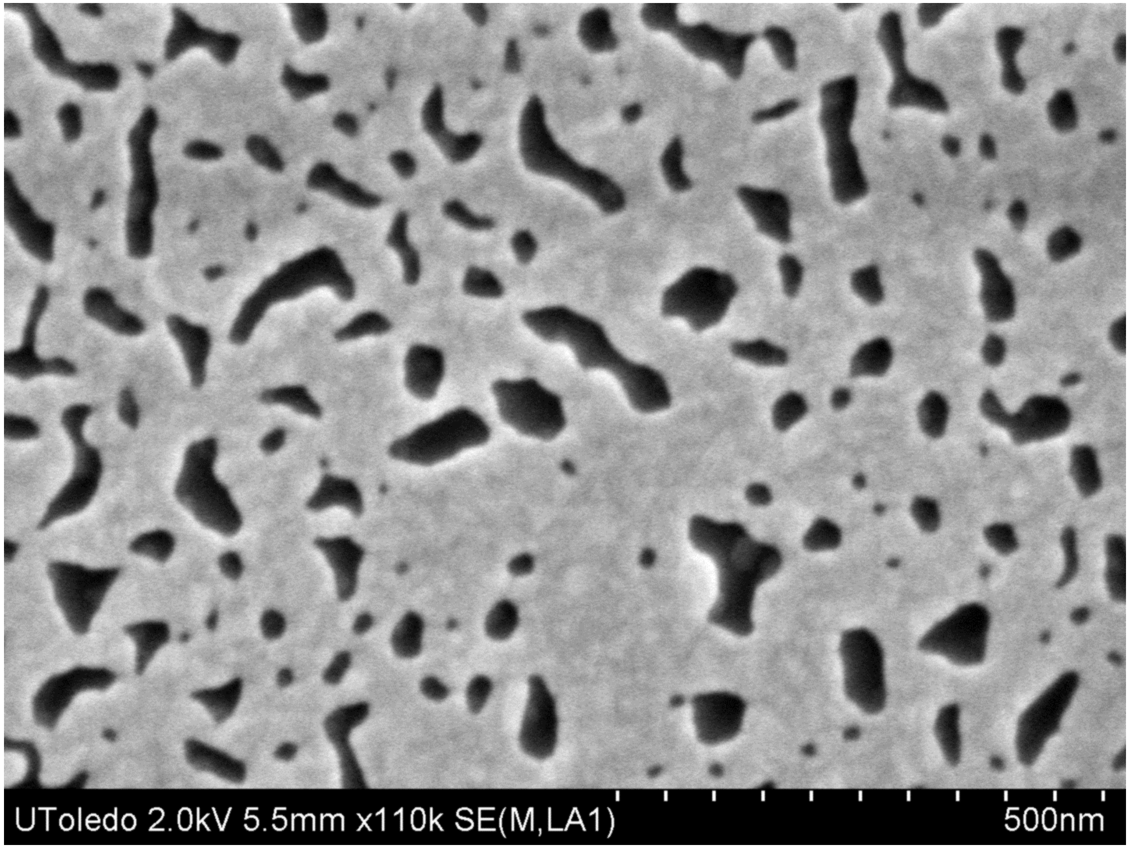
$$R = \frac{\rho}{t} \frac{L}{W} = R_s \frac{L}{W}$$

where R_s is the <u>Sheet Resistance</u>. Units are ohms, but can also express this as "ohms per square, or Ω/□, or Ω/sq.

- A square sheet with an R_s of 100 Ω/□ has a resistance of 100 Ω (regardless of the size of the square).

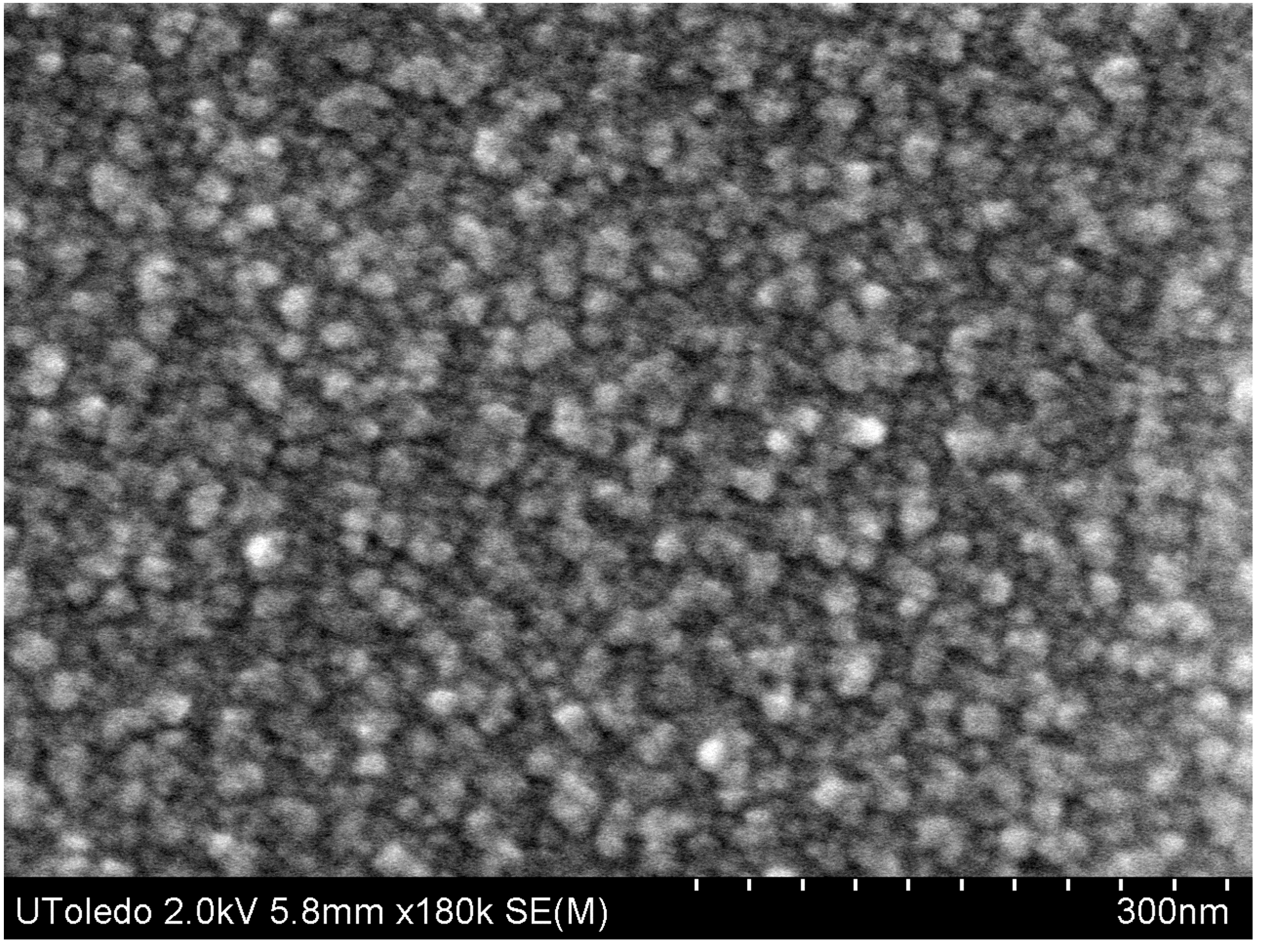
http://en.wikipedia.org/wiki/Sheet_resistance

Sheet Resistance – importance of film morphology



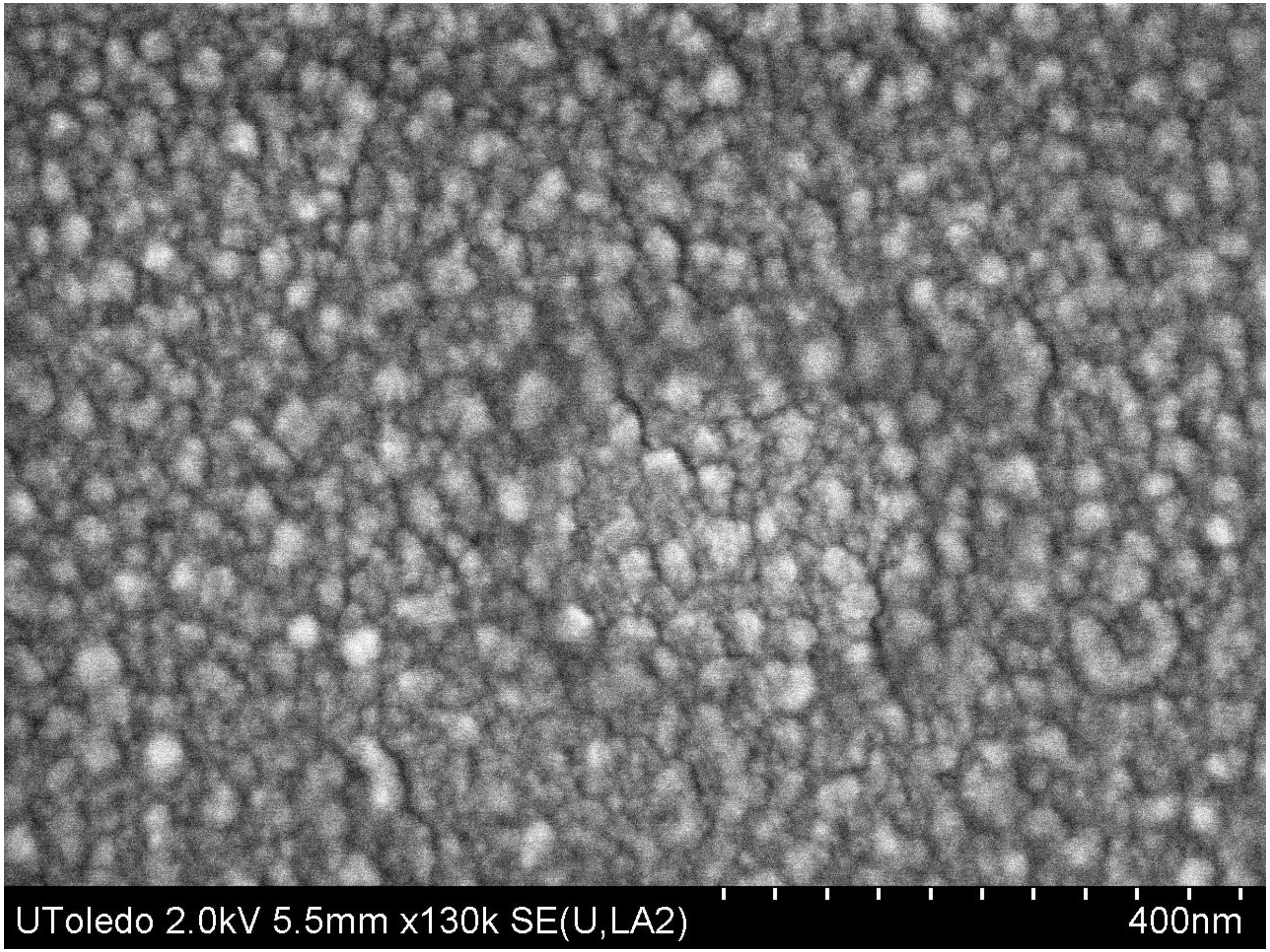
Scanning Electron Microscope (SEM) image of ~15 nm thick Au deposited by thermal evaporation.

Sheet Resistance – importance of film morphology



Scanning Electron Microscope (SEM) image of ~2.7 nm thick Cr deposited by sputtering from a Cr target.

Sheet Resistance – importance of film morphology



Scanning Electron Microscope (SEM) image of ~15 nm thick Cr deposited by sputtering from a Cr target.

Sheet Resistance – importance of film morphology

Phys. Status Solidi A **207**, No. 7, 1586–1589 (2010) / **DOI** 10.1002/pssa.200983732

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applications and materials science

Ultrathin chromium transparent metal contacts by pulsed dc magnetron sputtering

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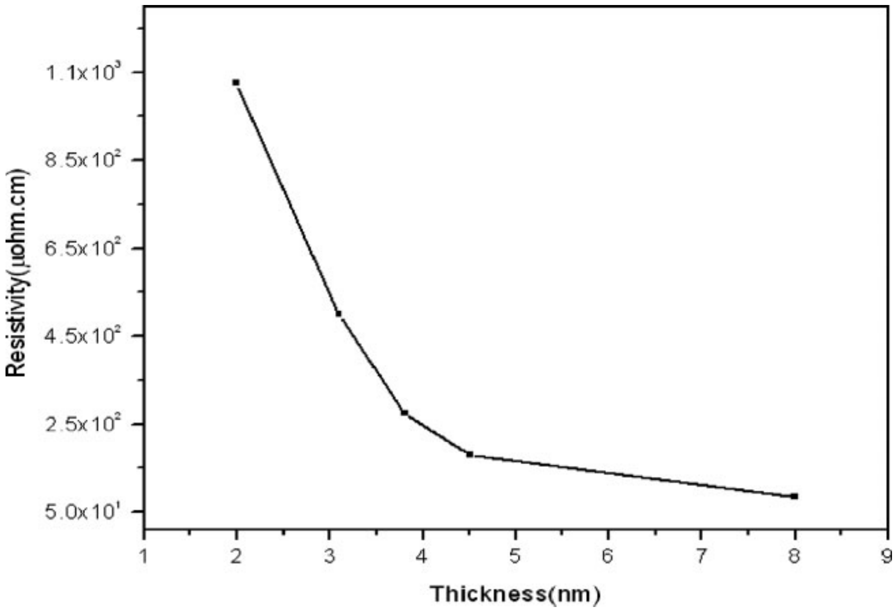
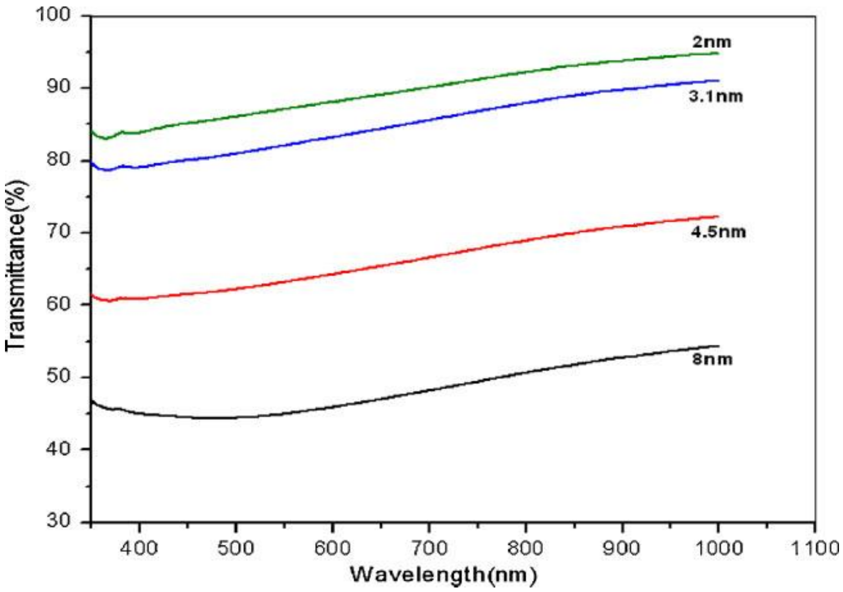
Thin metal films



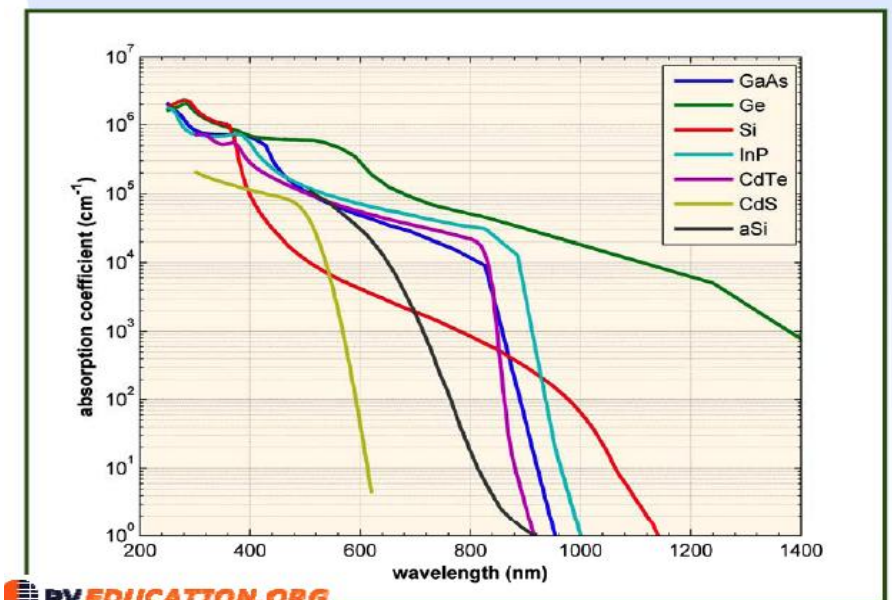


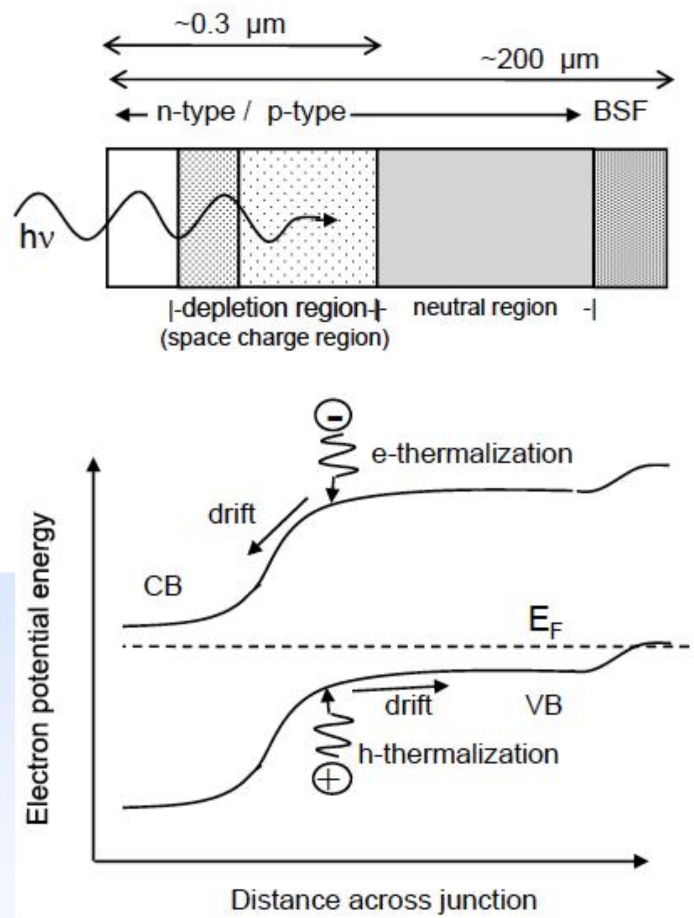
"The sheet resistance values corresponding to the 2, 3.1, 4.5 and 8 nm are 5×10^3, 1.6×10^3, 4×10^2 and 1×10^2 Ω/□, respectively."

Phys. Status Solidi A **207**, No. 7, 1586–1589 (2010) / **DOI** 10.1002/pssa.200983732

band diagram for a homojunction (n on p)

- Si (indirect band gap) will have typically a thick neutral region--carrier collection by diffusion
- most thin-film (direct band gap materials) will have mostly field-assisted collection



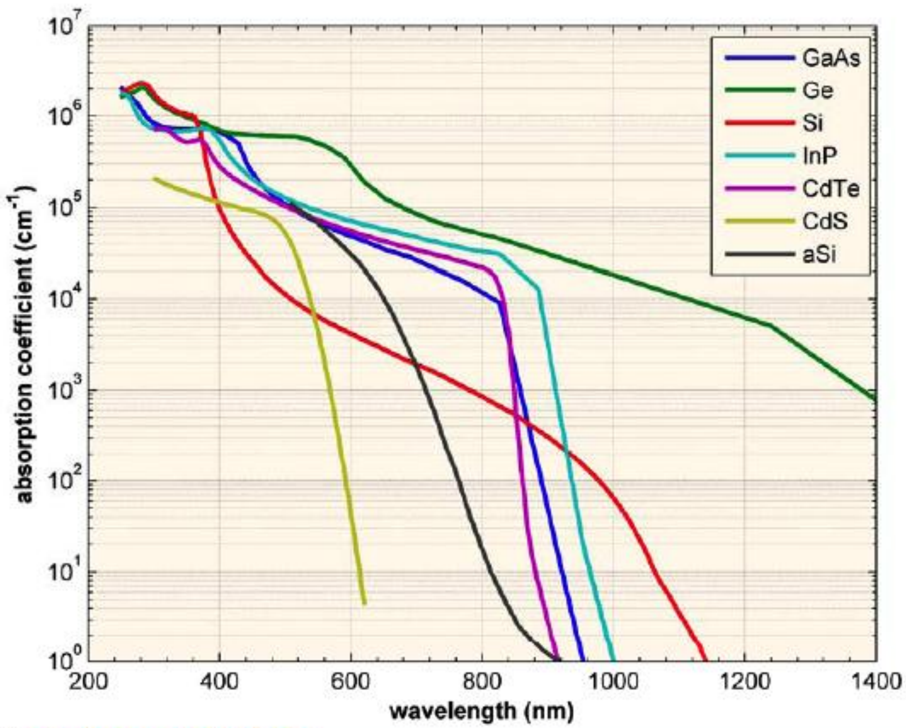


Solar cell structure and energy band diagram showing valence (VB) and conduction bands (CB), Fermi level (E_F), photoabsorption, electron-hole pair generation, thermalization, and drift.
(from Compaan, APS News April, 2005)

Absorb sunlight efficiently

What matters for absorption of sunlight to make a good solar cell?

High extinction coefficient, short absorption length, large **absorption coefficient**.



$$I = I_0 e^{-\alpha x}$$

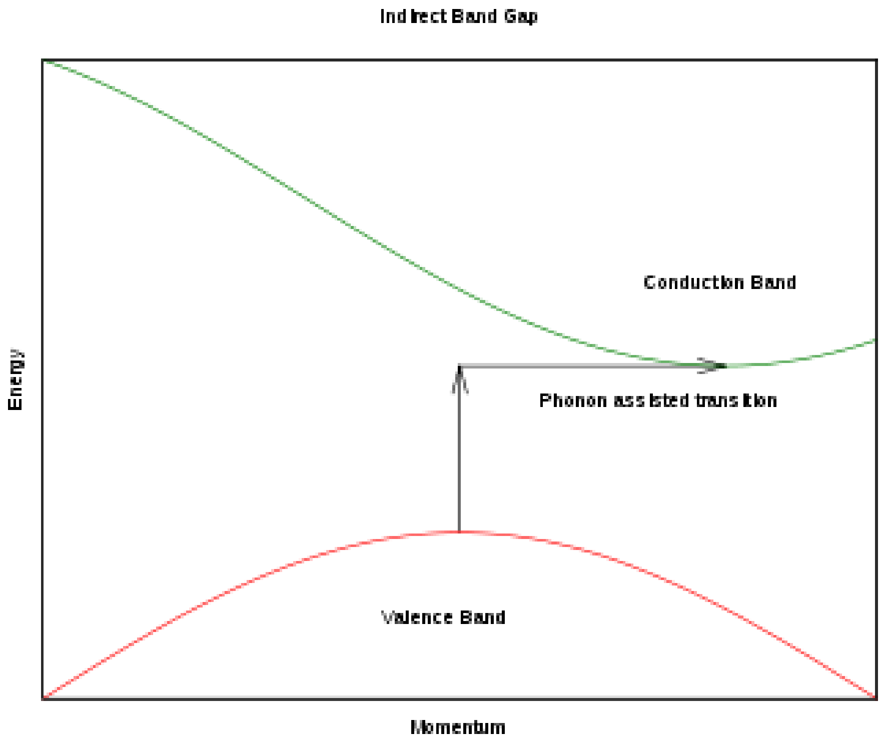
$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda) x}$$

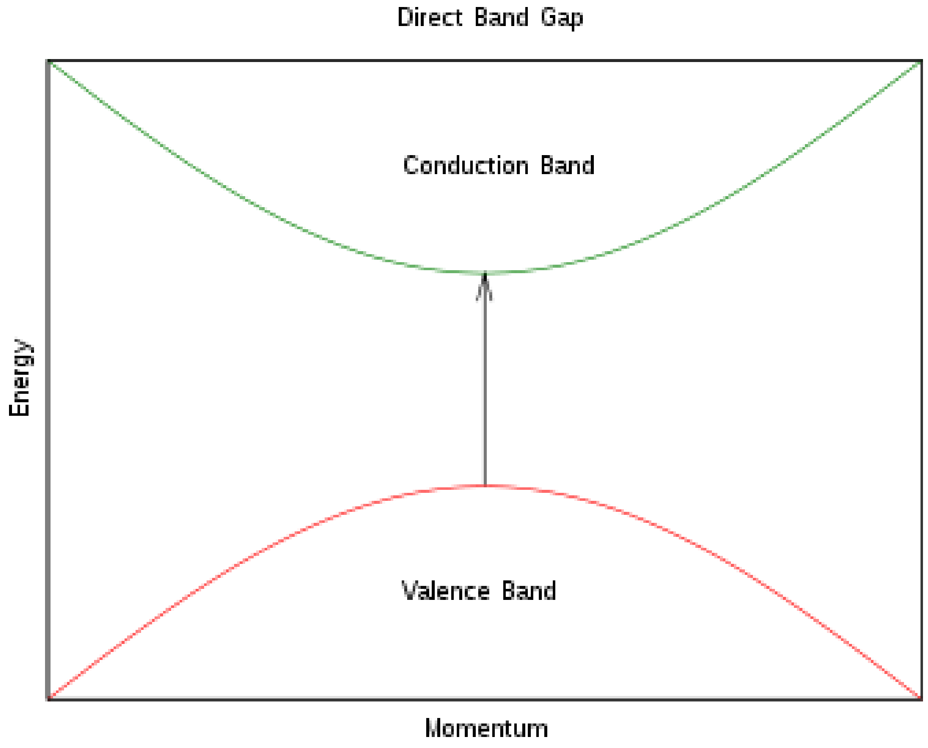
Bandgap

Low **reflection** loss (can't convert reflected photons).

How do we measure the parameters in **bold**?

Indirect and Direct Band Gaps





From Wikipedia

Measuring the bandgap energy (optical absorption)

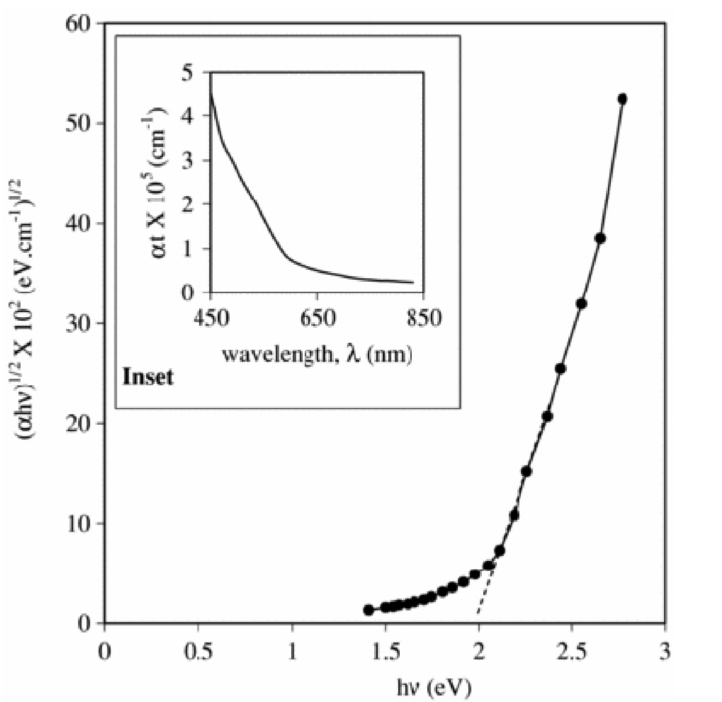
$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda)x} \rightarrow I(E) = I_0(E) e^{-\alpha(E)x}$$

Direct-gap semiconductor

$$\alpha(E) = \alpha_0 (E - E_g)^{\frac{1}{2}}$$

Indirect-gap semiconductor

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



Fe_2O_3, (haematite) – direct or indirect gap?

Semicond. Sci. Technol. **20** No 8 (August 2005) 705-709
doi:10.1088/0268-1242/20/8/009
Nanocrystalline haematite thin films by chemical solution spray
J D Desai, H M Pathan, Sun-Ki Min, Kwang-Deog Jung and Oh-Shim Joo

Measuring the bandgap energy (optical absorption)

$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda)x} \rightarrow I(E) = I_0(E) e^{-\alpha(E)x}$$

Direct-gap semiconductor

$$\alpha(E) = \alpha_0 (E - E_g)^{\frac{1}{2}}$$

Indirect-gap semiconductor

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

Crystal	Gap	E_{gu} eV 0 K	E_{gu} eV 300 K	Crystal	Gap	E_{gu} eV 0 K	E_{gu} eV 300 K
Diamond	i	5.4		HgTe[a]	d	-0.30	
Si	i	1.17	1.14	PbS	d	0.286	0.34-0.37
Ge	i	0.744	0.67	PbSe	d	0.165	0.27
αSn	d	0.00	0.00	PbTe	d	0.190	0.30
InSb	d	0.24	0.18	CdS	d	2.582	2.42
InAs	d	043	0.35	CdSe	d	1.840	1.74
InP	d	1.42	1.35	CdTe	d	1.607	1.45
GaP	i	2.32	2.26	ZnO		3.436	3.2
GaAs	d	1.52	1.43	ZnS		3.91	3.6
GaSb	d	0.81	0.78	SnTe	d	0.3	0.18
AlSb	i	1.65	1.52	AgCl		-	3.2
SiC(hex)		3.0	-	AgI		-	2.8
Te	d	0.33	-	Cu_2O		2.172	-
ZnSb		0.56	0.56	TiO_2		3.03	-

[a]HgTe is a semimetal; the bands overlap.
General references: D. Long, Energy bands in semiconductors. Interscience, 1968; also the A.I.P. Handbook, 3rd ed., Sec. 9.

Indirect gap: plotting α vs E shows an E^2 dependence, so plotting $\alpha^{1/2}$ shows a linear dependence.

Direct gap: Plotting α vs E shows an $E^{1/2}$ dependence, so plotting α^2 shows a linear dependence.

See, for example, http://engr.sjsu.edu/cme/MatELabs/MatE153/Ch7%20Optical%20Absorption.pdf, or http://engphys.mcmaster.ca/undergraduate/outlines/3pn4/LAB3PN4-2%20Jan08.pdf

Measuring the bandgap of a thin film (optically)

http://www.chalcogen.infim.ro/Patidar-CdSe-Final.pdf

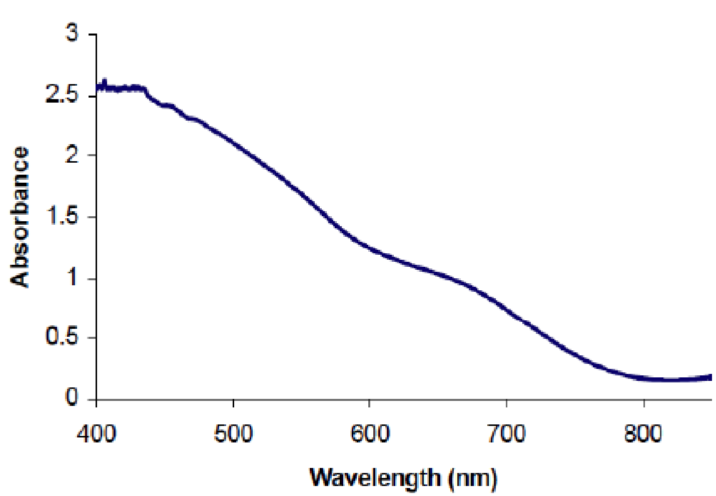


Fig 2. The absorption spectra of CdSe thin film.

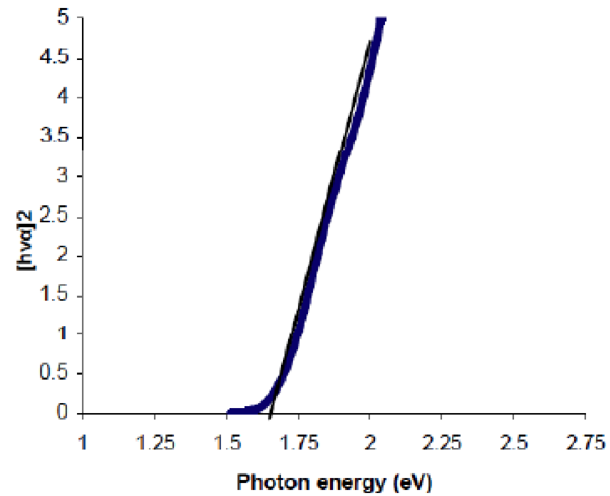


Fig.3. Energy band gap determination of CdSe thin film.

Therefore, if a plot of *h*ν versus α^2 forms a straight line, it can normally be inferred that there is a direct band gap, measurable by extrapolating the straight line to the $\alpha = 0$ axis. On the other hand, if a plot of *h*ν versus $\alpha^{1/2}$ forms a straight line, it can normally be inferred that there is an indirect band gap, measurable by extrapolating the straight line to the $\alpha = 0$ axis.
From http://en.wikipedia.org/wiki/Direct_and_indirect_band_gaps

Goals of the Absorption Coefficient Determination Lab (Unit) – address these in your lab report:

1) Measure the optical absorption coefficient (as a function of wavelength) for the CdS and CdTe films provided, make required plots, and the determine type and size of the band gaps.

2) Measure the optical absorption coefficient (as a function of wavelength) for the two different Si samples provided, make required plots, and determine the type and size of the band gaps.

3) Hall effect measurements (details TBD for Oct. 30).