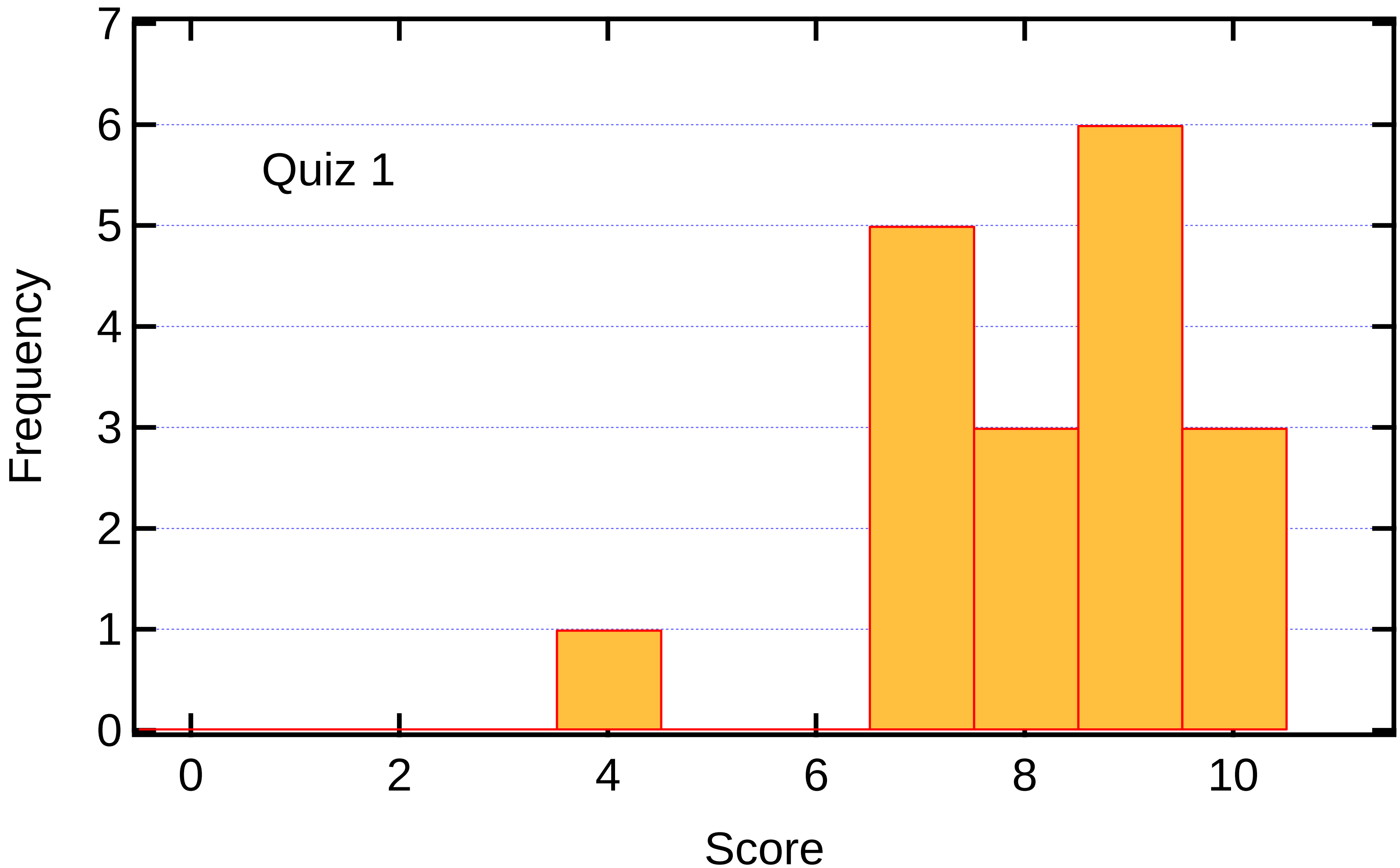
# Absorption coefficients of semiconductor thin films

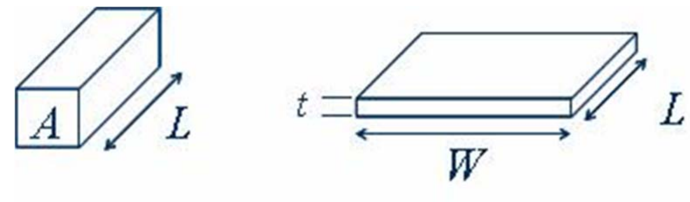
November 1, 2011

PHYS 4580, PHYS 6/7280
The University of Toledo
Profs. R. Ellingson and M. Heben

# Quiz #1 results



# Sheet Resistance (revisited)




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

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

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

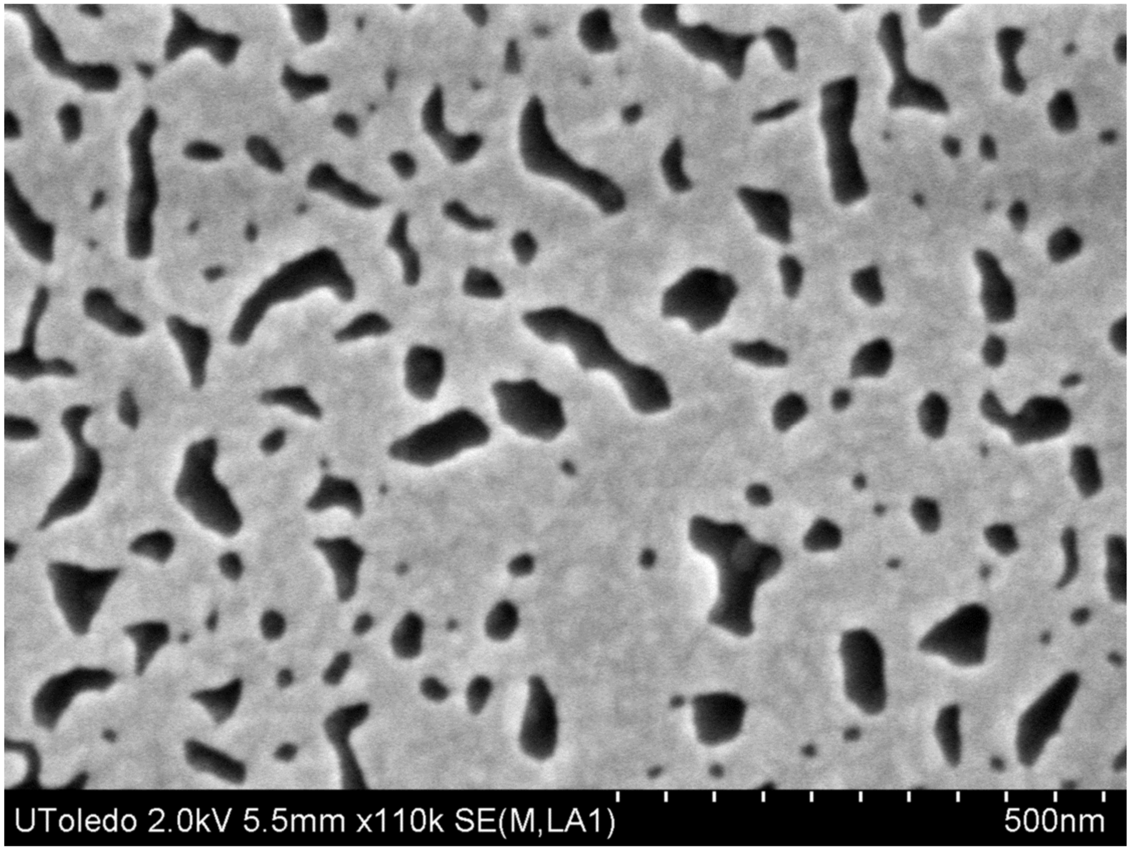
$$R = \frac{\rho}{t}\frac{L}{W} = R_s \frac{L}{W}$$

where $R_s$ is the Sheet Resistance. 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).

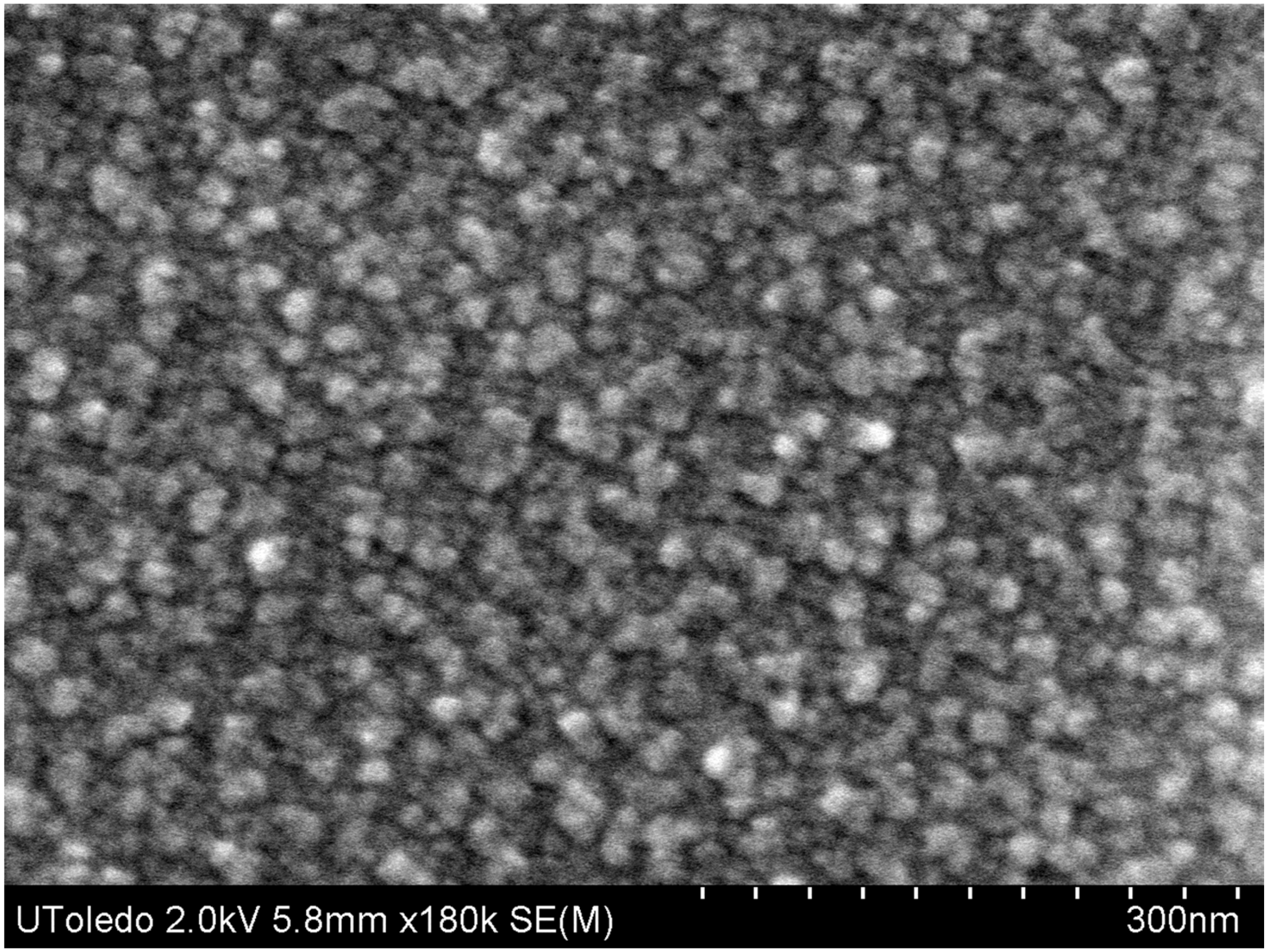
http://en.wikipedia.org/wiki/Sheet_resistance

# Sheet Resistance – importance of film morphology



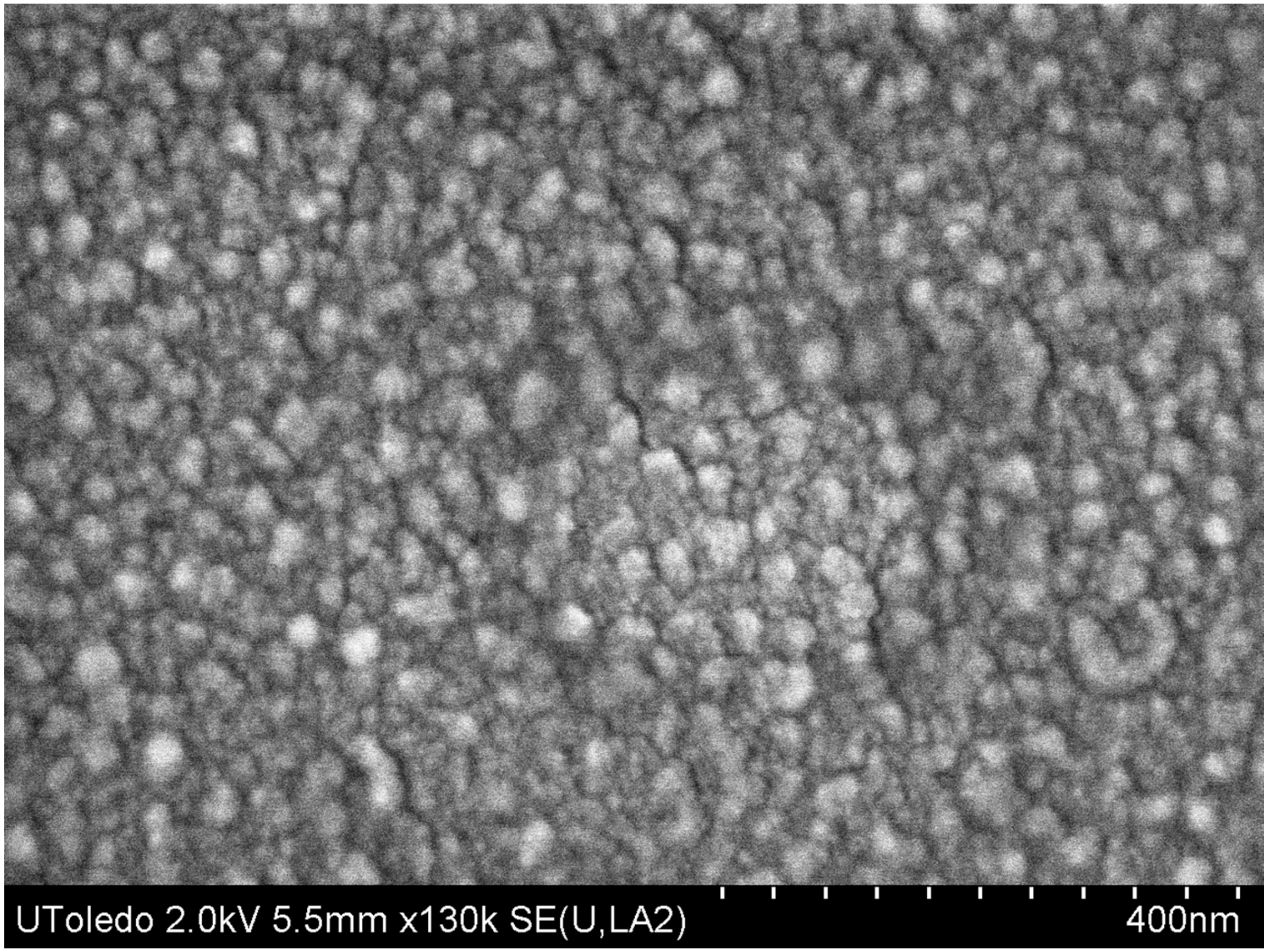

Scanning Electron Microscope (SEM) image of ~15 nm thick Au deposited by thermal evaporation.

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

physica status solidi a
www.pss-a.com
*applications and materials science*

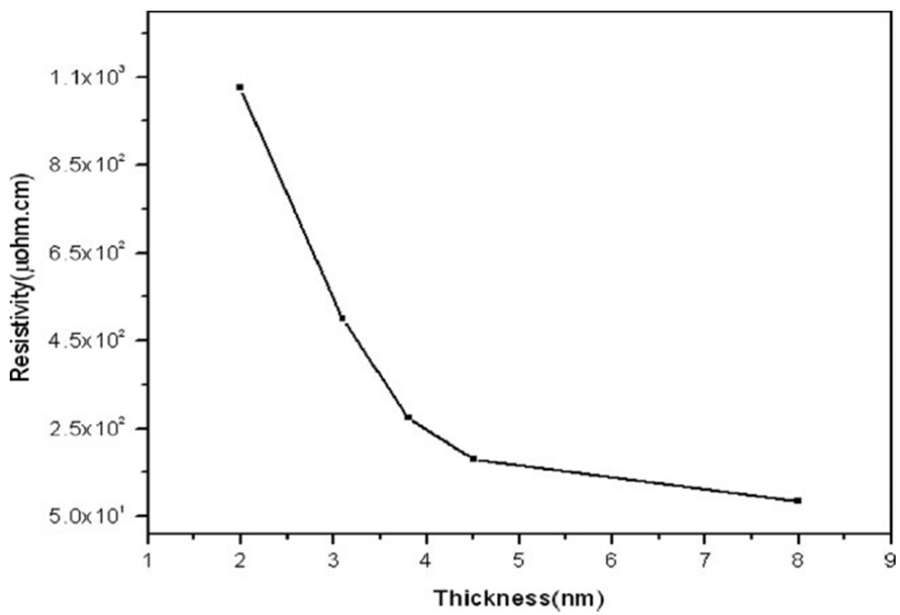
# Ultrathin chromium transparent metal contacts by pulsed dc magnetron sputtering

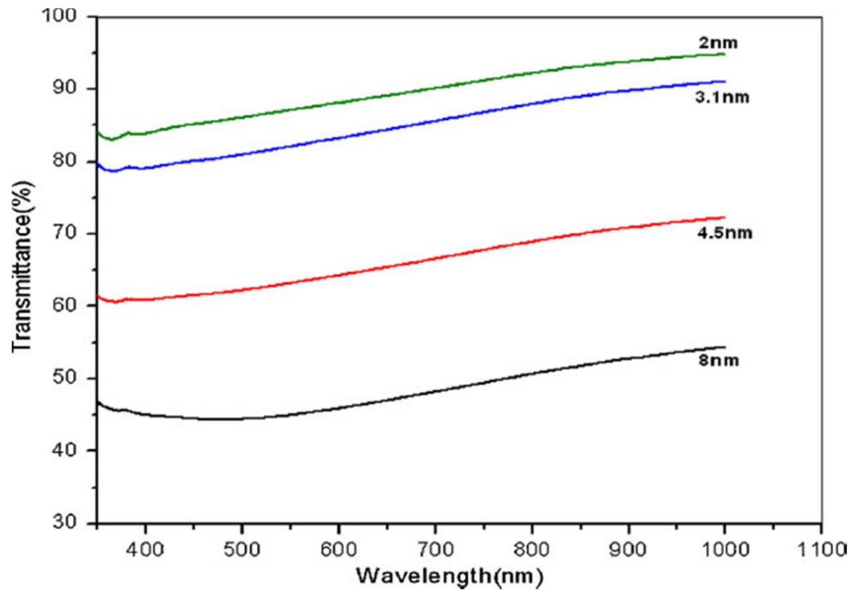
**K. V. Rajani[*,1], S. Daniels[1], P. J. McNally[2], F. Olabanji Lucas[2], and M. M. Alam[2]**

[1] Nanomaterials Processing Laboratory, National Centre for Plasma Science and Technology (NCPST), School of Electronic Engineering, Dublin City University, Dublin 9, Ireland
[2] Nanomaterials Processing Laboratory, Research Institute for Networks and Communications Engineering (RINCE), School of Electronic Engineering, Dublin City University, Dublin 9, Ireland

Received 5 June 2009, accepted 18 January 2010
Published online 9 June 2010

# Thin metal films



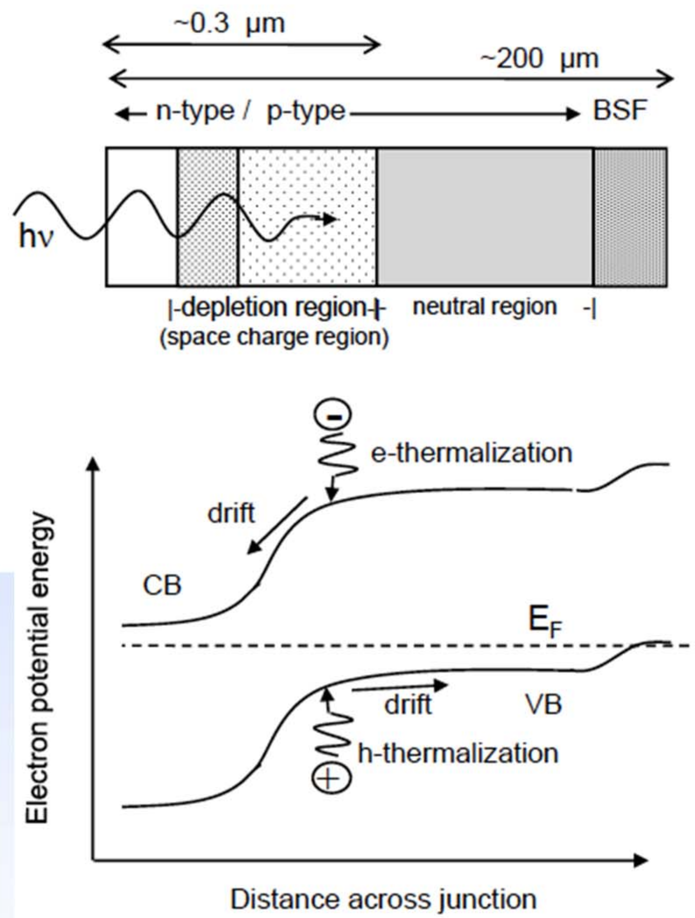




"The sheet resistance values corresponding to the 2, 3.1, 4.5 and 8 nm are $5x10^3$, $1.6x10^3$, $4x10^2$ and $1x10^2$ $\Omega/\square$, respectively."

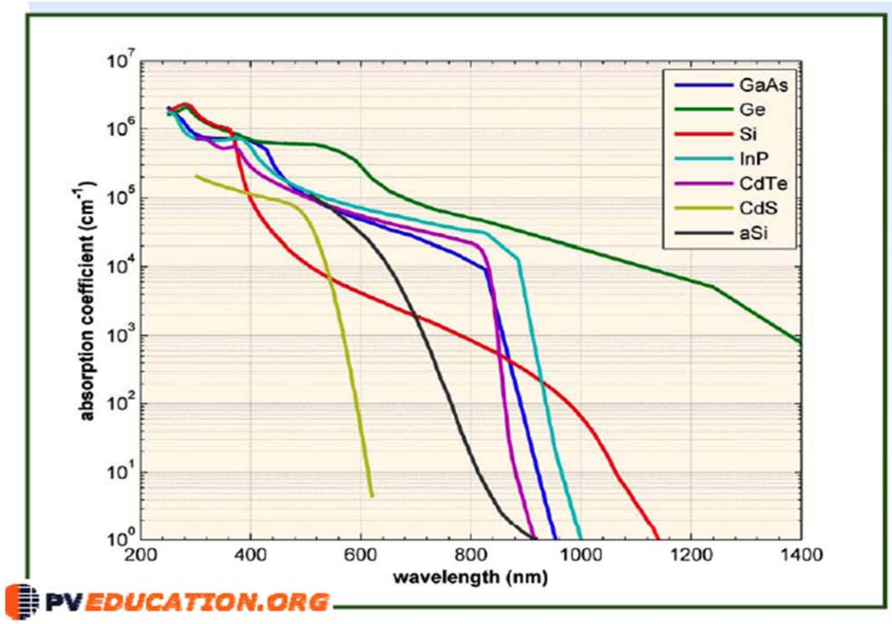
Phys. Status Solidi A **207**, No. 7, 1586–1589 (2010) / **DOI** 10.1002/pssa.200983732

# 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)

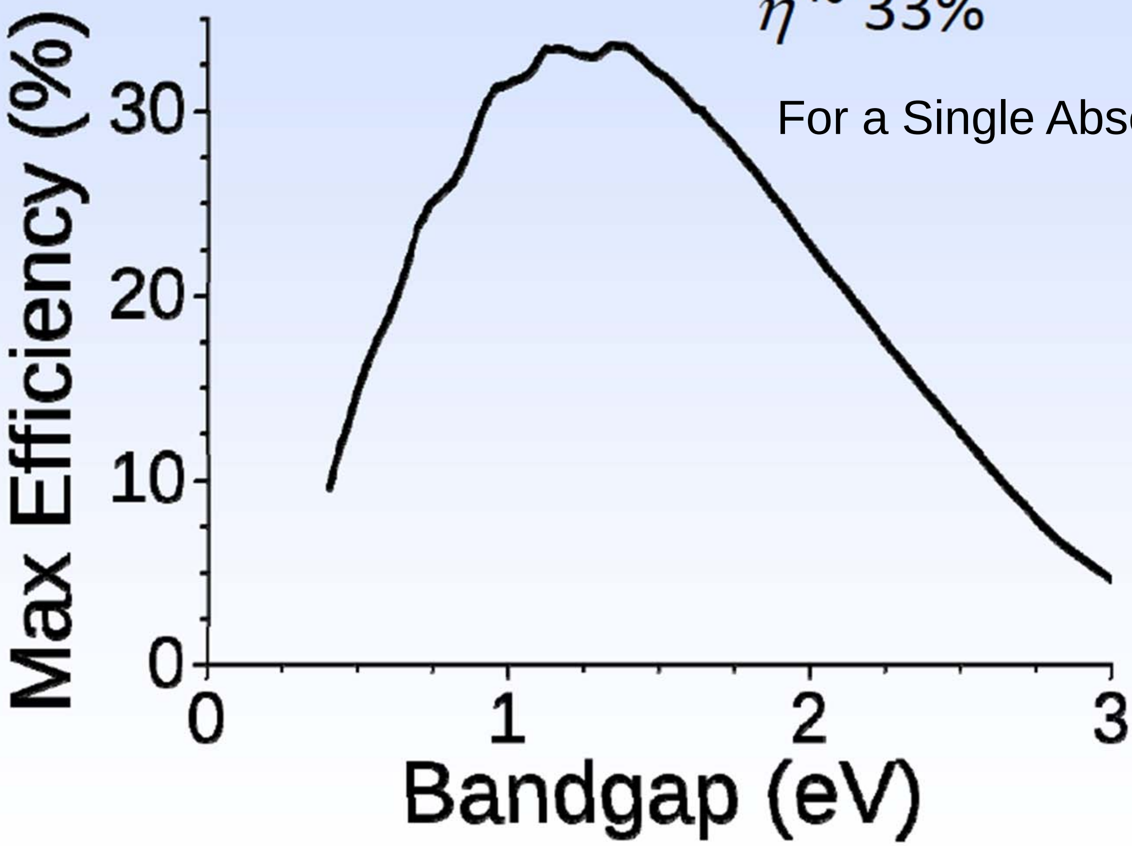


# Requirements/conditions for constructing a valuable solar cell

A partial list…

- Absorb sunlight efficiently to optimize photogeneration of carriers
- Achieve charge separation, directing electron and holes to different contacts (e.g., use doped materials for p-n junction)
- Demonstrate strongly rectifying (diode) behavior
- Avoid excessive electron-hole recombination within the solar cell (maximize photocurrent)
- Maintain as much of the electric potential as possible (avoid resistive losses, and optimize energy band offsets)
- Resist/avoid degradation by air and water (sealing the modules is often essential) – i.e. achieve stability
- Do all of these things (a) with high yield, (b) inexpensively, and © at very large production levels
- What else?

# Getting everything right…



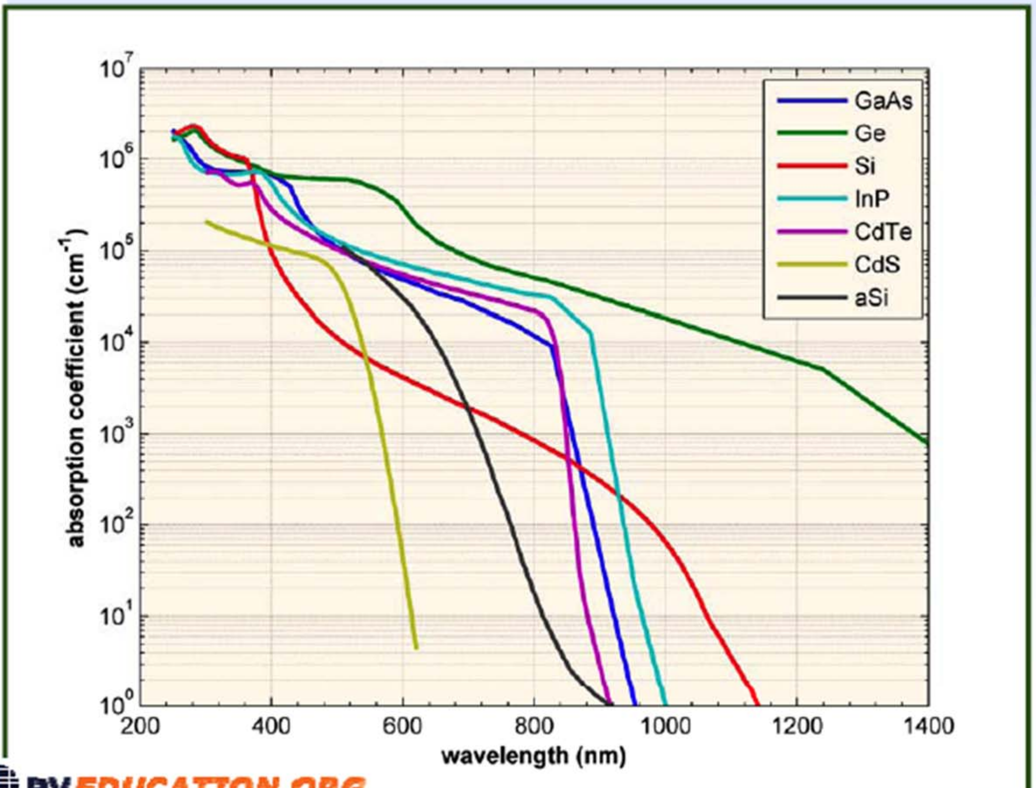

$\eta \sim 33\%$

For a Single Absorber Device

# Absorb sunlight efficiently

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

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




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

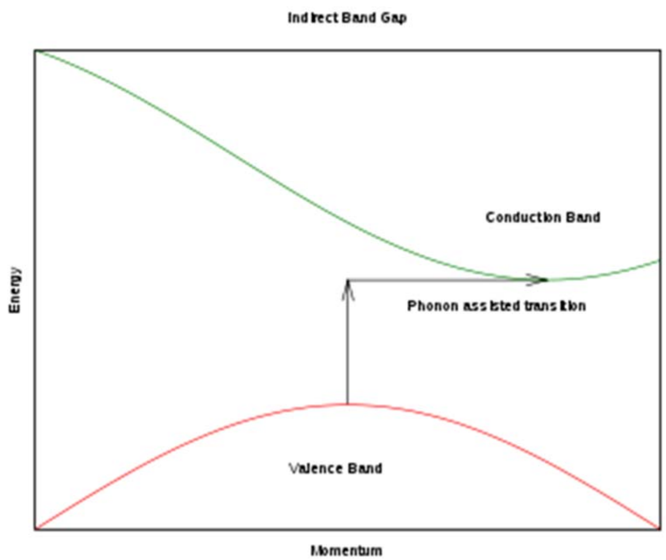
$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda) x}$$

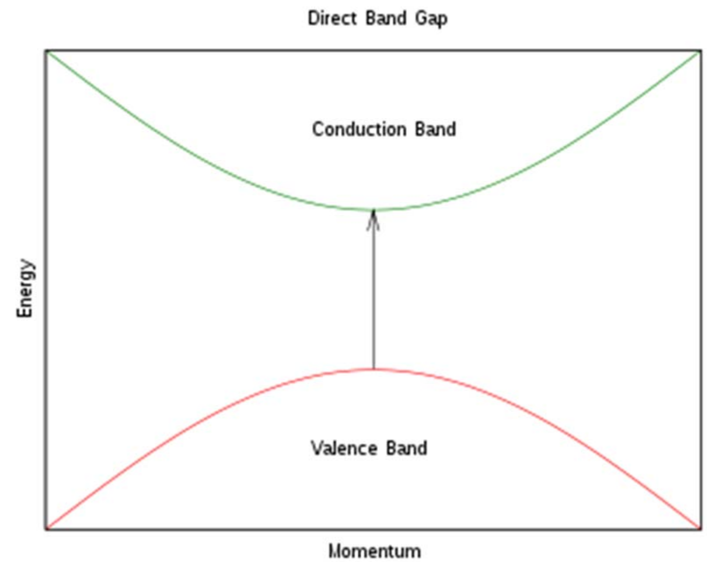
**Bandgap**

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)

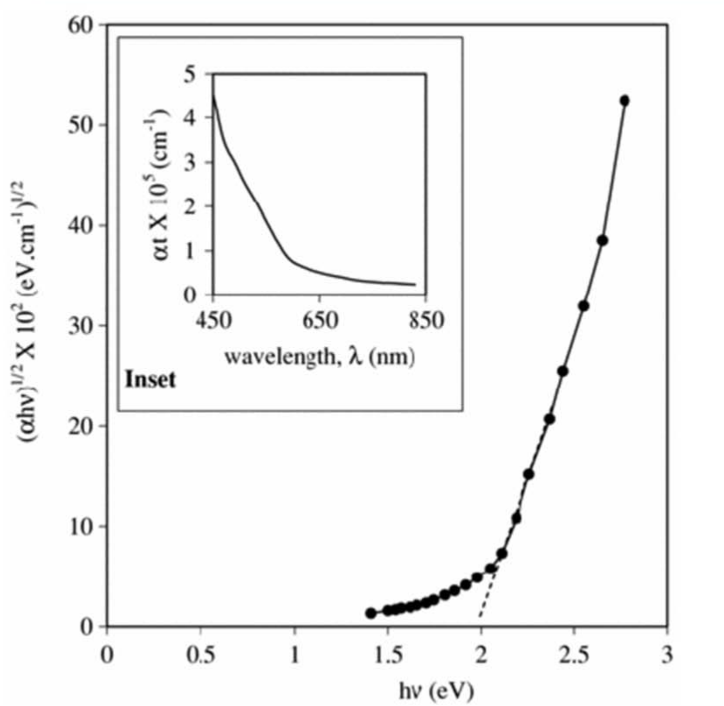
$$I(\lambda)=I_0(\lambda)e^{-\alpha(\lambda)x} \rightarrow I(E)=I_0(E)e^{-\alpha(E)x}$$

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)

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

**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 | $E_g$ eV 0 K | $E_g$ eV 300 K | Crystal | Gap | $E_g$ eV 0 K | $E_g$ 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 $\alpha^2$ 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

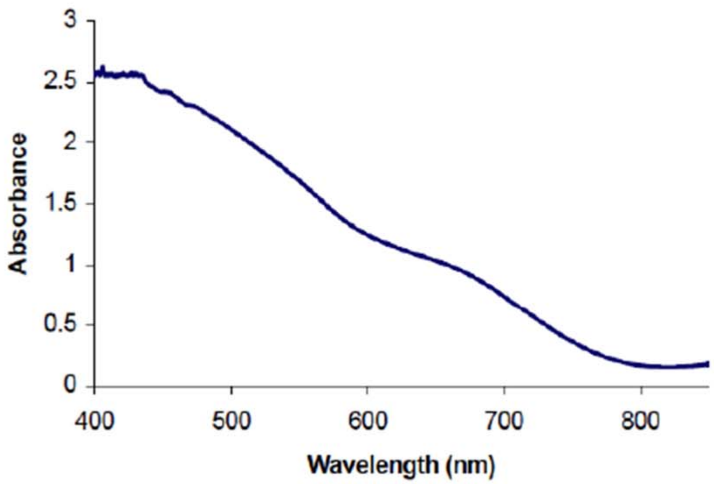



*Fig 2. The absorption spectra of CdSe thin film.*

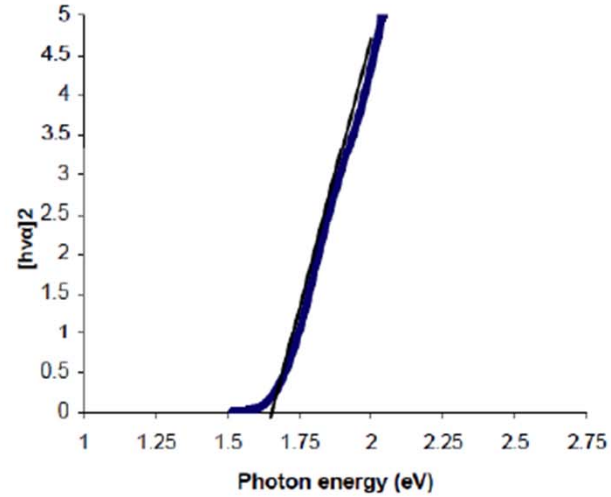



*Fig.3. Energy band gap determination of CdSe thin film.*

Therefore, if a plot of $h\nu$ versus $\alpha^2$ 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 $h\nu$ 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 for CdS and CdTe films provided.

2) Determine type and size of the band gap for CdS and CdTe

3) Measure the absorption spectrum of the TCO/CdS/CdTe film stack and estimate the thickness of the CdTe and CdS layers in the stack using the data obtained in (1).