Topics Relevant to CdTe Thin Film Solar Cells

March 13, 2012

The University of Toledo, Department of Physics and Astronomy
SSARE, PVIC

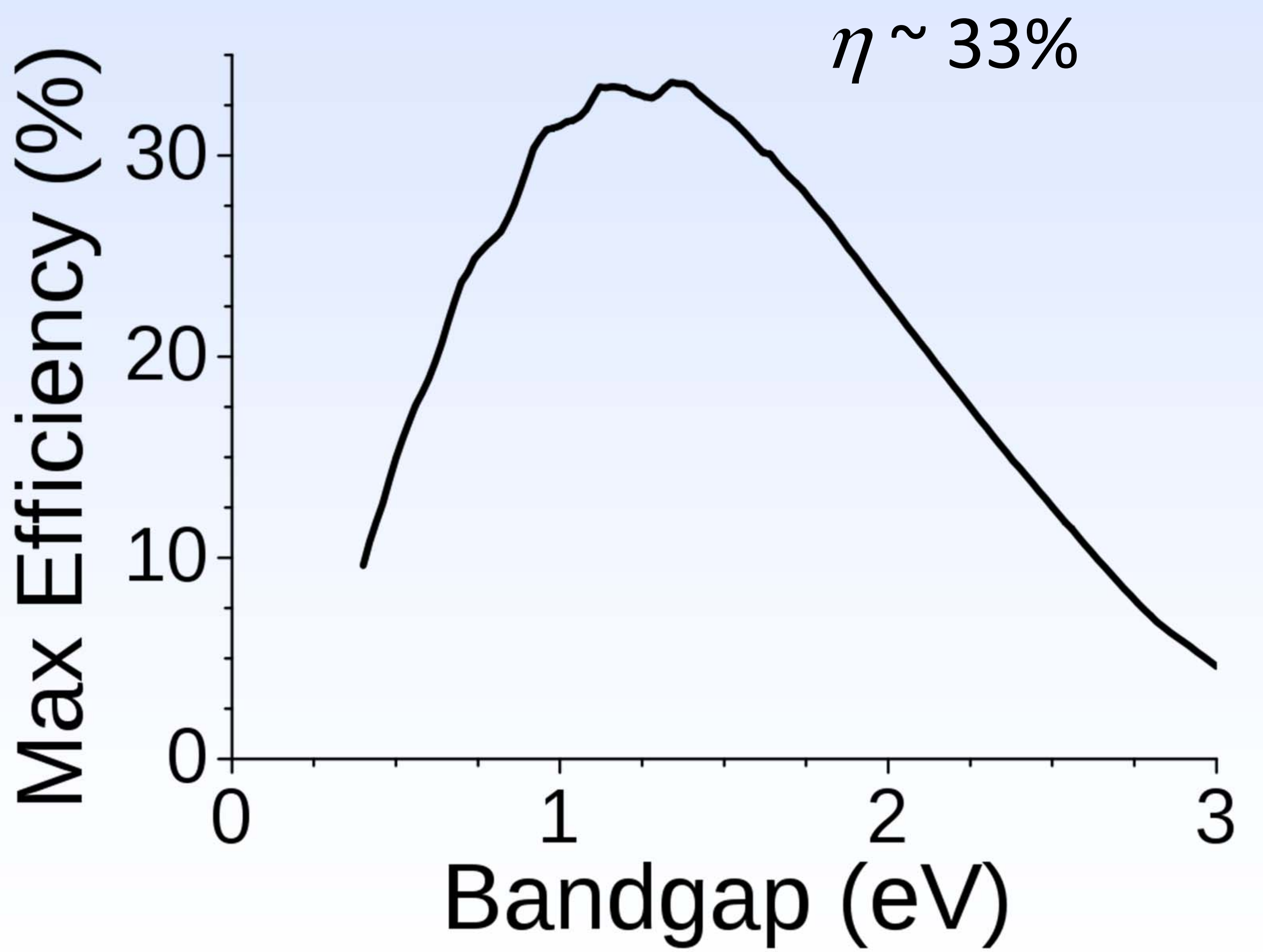
Principles and Varieties of Solar Energy (PHYS 4400)
and
Fundamentals of Solar Cells (PHYS 6980)

Requirements/conditions for constructing a valuable solar cell

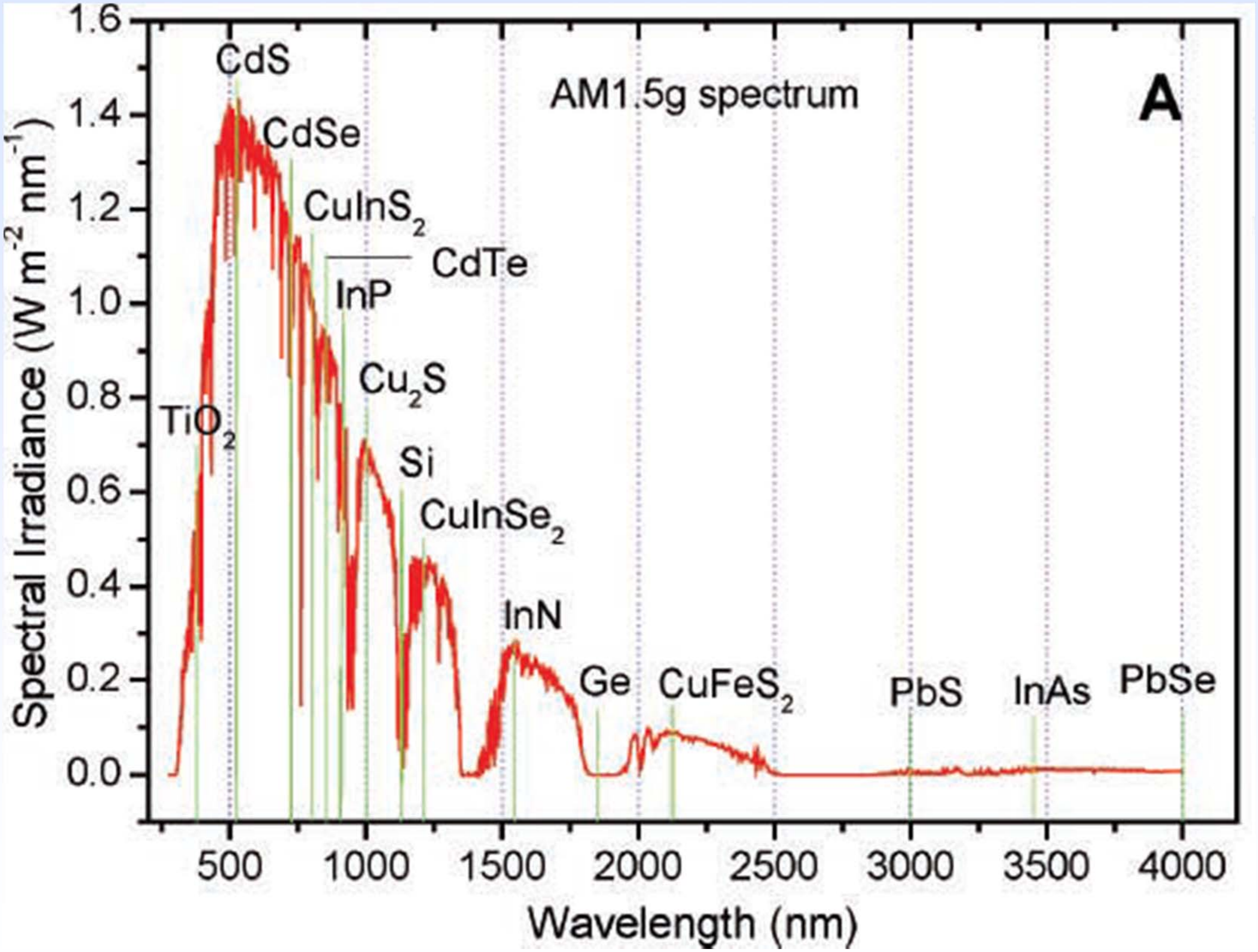
A partial list…

- 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…

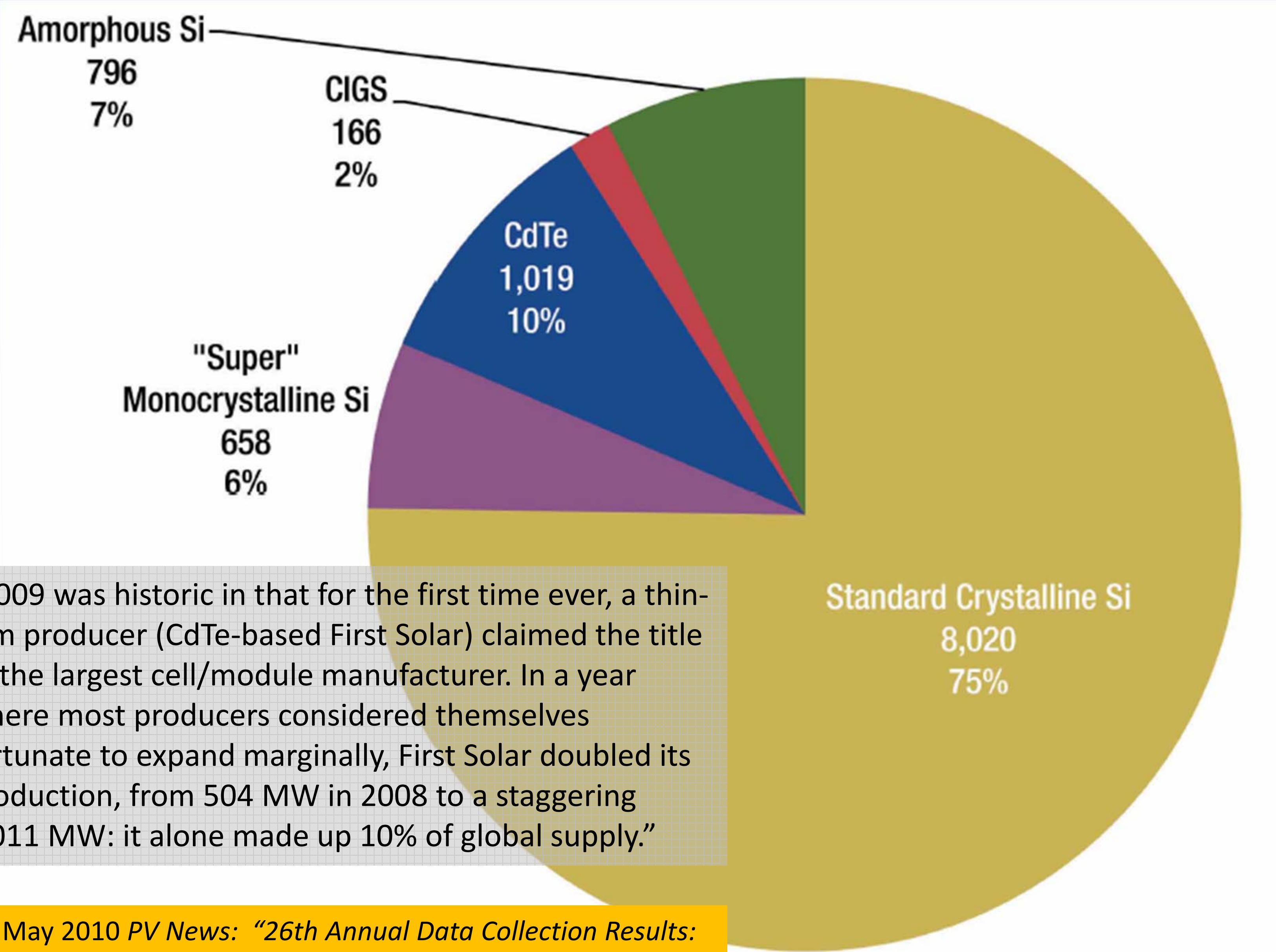


Semiconductor bandgaps relative to the solar spectrum



Dr. Jianbo Gao

Commercial Photovoltaics as of 2010



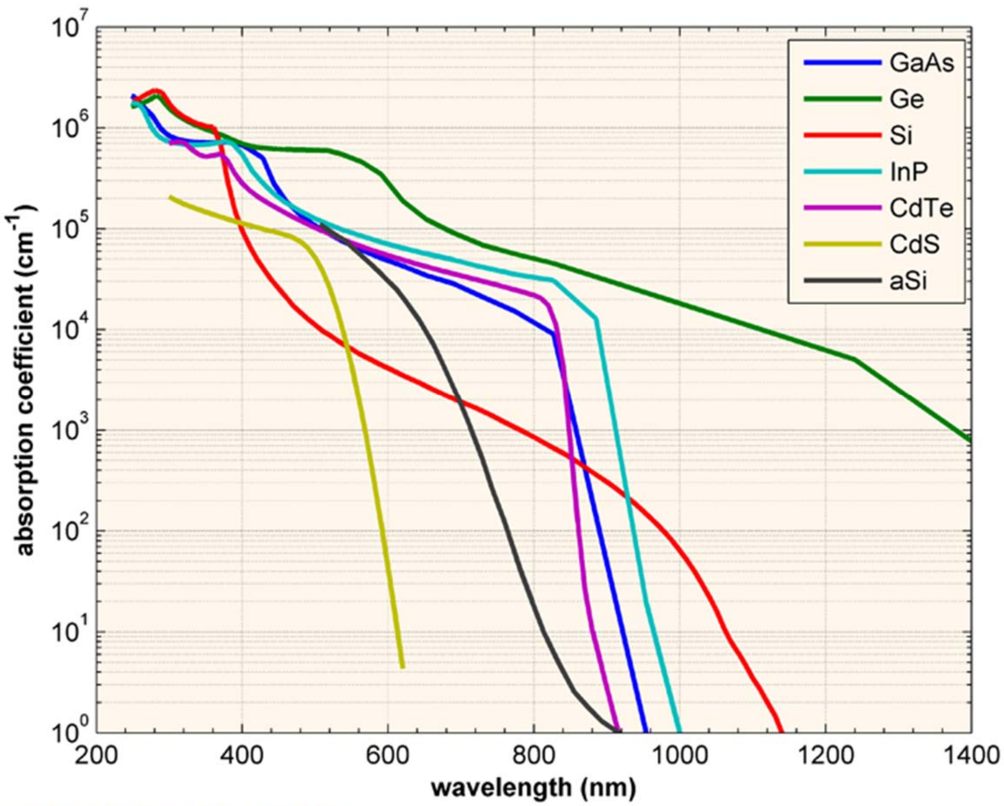
"2009 was historic in that for the first time ever, a thin-film producer (CdTe-based First Solar) claimed the title of the largest cell/module manufacturer. In a year where most producers considered themselves fortunate to expand marginally, First Solar doubled its production, from 504 MW in 2008 to a staggering 1,011 MW: it alone made up 10% of global supply."

from May 2010 *PV News: "26th Annual Data Collection Results: Another Bumper Year for Manufacturing Masks Turmoil"*

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**?

Attained vs. attainable efficiencies

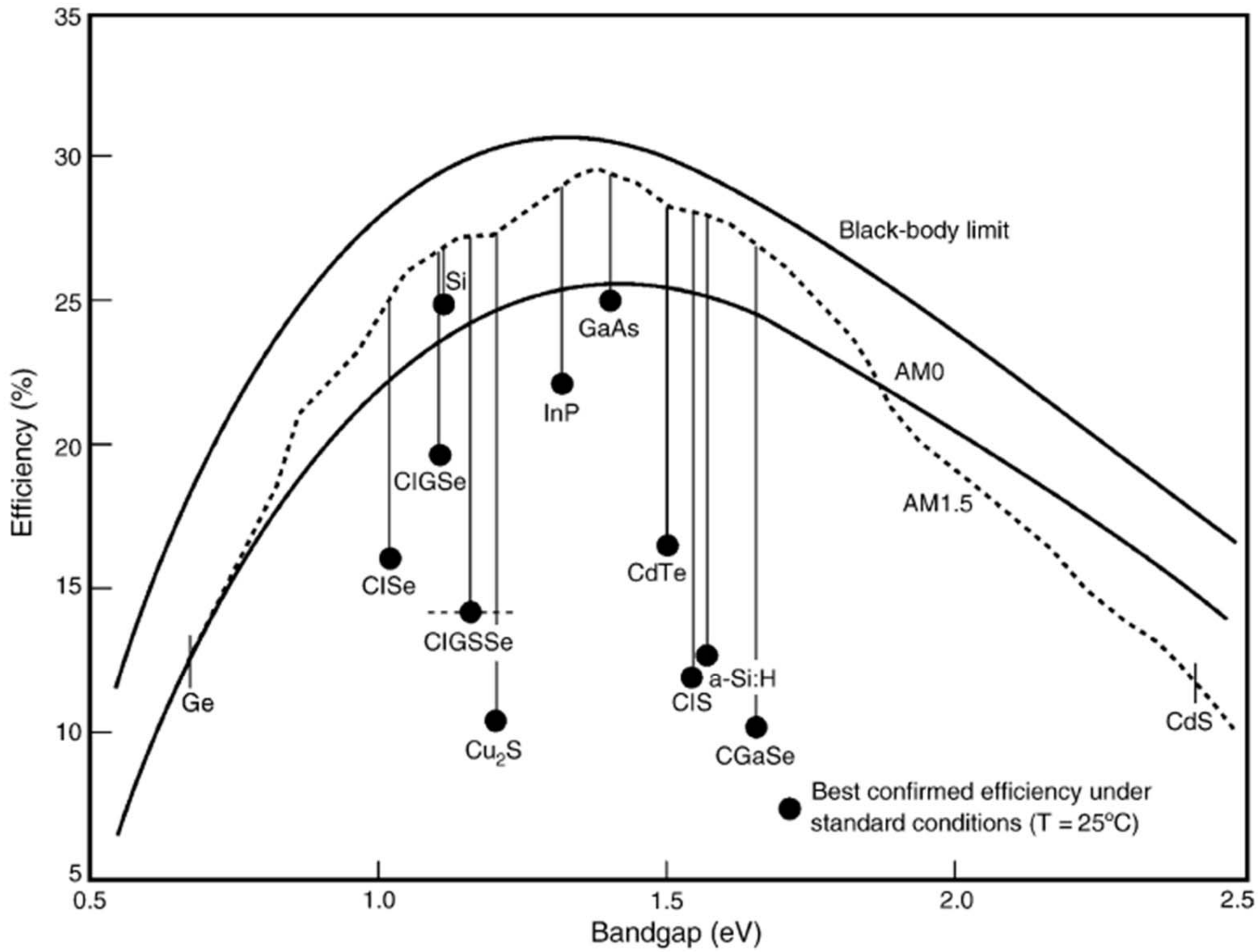


Fig. 3. Performance gaps between best device efficiencies in the laboratory and attainable efficiencies for several solar cell technologies.

L.L. Kazmerski / Journal of Electron Spectroscopy and Related Phenomena 150 (2006) 105–135

Attained vs. attainable **open circuit photovoltage**

Cell Type	E_g at RT (eV)	V_{OC}^{MAX} (V)	V_{OC} (V)	V_{OC} loss (V)	V_{OC}/V_{OC}^{MAX} (%)
SC-Si	**1.12**	**0.84**	**0.71**	**0.13**	**85**
GaAs	**1.42**	**1.14**	**1.02**	**0.12**	**90**
InP	**1.28**	**1.00**	**0.88**	**0.12**	**88**
CdTe	**1.45**	**1.17**	**0.84**	**0.33**	**72**
CIGS	**1.14**	**0.86**	**0.72**	**0.14**	**84**
a-Si	**1.7**	**1.42**	**0.86**	**0.56**	**61**
DSS					
(black dye)	**1.4**	**1.12**	**0.72**	**0.40**	**64**
(Red N719)	**1.6**	**1.32**	**0.85**	**0.47**	**64**
(Red N3)	**2.0**	**1.72**	**0.80**	**0.92**	**47**
OPV	**1.55**	**1.27**	**0.75**	**0.52**	**59**

Attained vs. attainable **short-circuit photocurrent**

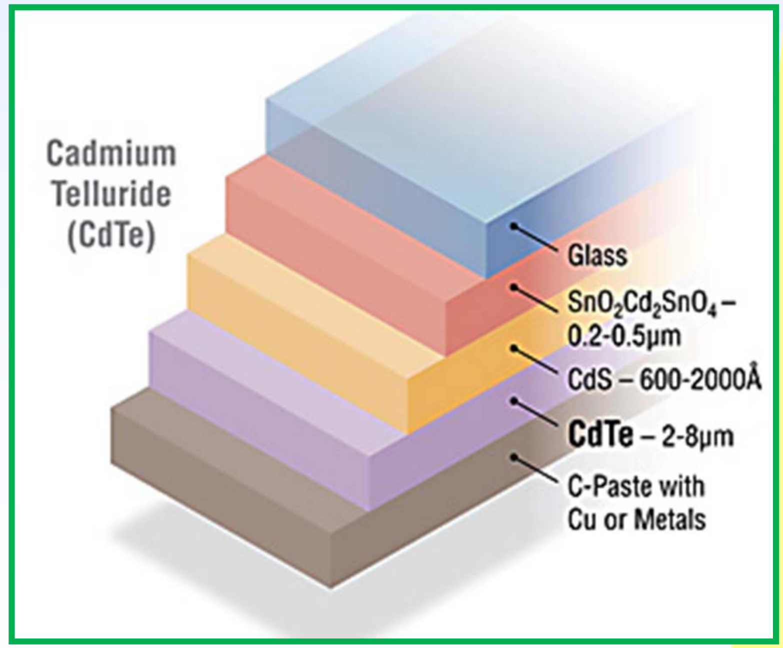
Cell Type	E_g at RT (eV)	J_{SC}^{MAX} (mA/cm^2)	J_{SC} (mA/cm^2)	J_{SC}/J_{SC}^{MAX} (%)
SC-Si	1.12	43.8	42.7	98
GaAs	1.42	32.0	28.5	89
InP	1.28	36.3	29.5	81
CdTe	1.45	30.8	25.9	84
CIGS	1.15	42	33.5	80
a-Si	1.7	22.4	17.5	78
DSS (black dye) (Red N719) (Red N3)	 1.4 1.6 2.0	 33.3 25.5 14.4	 20.5 17.7 9.2	 62 70 64
OPV	1.55	26.9	14.7	55

Basic CdTe PV Device Architecture(s)

Light

Glass substrate
ITO (low resistivity TCO)
SnO_2 (high resistivity TCO)
n-doped CdS (window layer)
p-doped CdTe (absorber)
Au or Ni-Al metal contact

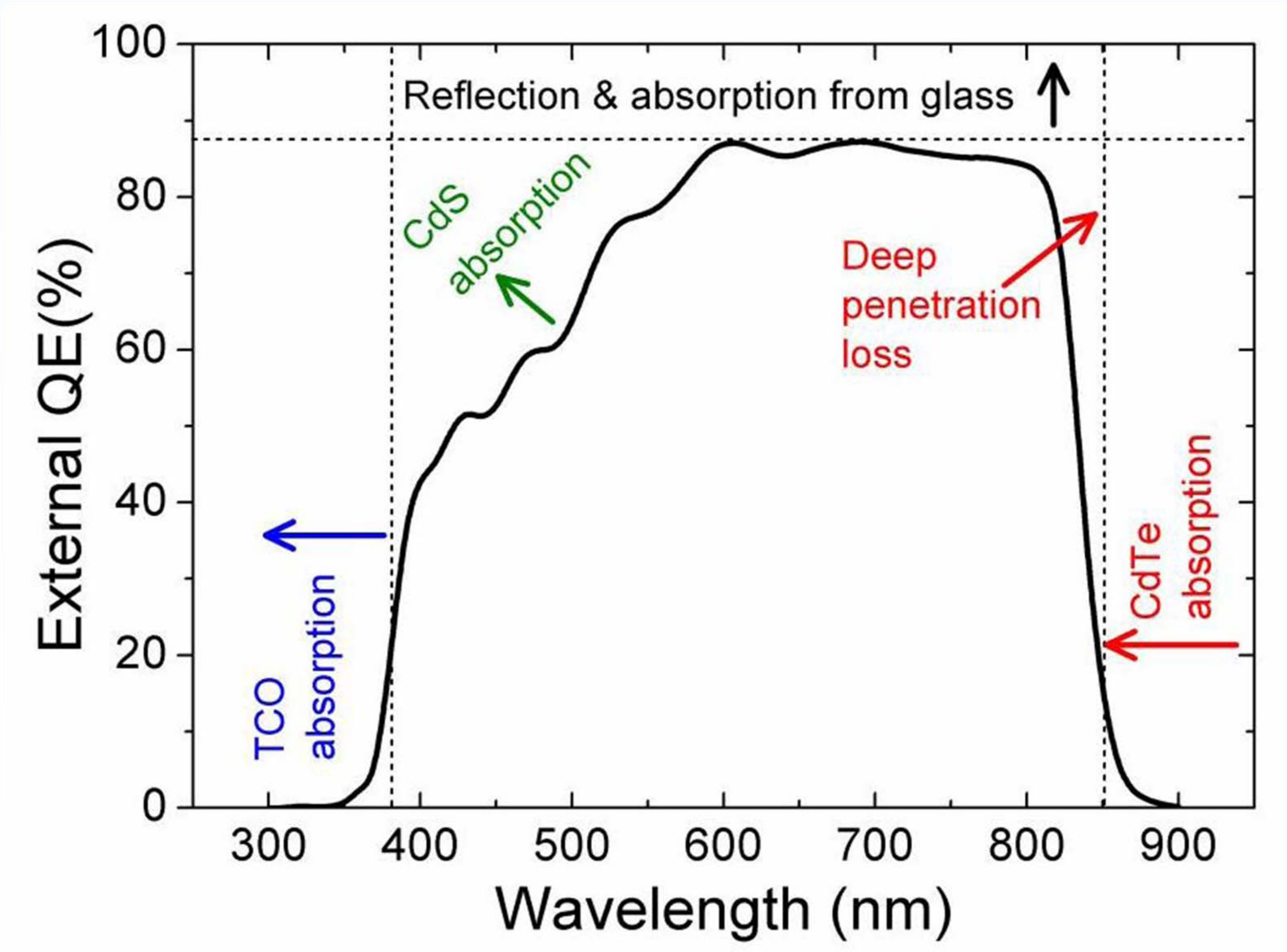
"superstrate"



http://en.wikipedia.org/wiki/File:Cadmium_telluride_thin_film_solar_cell.png

http://www.nrel.gov/pv/thinfilm.html

EQE for typical CdTe solar cell



Naba R. Paudel, University of Toledo Dissertation: "Stability issues in sputtered CdS/CdTe solar cells"

TCO materials for used w/ CdTe solar cells

Materials	Resistivity	Transmission	Stability
SnO_2:F	$(5\text{-}7)\times10^{-4}$ Ω-cm	~80%	excellent
SnO_2:In_2O_3	2.5×10^{-4} Ω-cm	~85%	good
In_2O_3:F	2.5×10^{-4} Ω-cm	~85%	good
In_2O_3:GeO_2	2×10^{-4} Ω-cm	~85%	good
Cd_2SnO_4	2×10^{-4} Ω-cm	>85%	fair
ZnO:Al_2O_3	$(4\text{-}6)\times10^{-4}$ Ω-cm	>85%	fair
ZnO:In	8×10^{-4} Ω-cm	~85%	good

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CdS and CdTe sputtering system

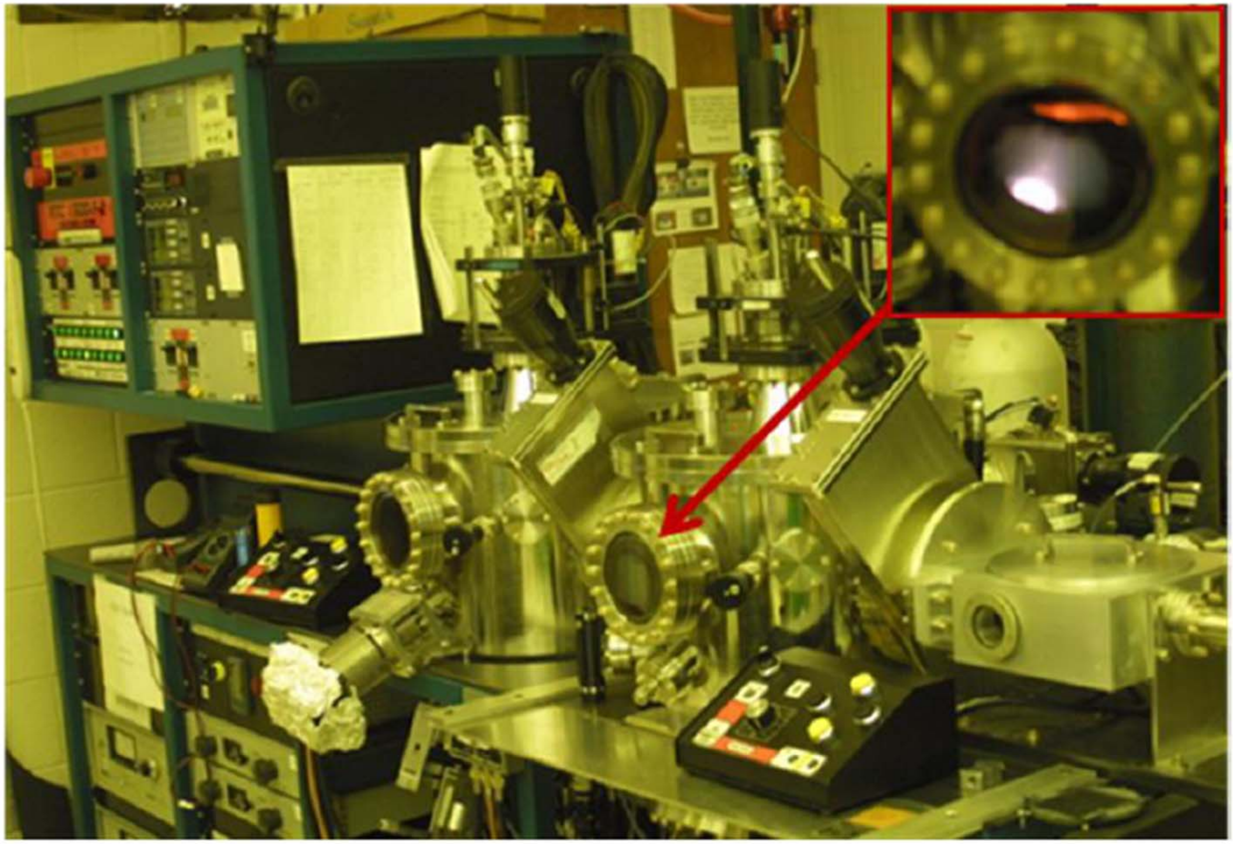

Figure 2-2. CdS/CdTe sputtering system designed by AJA International located at MH3023 in University of Toledo. [Inset shows CdTe plasma through the viewport of chamber B during sputter deposition. The CdTe deposition is going on the glass substrate which is face down and rotating continuously for uniform coating.]

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Sputtered CdS film

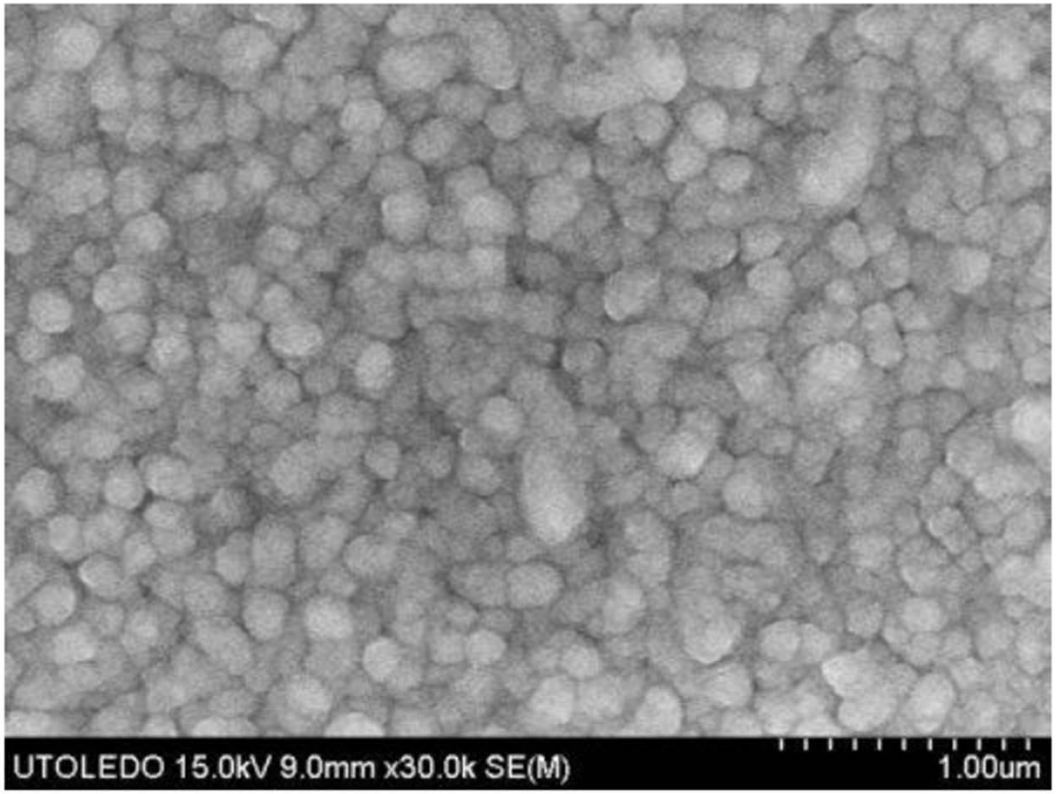

Figure 1-14. Secondary electron micrograph of as grown CdS film sputtered on SnO_2:F coated glass substrate.

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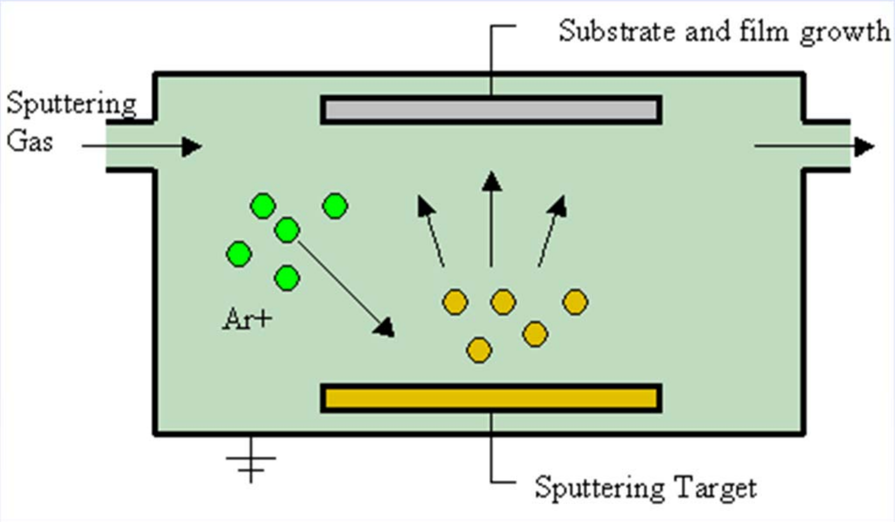
Sputter deposition

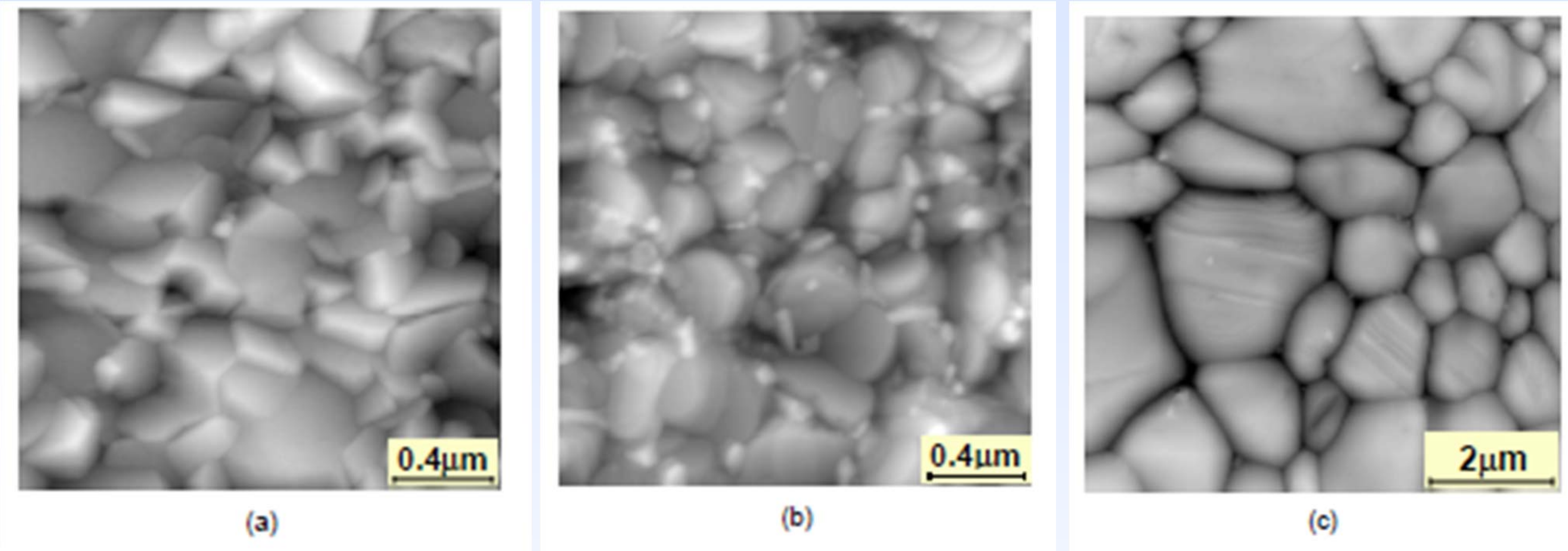


- Sputtered atoms have a wide range of energies;
- Ballistic atoms or ions can result in resputtering from thin film;
- Control of the atom energetic distribution can be accomplished through variation of chamber inert gas pressure (e.g., Ar);
- Note that CdTe sputters (and evaporates) congruently, i.e., as a CdTe molecule. This maintains very close 1:1 stoichiometry of the resulting film.

http://heraeus-targets.com/en/technology/_sputteringbasics/sputtering.aspx

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

$CdCl_2$ treatment (recrystallization of CdTe)



PVD CdTe films: (a) untreated, (b) and (c) after CdCl2 heat treatment at 350° and 400°C, respectively.

Studies of Recrystallization of CdTe Thin Films After CdCl Treatment
H.R. Moutinho, M.M. Al-Jassim, F.A. Abufoltuh, D.H. Levi, P.C. Dippo, R.G. Dhere, and L.L. Kazmerski
Presented at the 26th IEEE Photovoltaic Specialists Conference, September 29–October 3, 1997, Anaheim, California

Effects of $CdCl_2$ treatment on as-deposited CdTe films

- Results in CdTe grain growth (especially w/ sputtered films and PVD-grown films, less so w/ CSS)
- Reduces lattice strain (also promotes grain growth)
- Increases minority carrier lifetime (~ x10), perhaps due to reduction in deep level defect densities within the bandgap.