

Modern photovoltaic technologies

PHYS-609

Part 1.3 Thin-film solar cells*

- CIGS solar cells
- CdTe solar cells

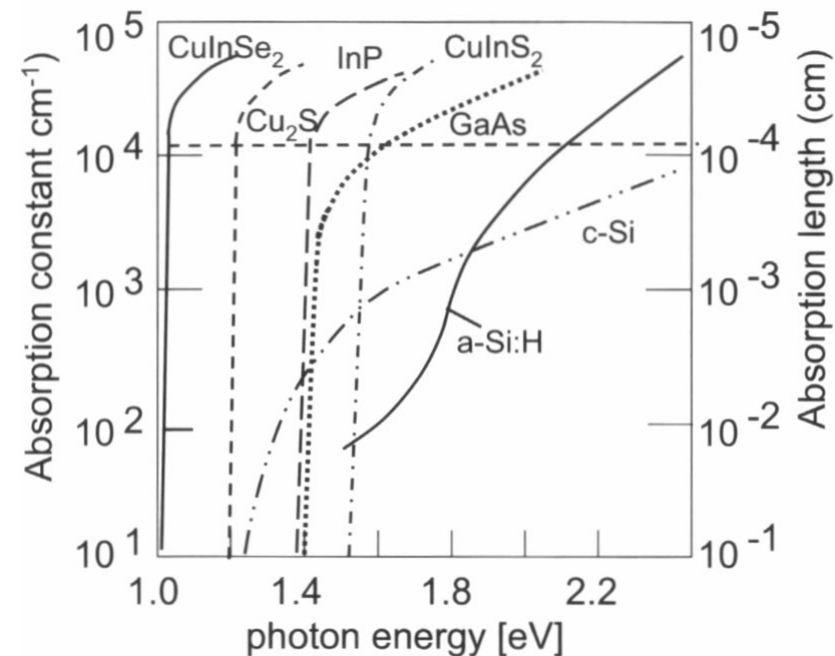
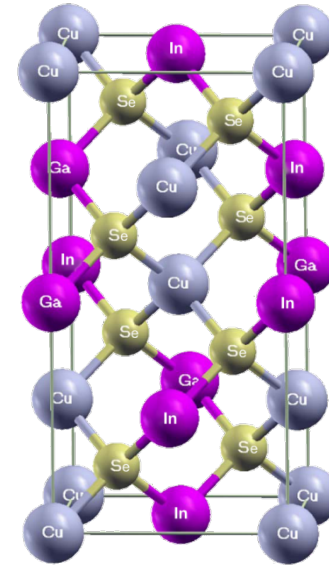
* Amorphous Si and perovskite cells are also thin-film technologies and will be covered on Day 2 & 3

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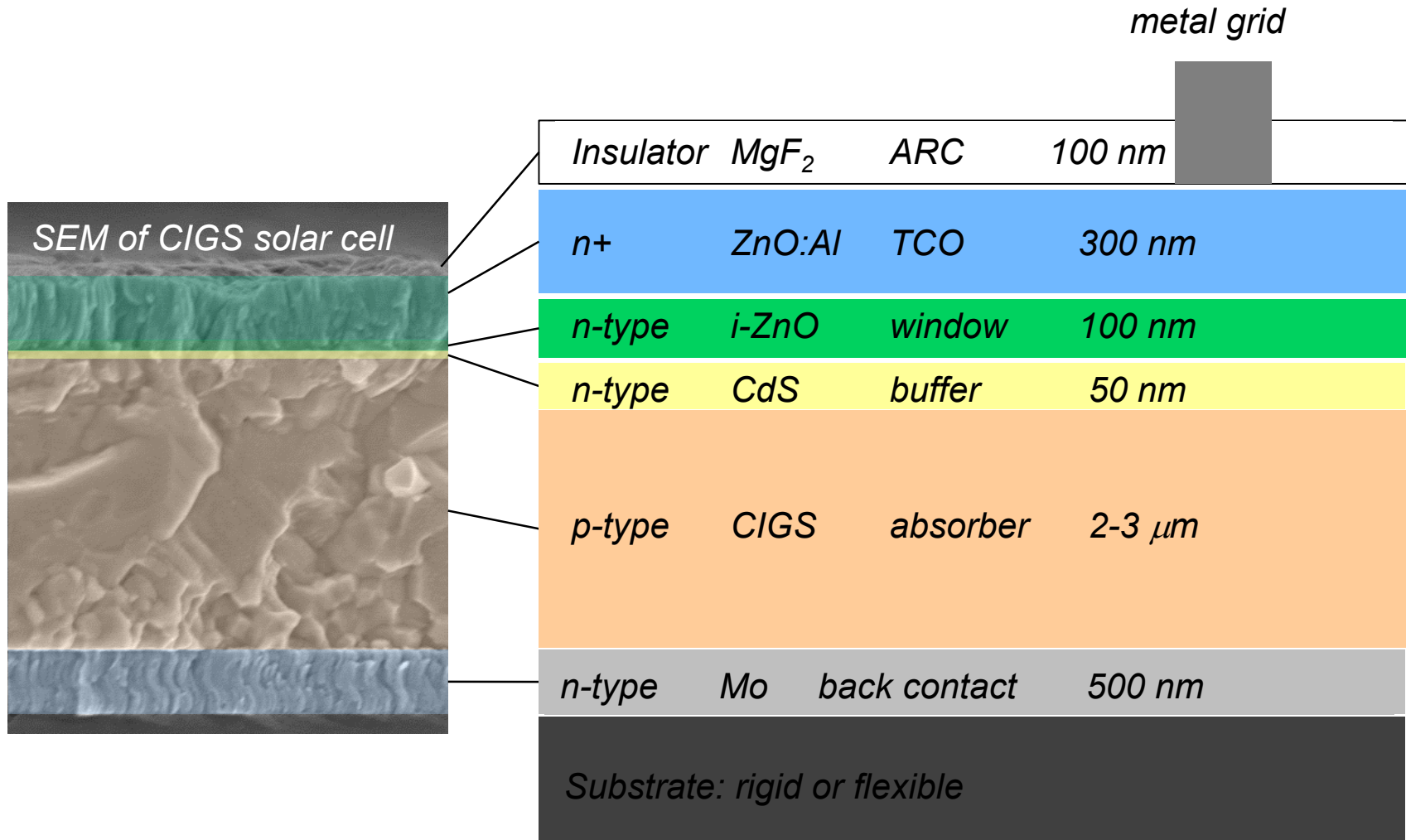
Cu(In,Ga)Se₂ (CIGS) solar cells

CuInSe₂ = CIS

- crystal structure:
 - tetragonal chalcopyrite (CuFeS₂) structure derived from cubic ZnSe
- direct gap semiconductor
 - band gap 1.04eV – 1.68eV (adding Ga)
 - absorption coefficient > 10⁴ cm⁻¹
 - => thickness of <1μm is enough to absorb light
- p-type conductivity
 - Cu vacancies -> intrinsic p-doping
 - electrically inactive grain boundaries
 - polycrystalline material
 - => robustness, flexible substrates



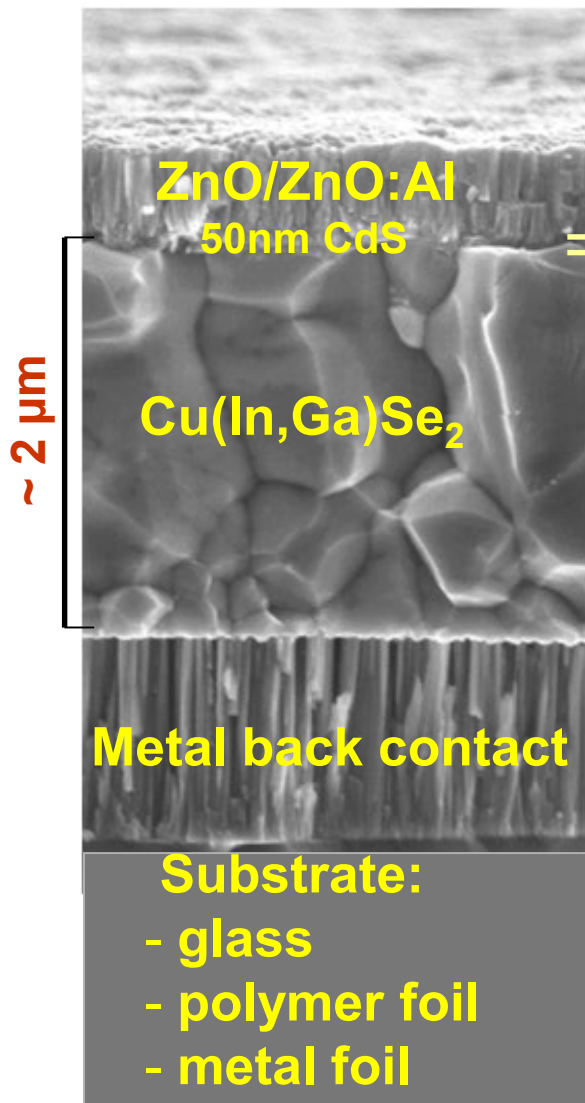
Structure of CIGS cell



Resistivity (Ω cm):

ZnO:Al ($\sim 10^{-3}$), i-ZnO ($\sim 10^5$), CdS ($\sim 10^5$), CIGS ($\sim 10^2$), Mo ($\sim 10^{-6}$)

Fabrication of CIGS solar cells

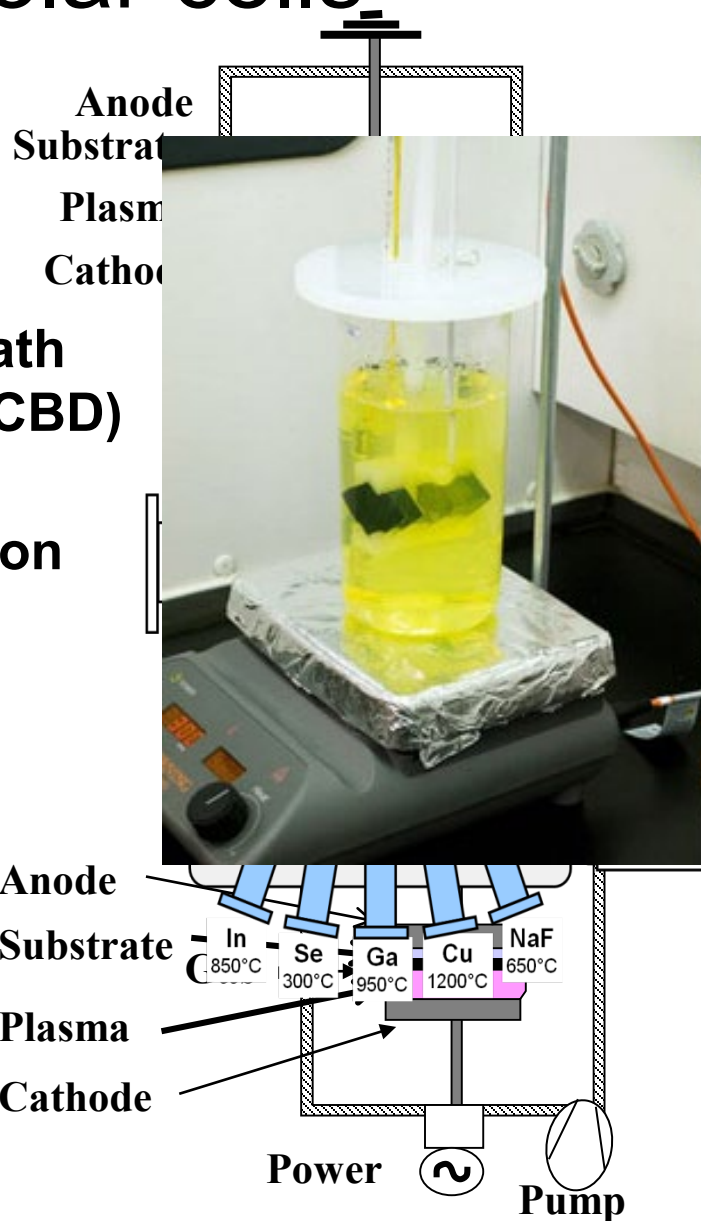


Sputtering

**Chemical Bath
Deposition (CBD)**

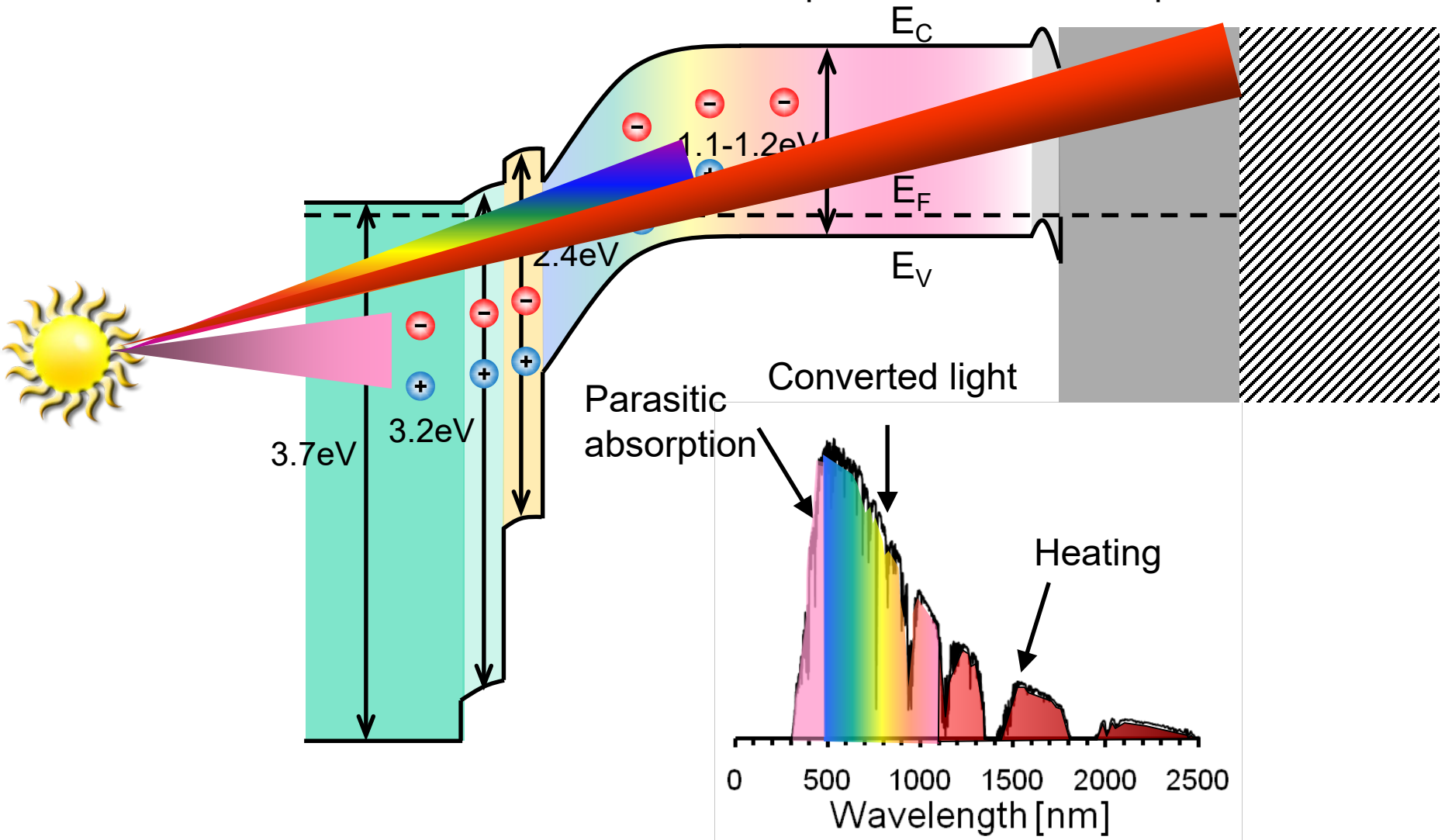
Co-evaporation

Sputtering

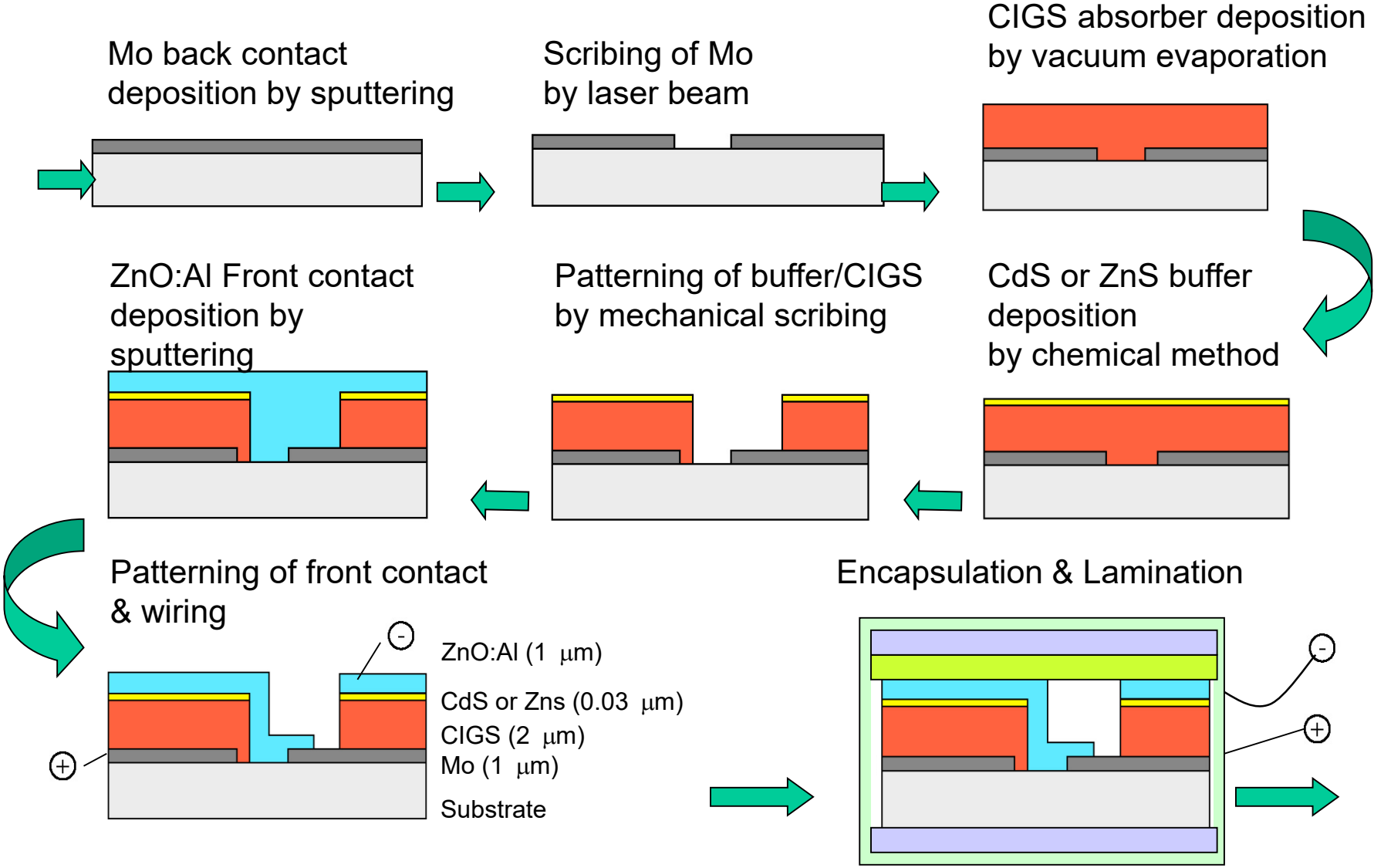


Operation of CIGS solar cell

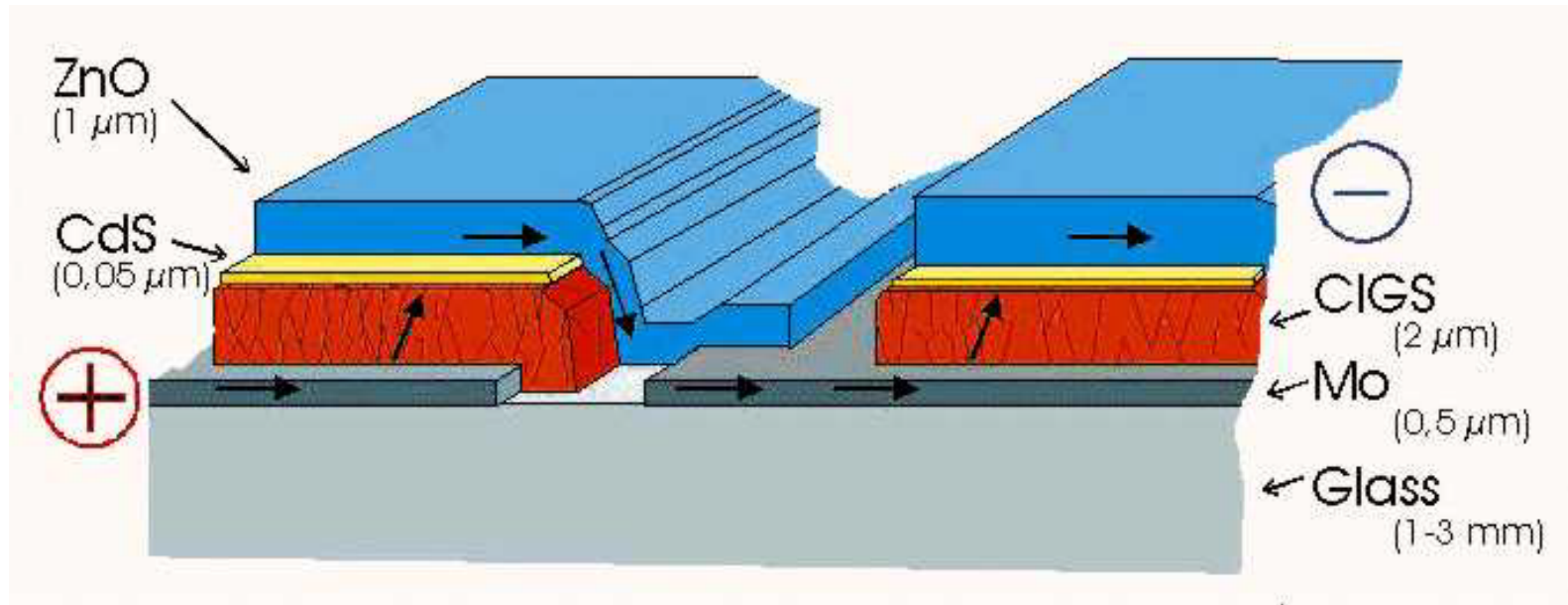
ZnO:Al	i-ZnO	CdS	CIGS	MoSe ₂	Mo	Substrate
300nm	50nm	50nm	1-3μm	10nm	0.5μm	



CIGS solar module fabrication



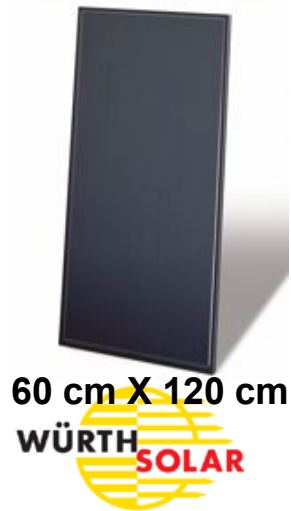
Monolithic interconnection in modules



- Connections between cells are made between deposition of individual layers (in contrast to wiring of individual silicon cells solar)
- Lasers and/or sharp needles are used for scribing

CIGS solar modules on glass

Solar Frontier (Japan), NICE Solar (Manz Solar) (Germany), Avancis (Germany), Honda (Japan), TSMC (Taiwan), ...

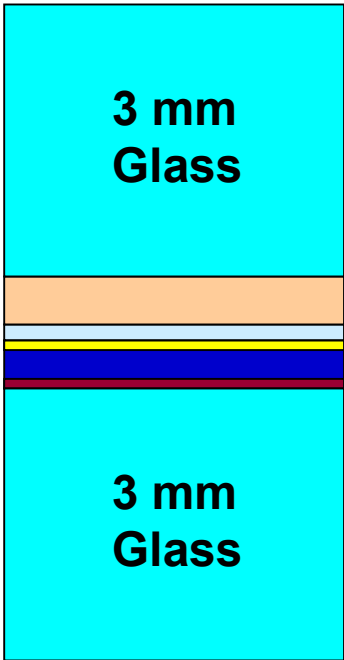


Solar Frontier

Flexible thin film solar modules



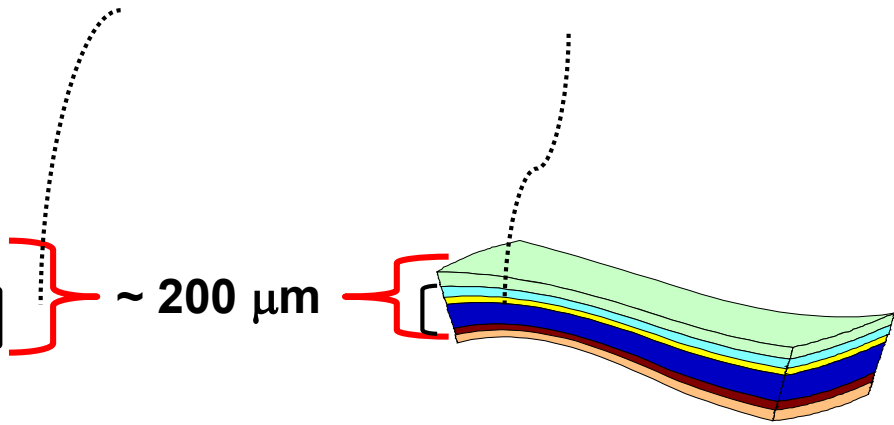
Mature technology



Emerging technology

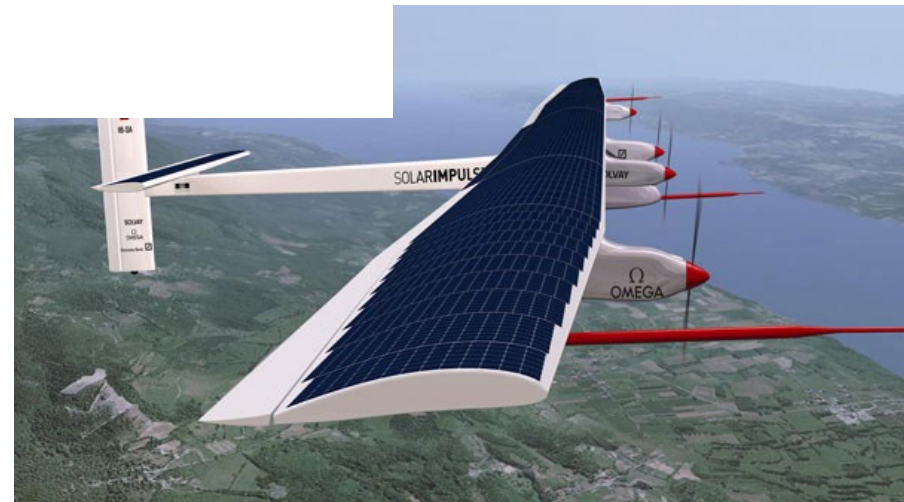
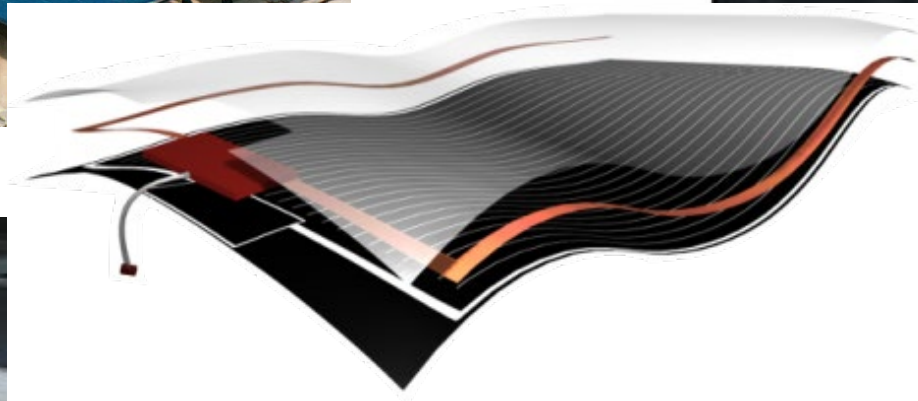


Solar cell thickness ~ 4 μm

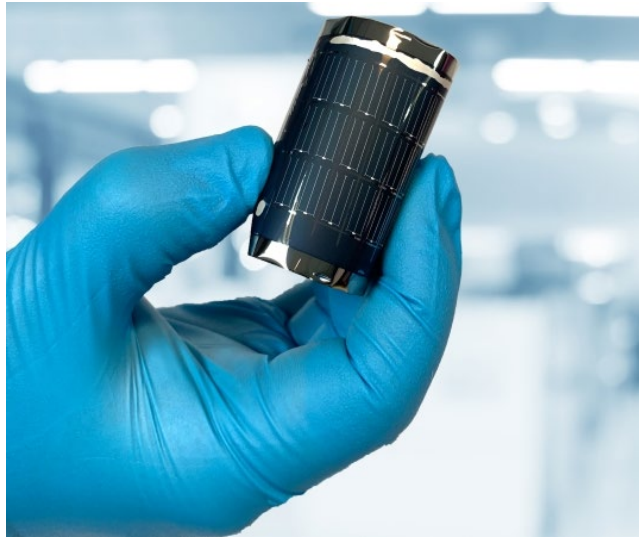


Modules on foils: Flexible Lightweight

Targeted applications for flexible solar cells

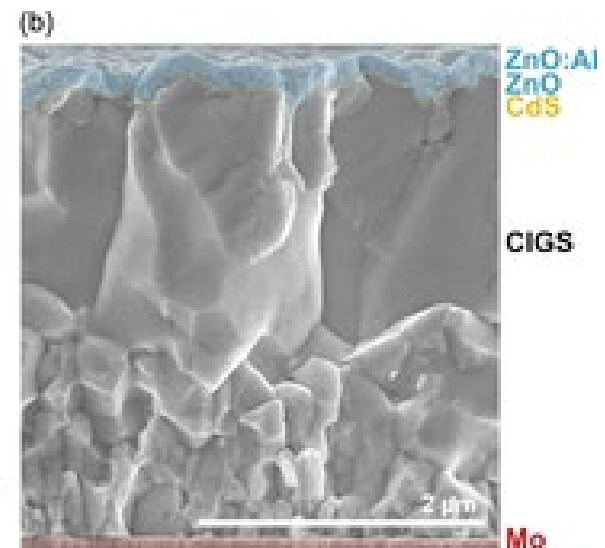
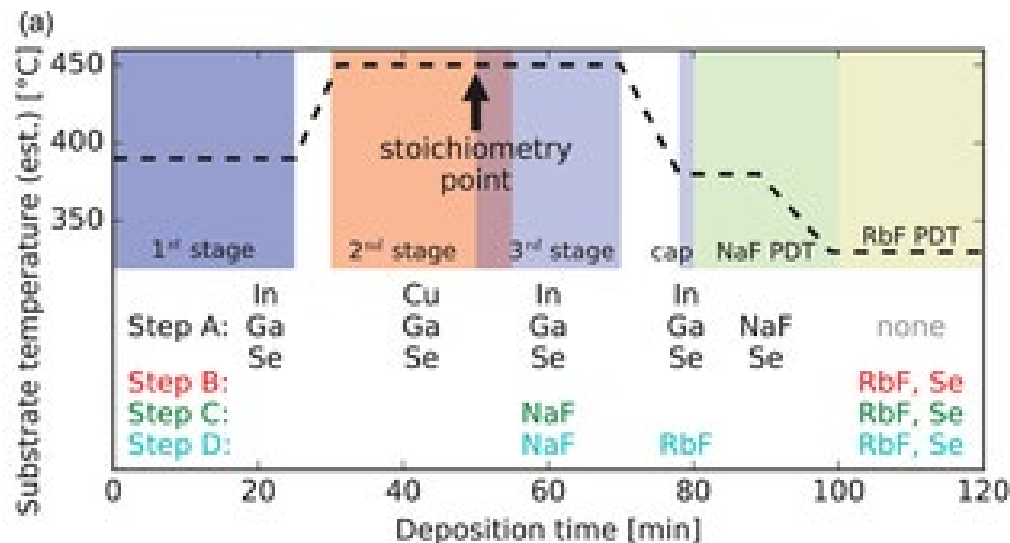


CIGS on flexible polymer substrate



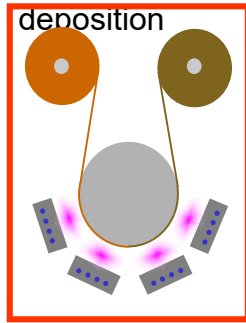
World record 21.4% flexible CIGS cell on polyimide substrate (Empa, 2021)

- Complex 3-stage evaporation process at 450°C together with NaF & RbF co-doping

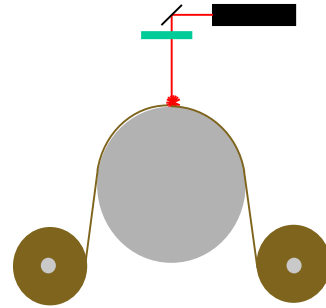


Roll-to-roll manufacturing

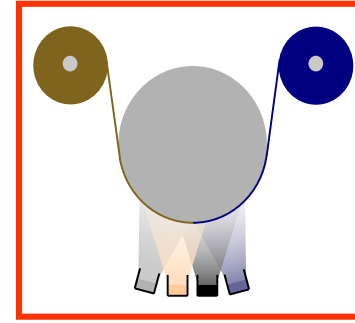
Back contact sputter deposition



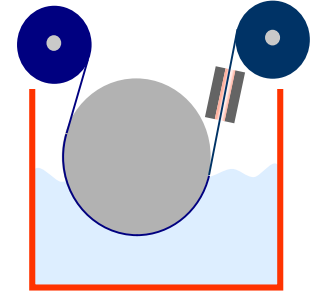
Laser scribing P1



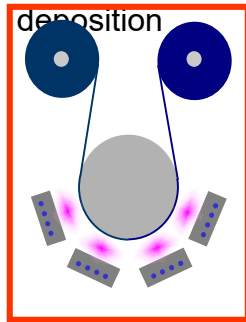
CIGS co-evaporation



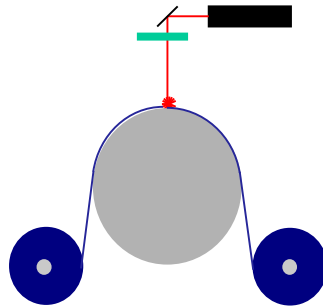
Buffer layer deposition by chemical bath



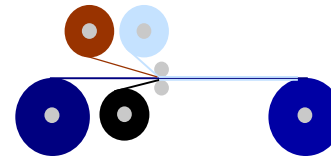
Front contact sputter deposition



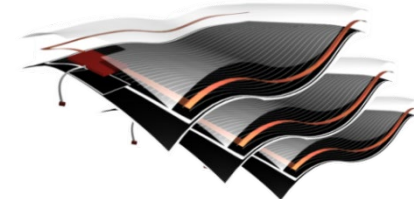
Laser scribing P2&P3



Contacts application Lamination



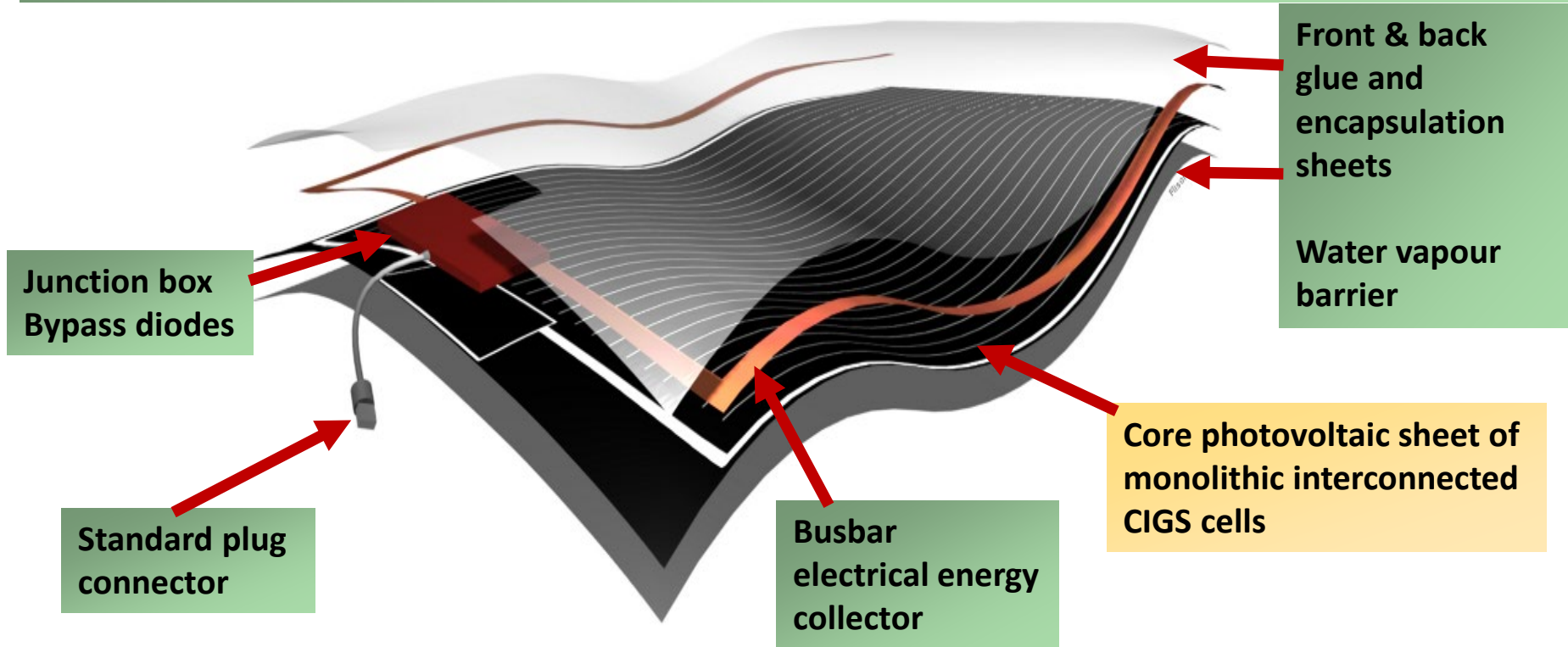
Module cutting
Junction box and connector application



Flexible CIGS solar module

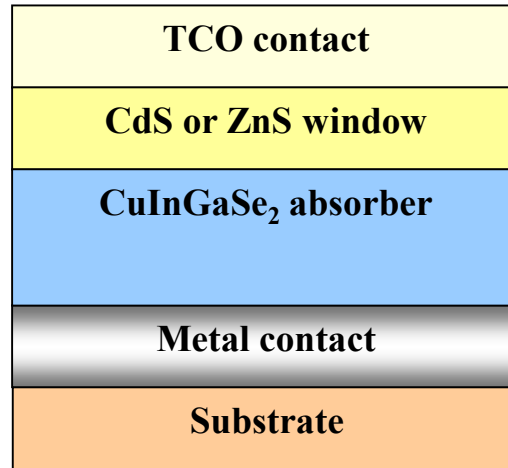
Front-end processing: Active layers & metal grid coatings on Substrate material

Back-end processing: Contacts, Encapsulation foils, Lamination, Junction Box



- High material costs in back-end processing
- Sophisticated automatization available
- Production area intensive

Summary CIGS thin film technology

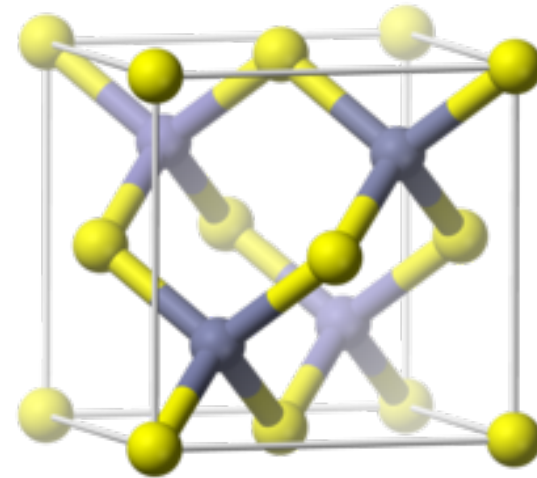


- Efficiency on various substrates:
 - 23.4% on glass (SolarFrontier, 2019)
 - 22.2% on flexible polymer foil (Empa, 2022)
 - 17.6% module efficiency (NICE Solar, 2019)
- Suited for BIPV and mobile applications

CdTe solar cells

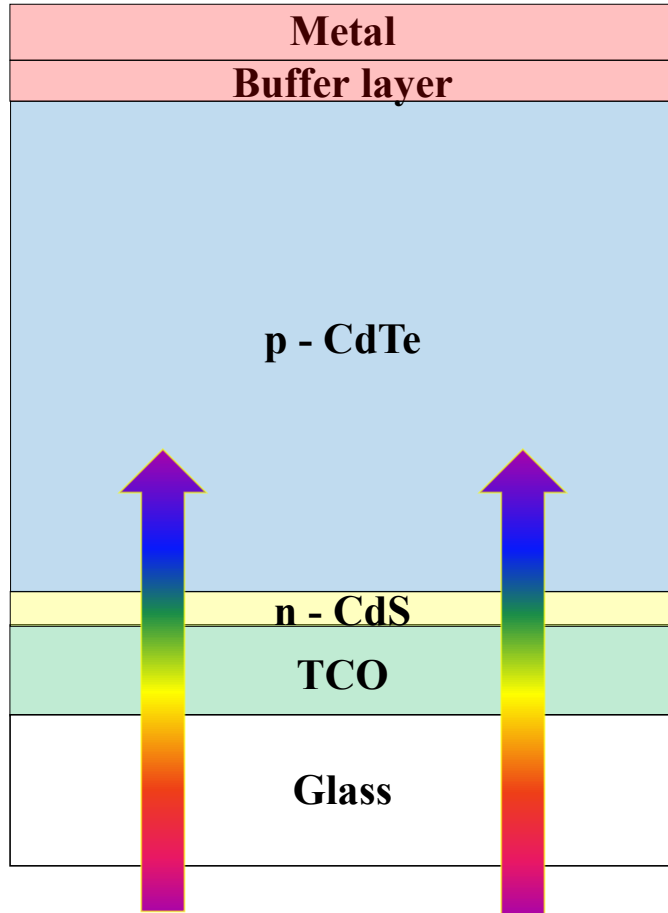
CdTe material

- Almost ideal energy band gap of 1.45 eV at room temp
- High absorption coefficient (1 μm CdTe absorbs >92% of the photons with energy above band gap)
- Simple growth of CdTe
- Chemically and thermally robust



Structure of CdTe solar cells

- Superstrate configuration is used for high efficiency CdTe cells:
- Substrate must be transparent (glass)



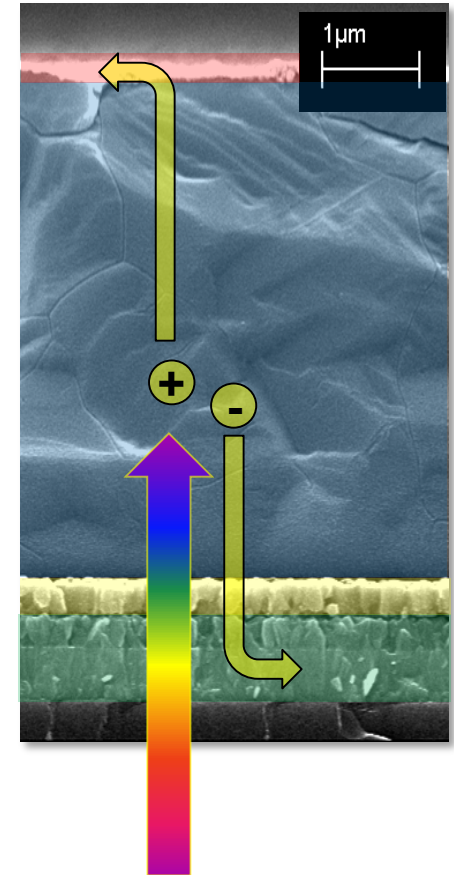
Back contact 50 - 2000 nm

Absorber 2 - 10 μm

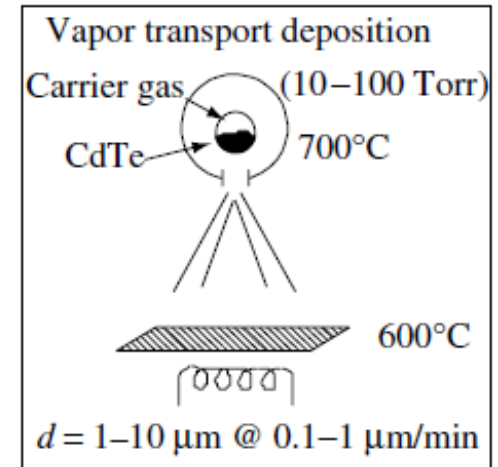
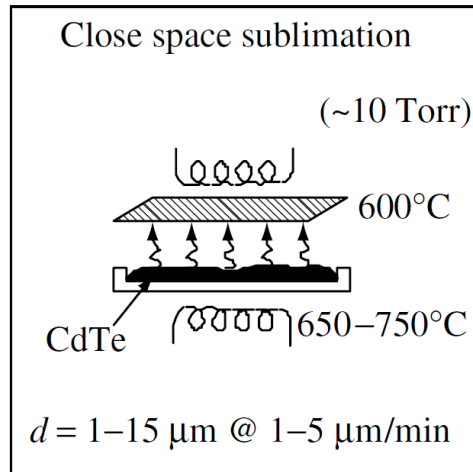
Window 30 - 500 nm

Front contact 0.5 - 1 μm

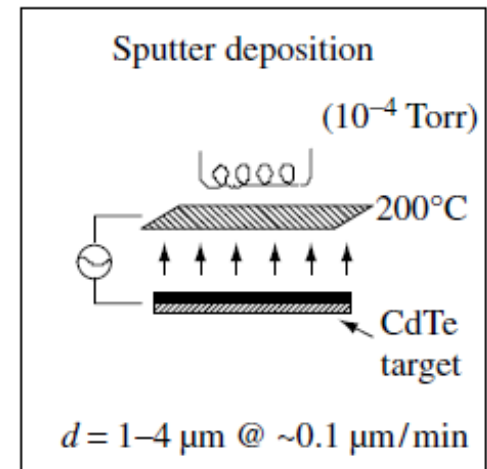
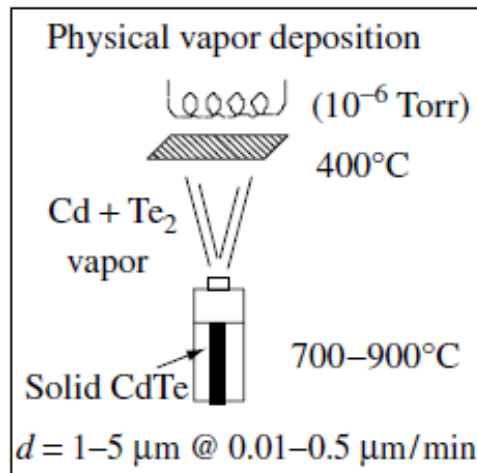
Substrate 1 - 3 mm



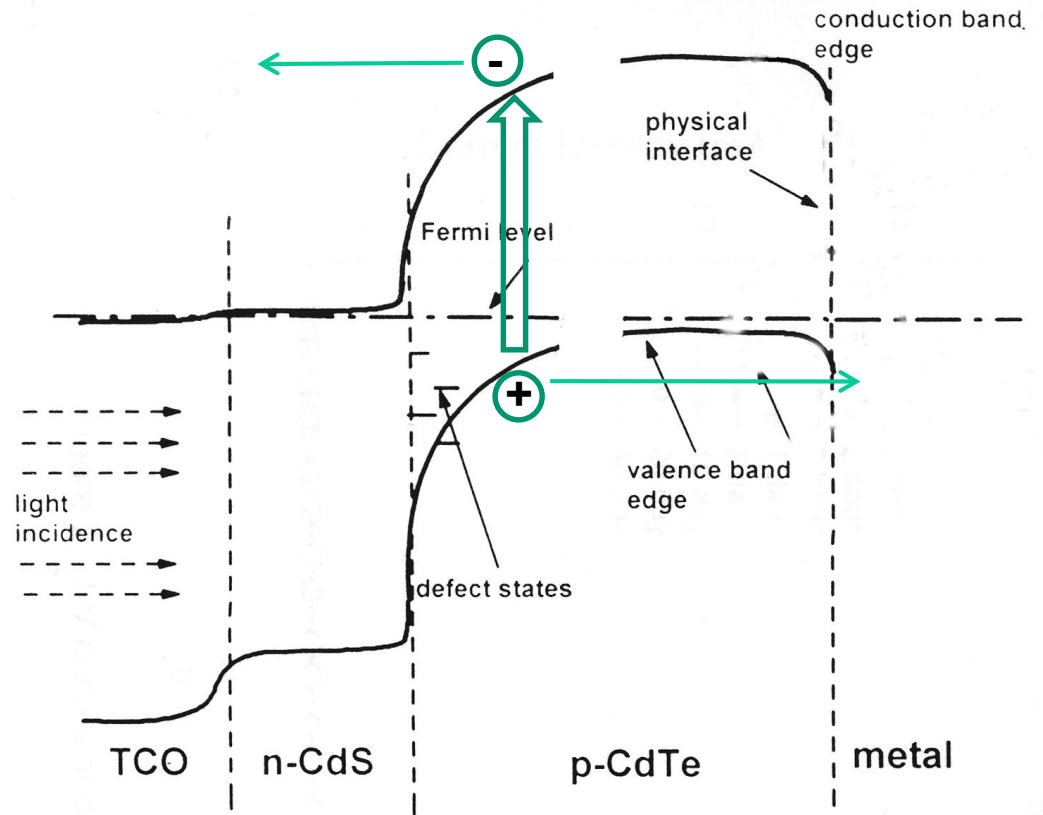
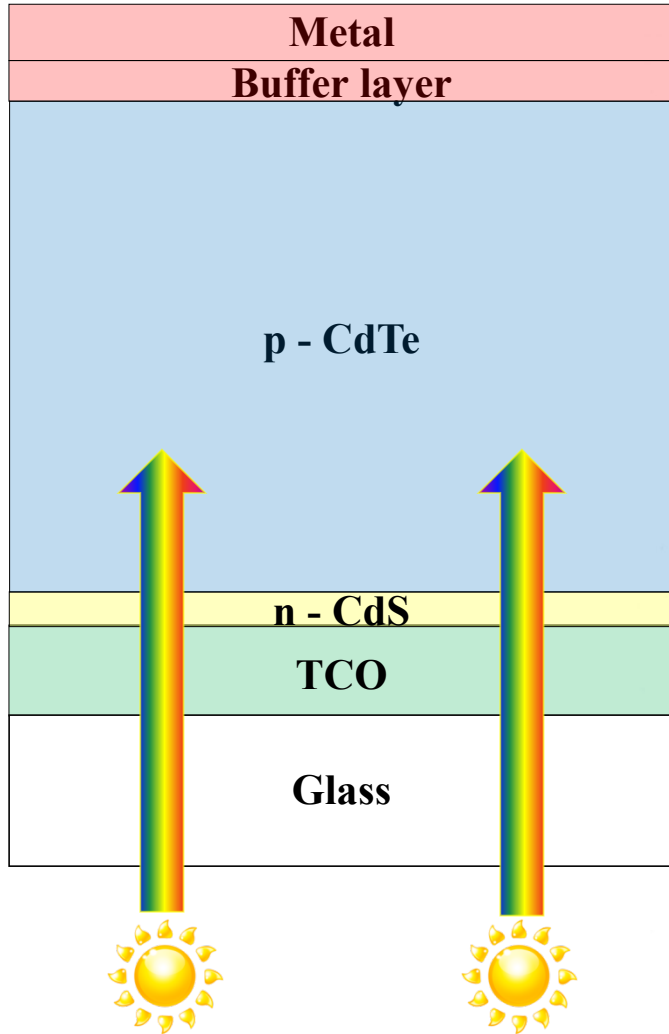
Deposition methods for CdTe



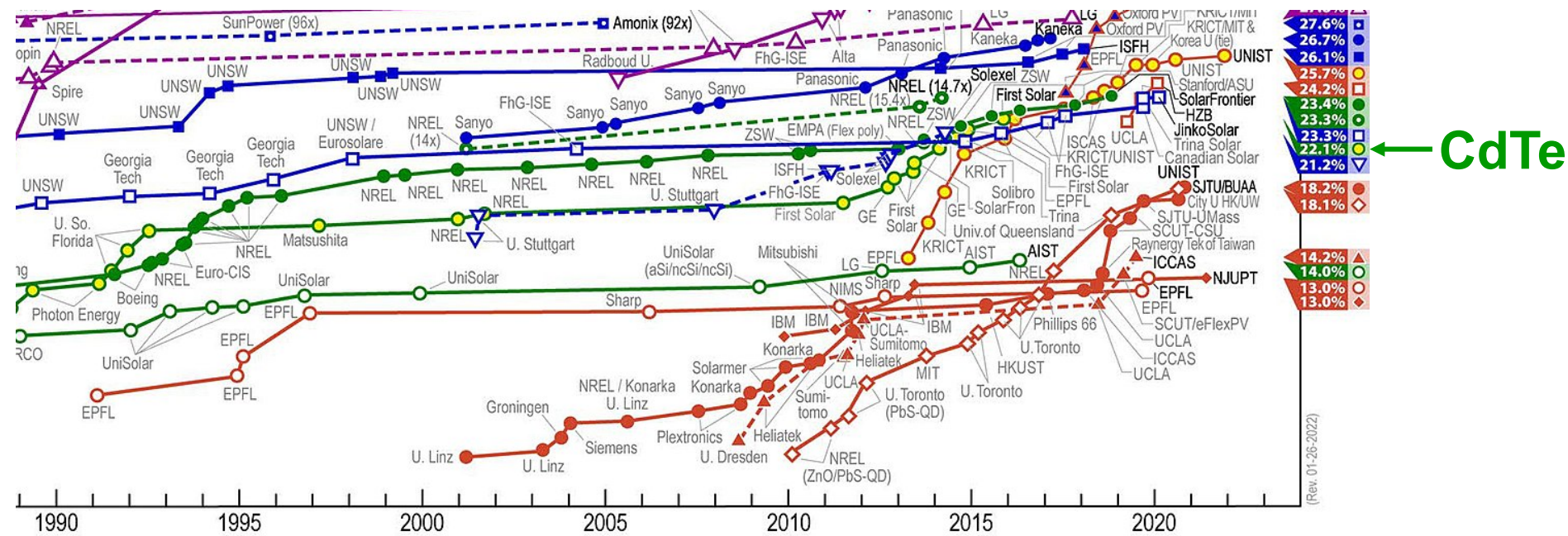
Vacuum techniques



Operation



Efficiency of CdTe solar cells



- Significant efficiency improvement from 16.7% to 22.1% within 6 years thanks to industrial research at FirstSolar and GE Global Research

First Solar – the only CdTe company

- More than 10 GW installed worldwide
- 30 manufacturing lines worldwide w/ > 5 GW of annual manufacturing capacity
- Research lab solar cell efficiency 22.1% (2017)

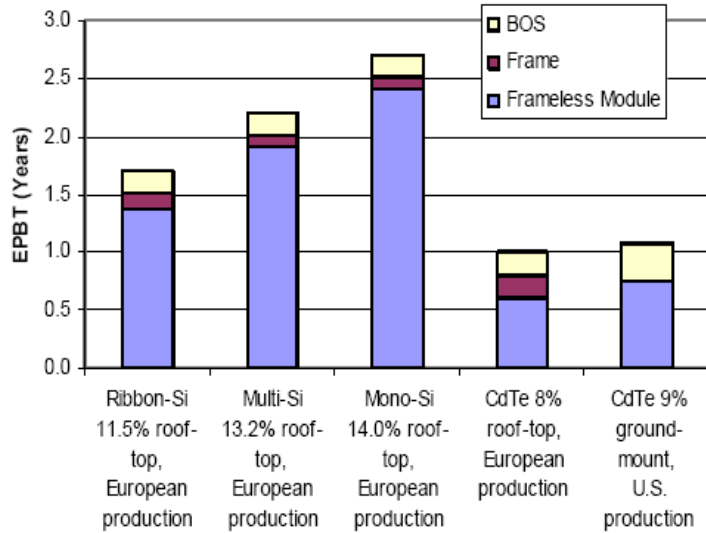


18.6% module efficiency (2017)



Environmental aspects of Cd

Energy Payback Times

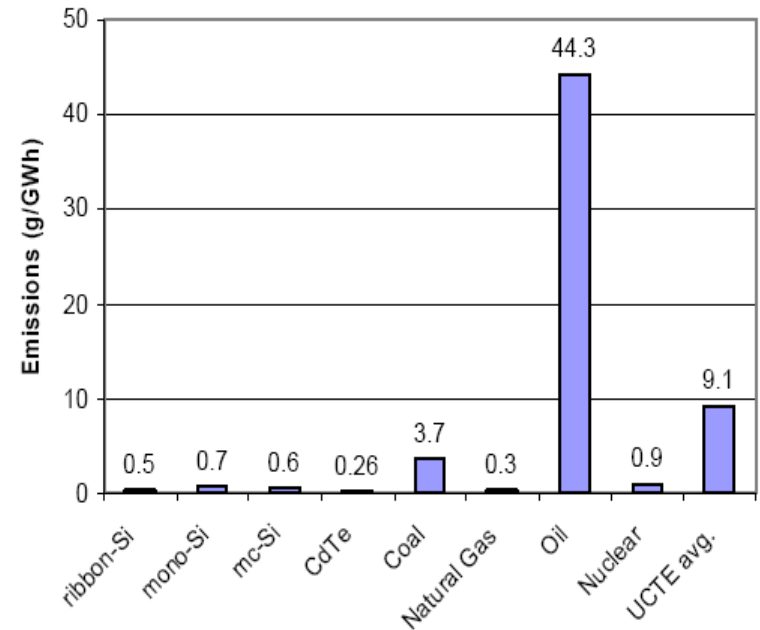


-Alsema & de Wild, *Material Research Society, Symposium vol. 895, 73, 2006*
 -deWild & Alsema, *Material Research Society, Symposium vol. 895, 59, 2006*
 -Fthenakis & Kim, *Material Research Society, Symposium vol. 895, 83, 2006*
 -Fthenakis & Alsema, *Progress in Photovoltaics, 14, 275, 2006*

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Total Life-Cycle Cd Emissions



(PV based on UTCE electricity grid)

25

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- CdTe has one of the lowest energy pay-back times

- CdTe is a stable compound
- No Cd emission during normal operation
- CdTe modules have the lowest total life-cycle Cd emission

Summary CdTe technology

- CdTe solar cells are fabricated in **superstrate configuration**
- Maximum efficiency:
 - 22.1 % on glass** (First Solar)
 - 18.6 % modules** (First Solar)
- Highest market share among thin-film technologies

