

Modern photovoltaic technologies

PHYS-609

Part 1.3 Thin-film solar cells*

- CdTe solar cells
- CIGS solar cells

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

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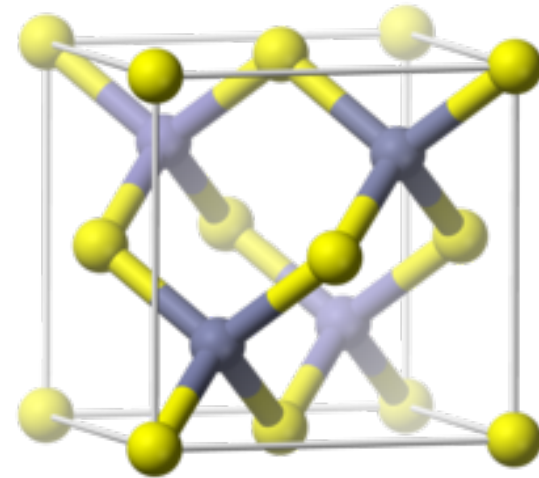
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Materials Science and Technology

CdTe solar cells

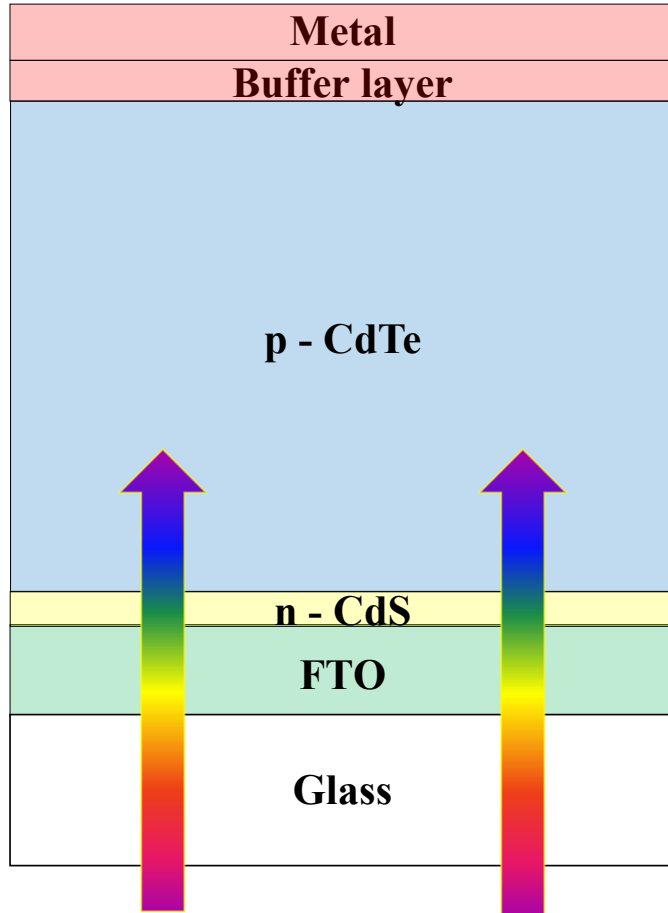
CdTe material

- 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)



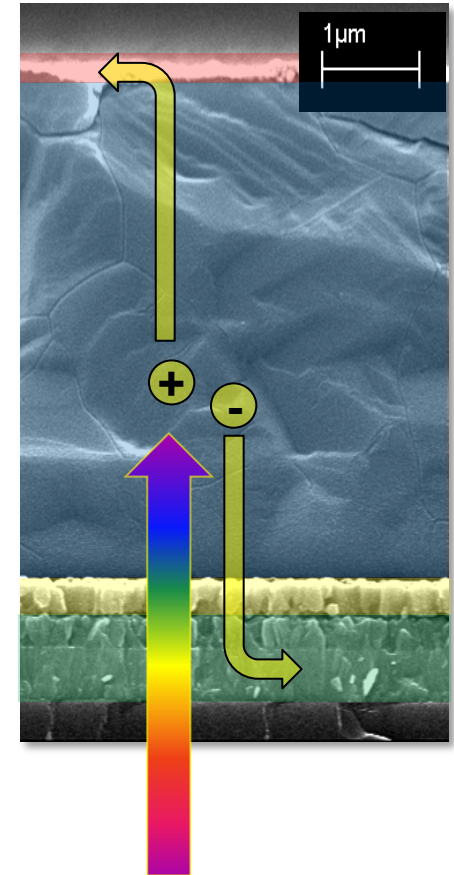
Back contact 50 - 2000 nm

Absorber 2 - 10 μm

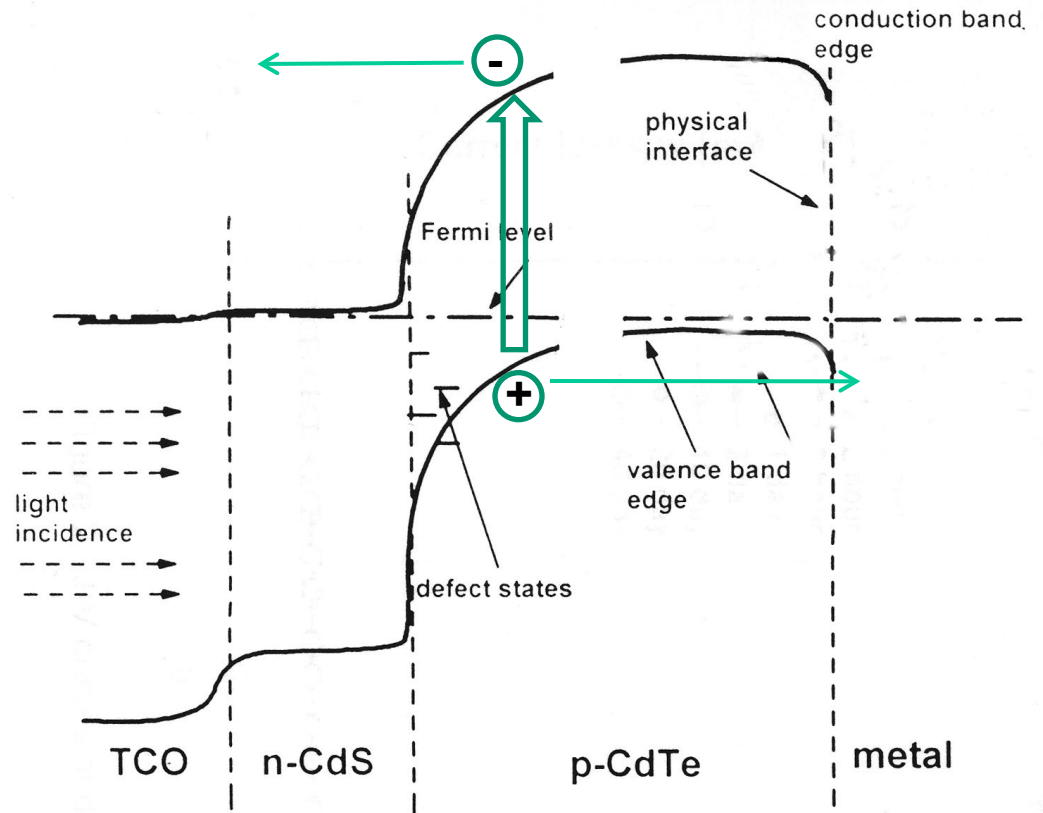
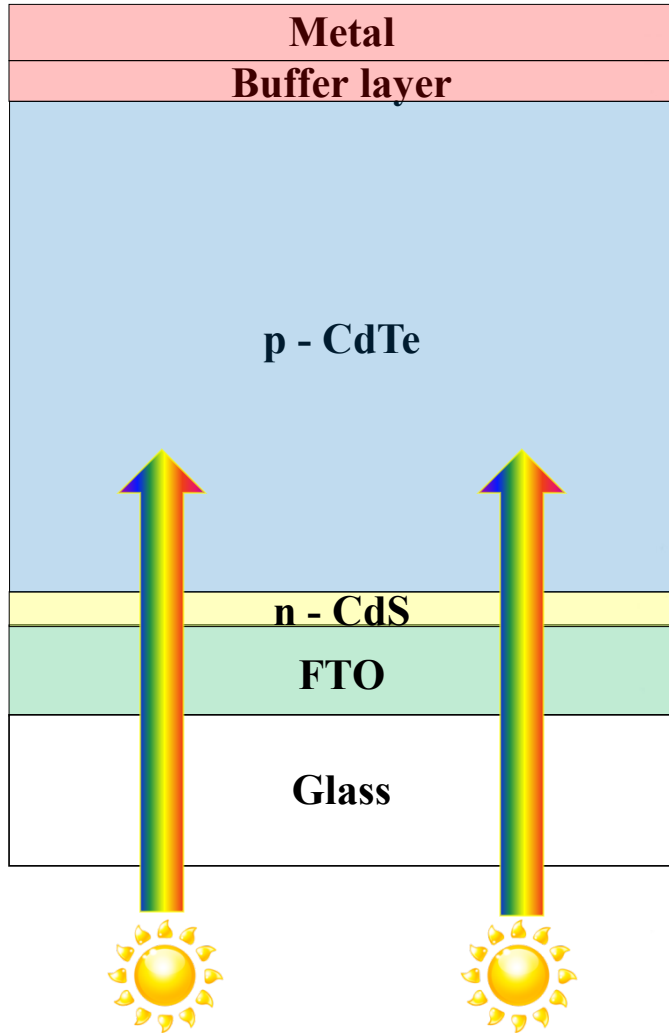
Window 30 - 500 nm

Front contact 0.5 - 1 μm

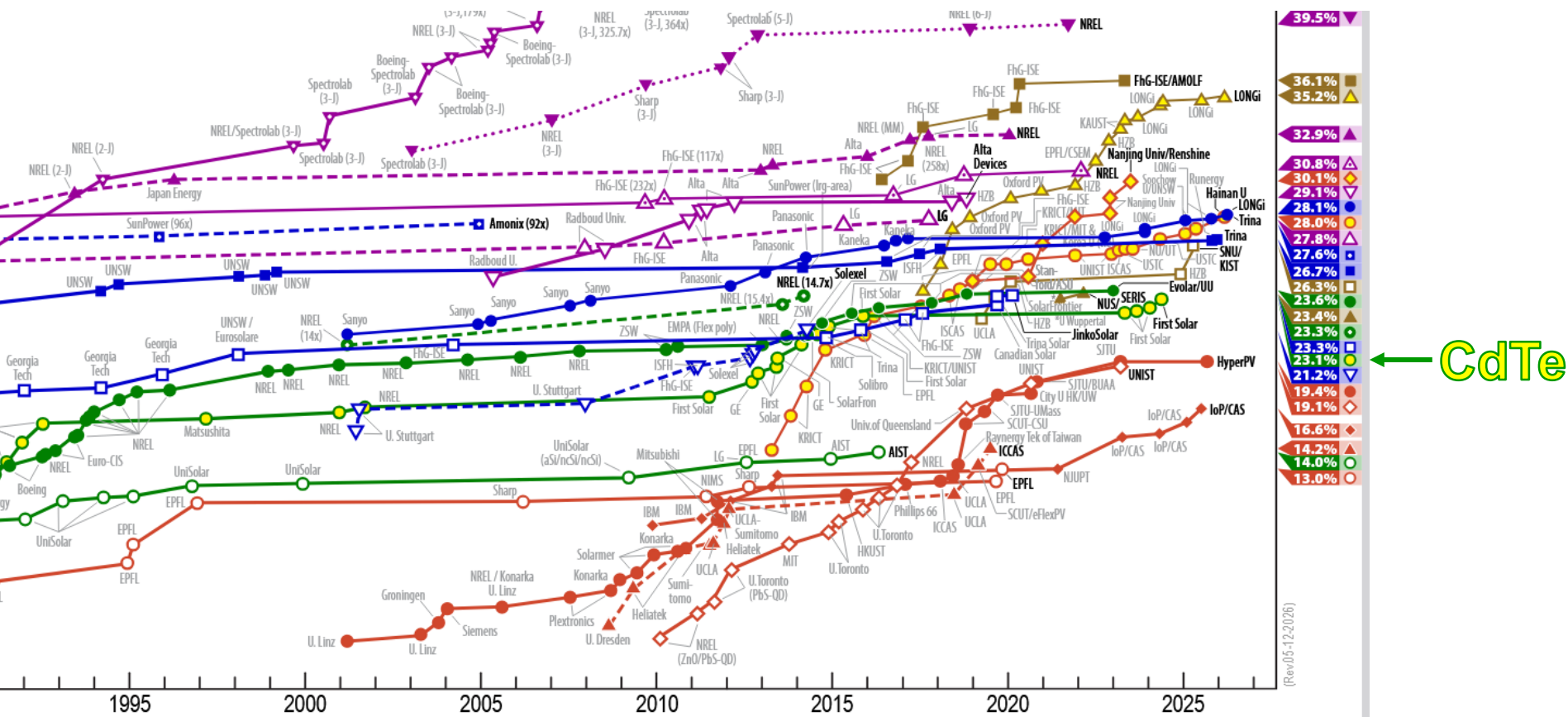
Substrate 1 - 3 mm



Operation



Efficiency of CdTe solar cells



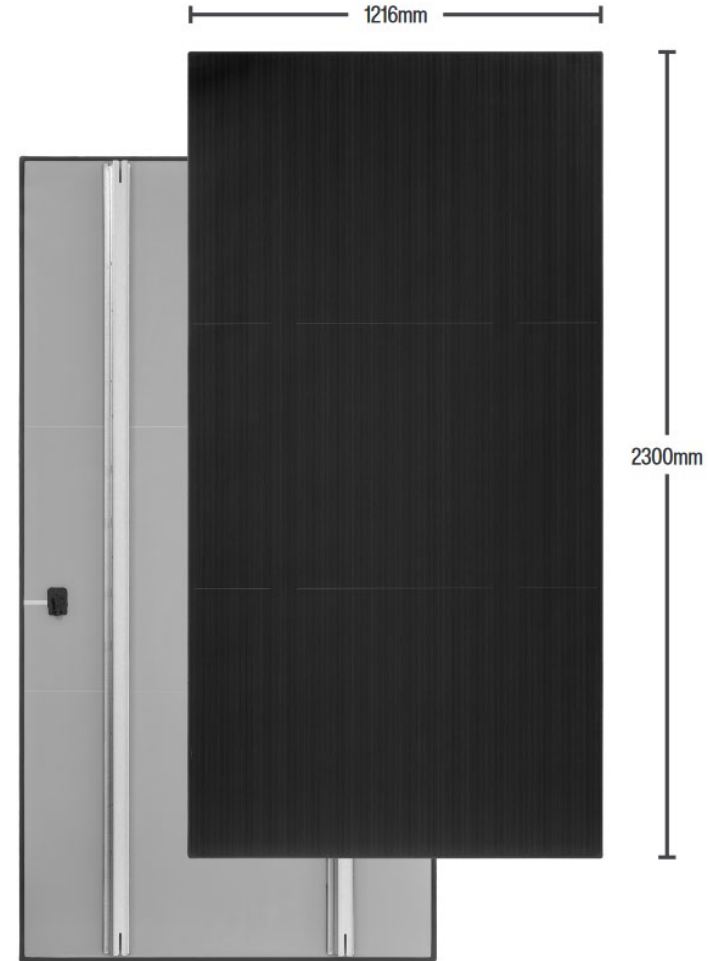
- Significant efficiency improvement from 16.7% to > 22% within 6 years thanks to competitive industrial research at FirstSolar and GE Global Research

First Solar – the only CdTe company

- More than 10 GW installed worldwide
- 30 manufacturing lines worldwide
w/ > 5 GW of annual manufacturing capacity
- 19.7% module efficiency (Series 7 modules)



FirstSolar sells large-scale utility plants



Monolithic interconnection for thin-film PV

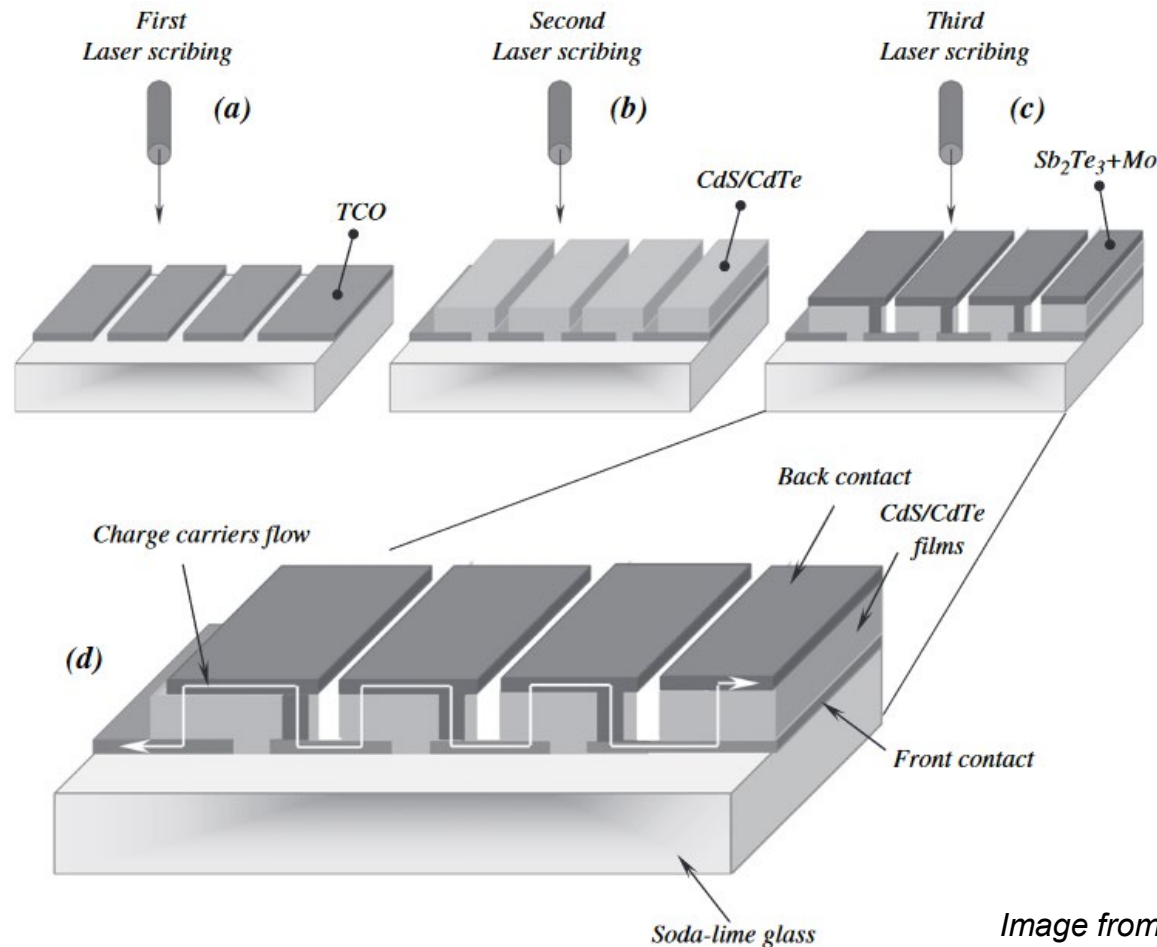
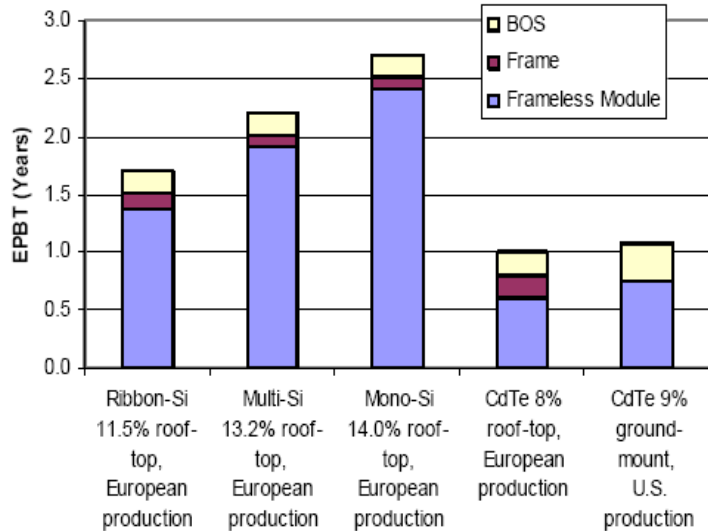


Image from: A. Bosio et al., PIP 2006

- Typical for thin-film techs on insulating substrates: CdTe, CIGS, a-Si, perovskites
- Patterning is performed by mechanical or laser scribing between deposition steps

Environmental aspects of Cd

Energy Payback Times

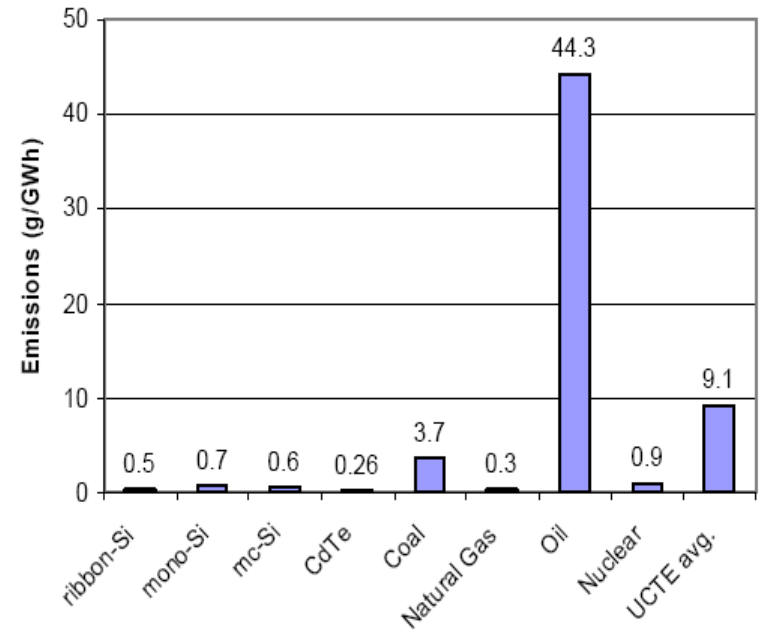


-Alsema & de Wild, *Material Research Society, Symposium vol. 895, 73, 2006*
 -deWild & Alsema, *Material Research Society, Symposium vol. 895, 59, 2006*
 -Fthenakis & Kim, *Material Research Society, Symposium vol. 895, 83, 2006*
 -Fthenakis & Alsema, *Progress in Photovoltaics, 14, 275, 2006*

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Total Life-Cycle Cd Emissions



(PV based on UTCE electricity grid)

25

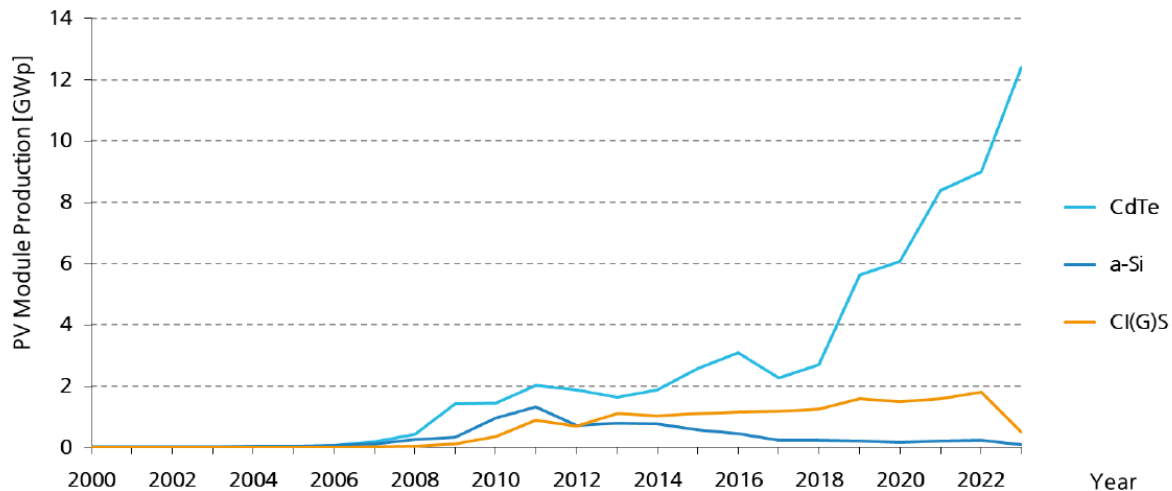
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- CdTe has one of the lowest energy pay-back times

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

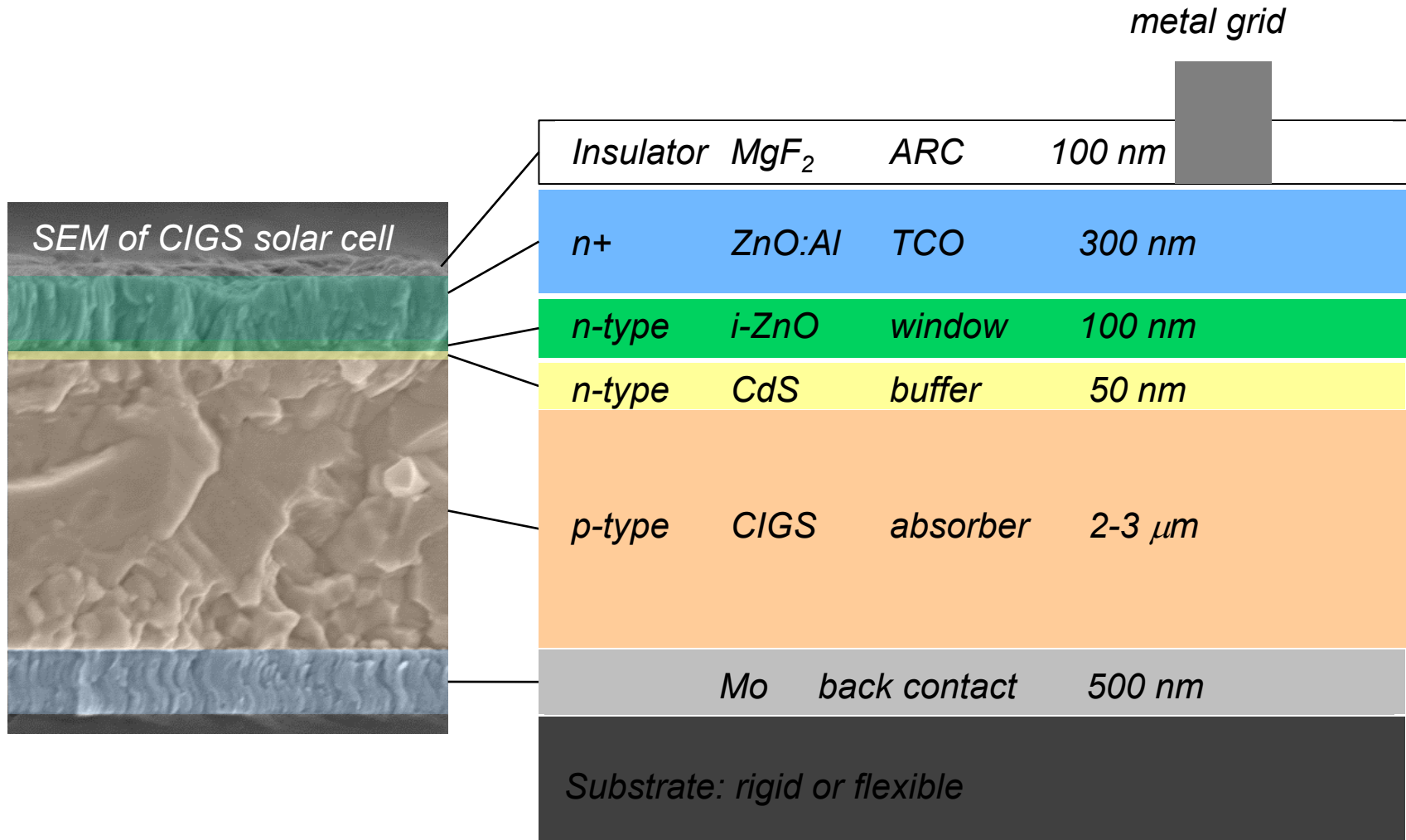
Summary CdTe technology

- CdTe solar cells are fabricated in **superstrate configuration**
- Maximum efficiency:
 - 23.1 % on glass** (First Solar)
 - 19.7 % modules** (First Solar)
- Highest market share among thin-film technologies



Cu(In,Ga)Se₂ (CIGS) solar cells

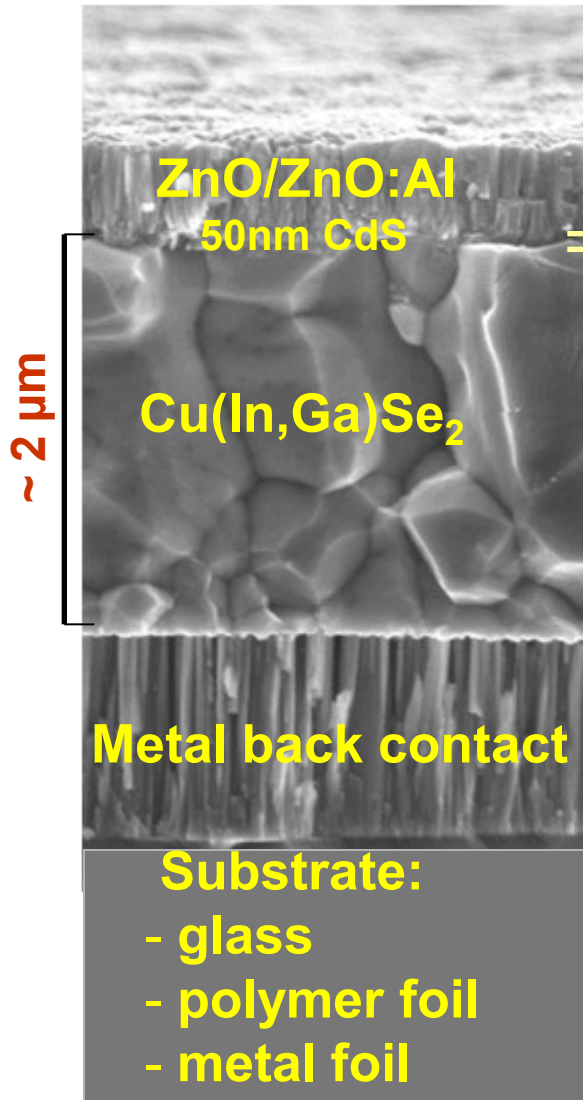
Structure of CIGS cell



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

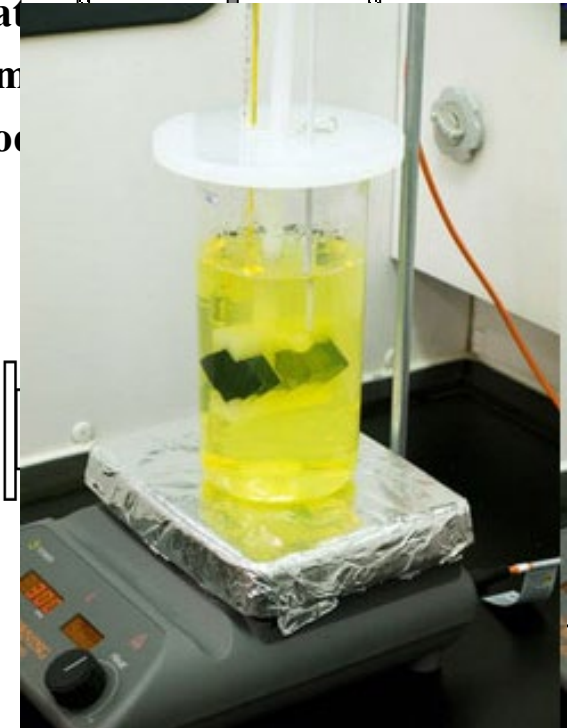
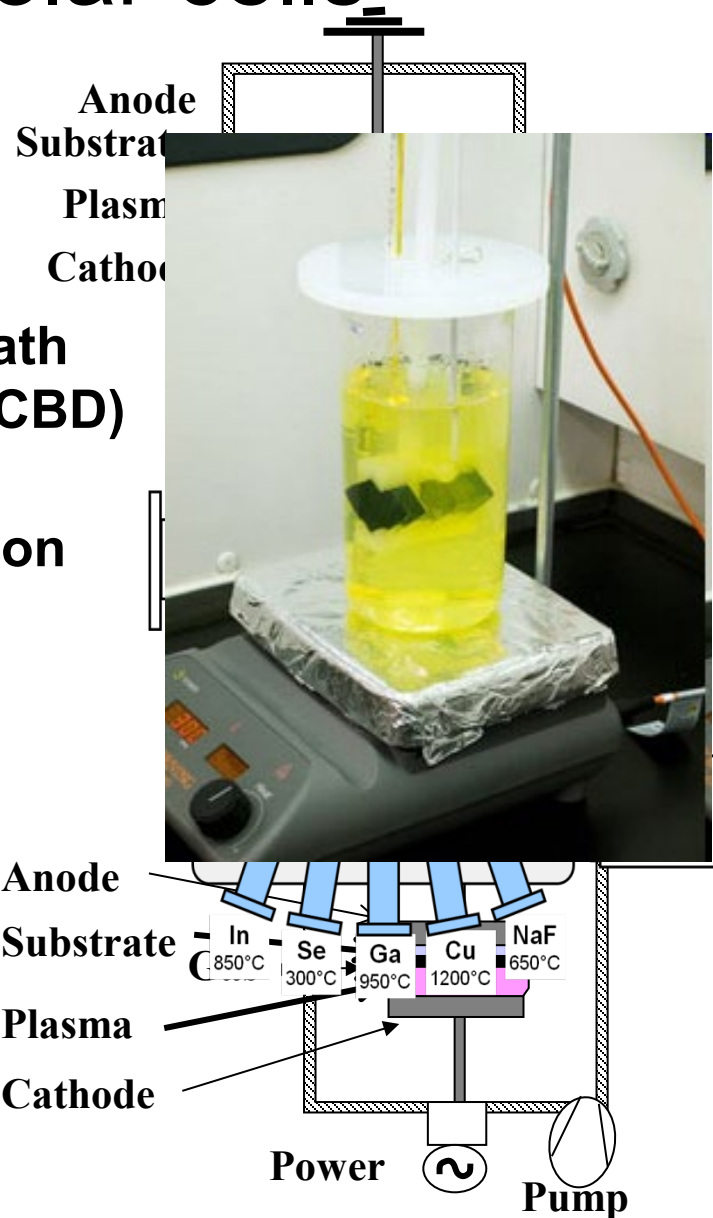


Sputtering

**Chemical Bath
Deposition (CBD)**

Co-evaporation

Sputtering



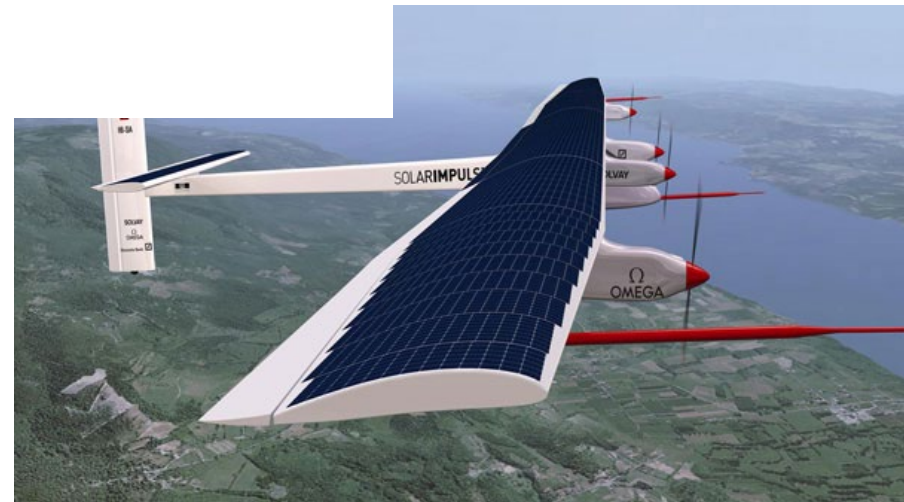
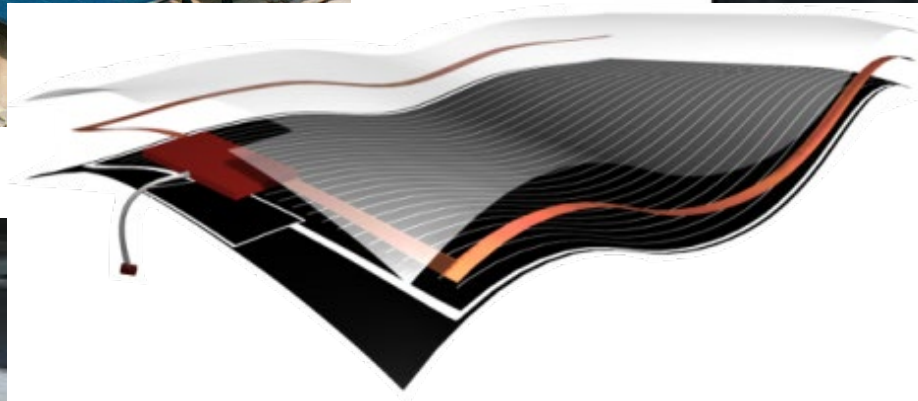
CIGS solar modules on glass

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

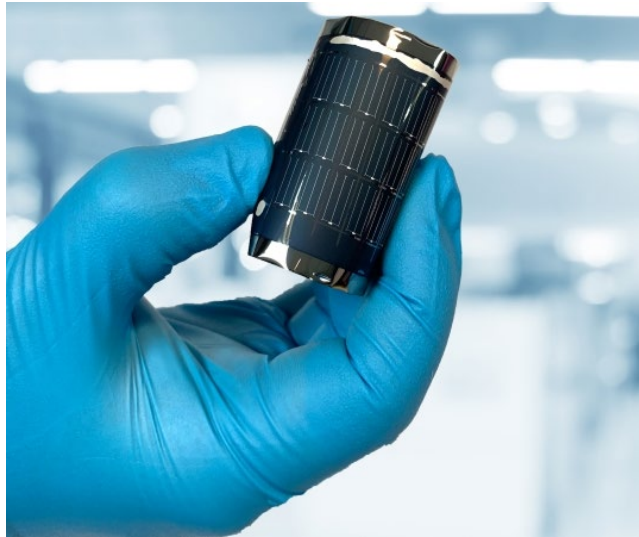


Solar Frontier

Targeted applications for flexible solar cells

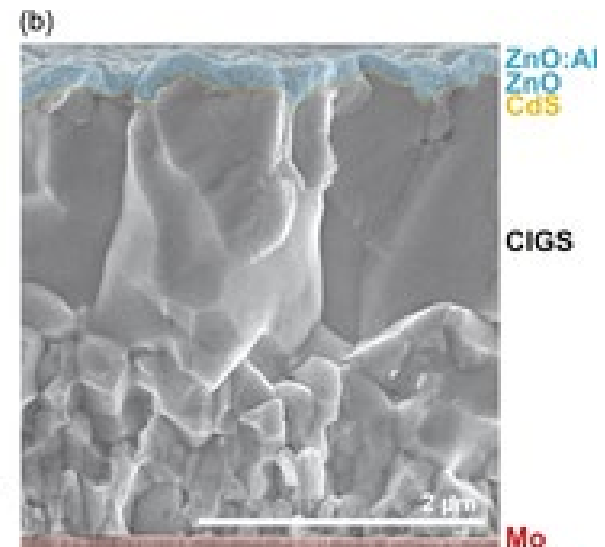
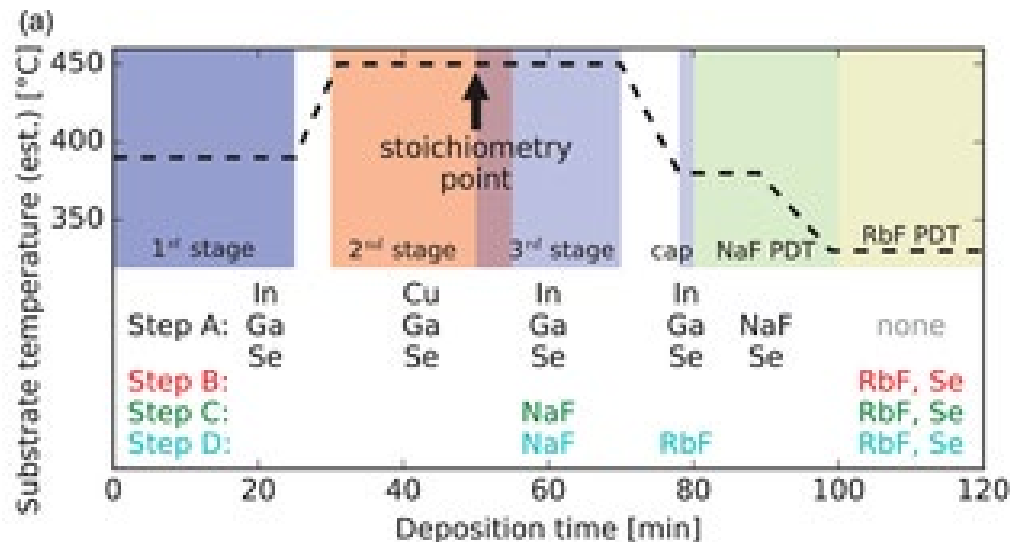


CIGS on flexible polymer substrate



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

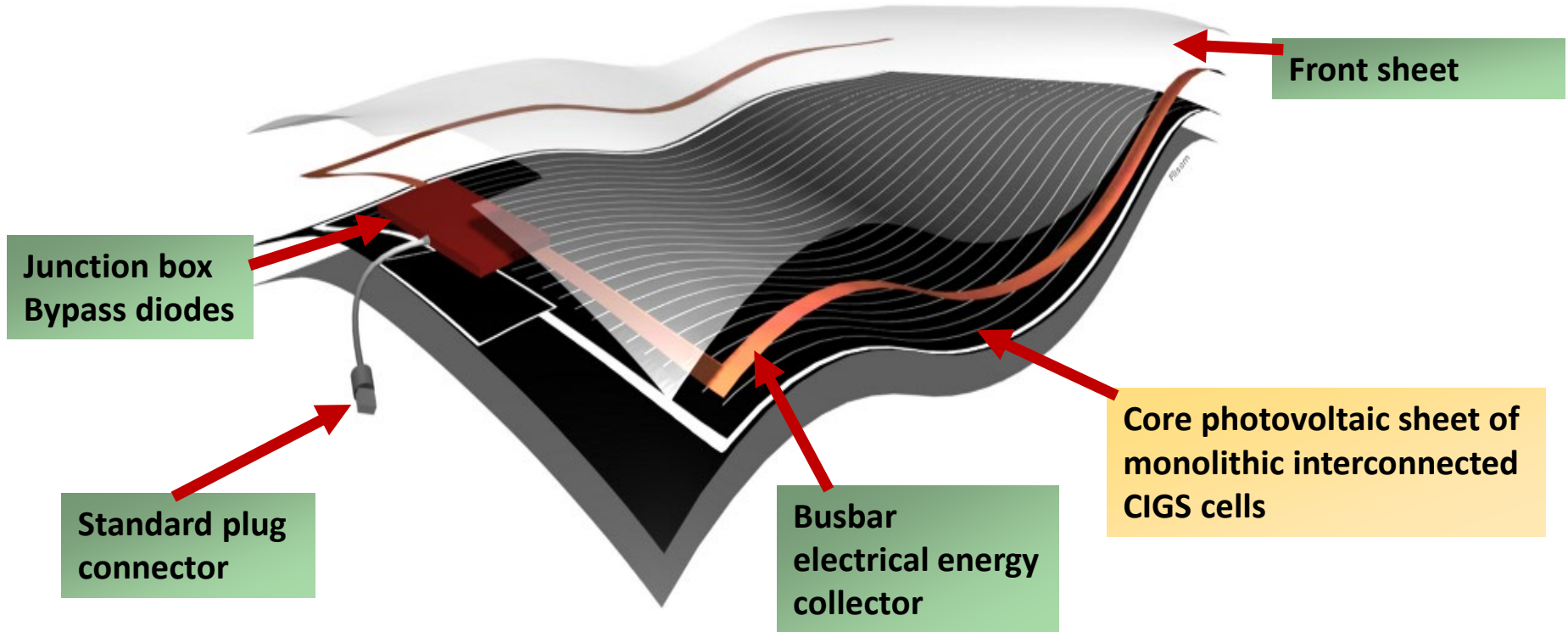
- Complex 3-stage evaporation process at 450°C together with NaF & RbF co-doping



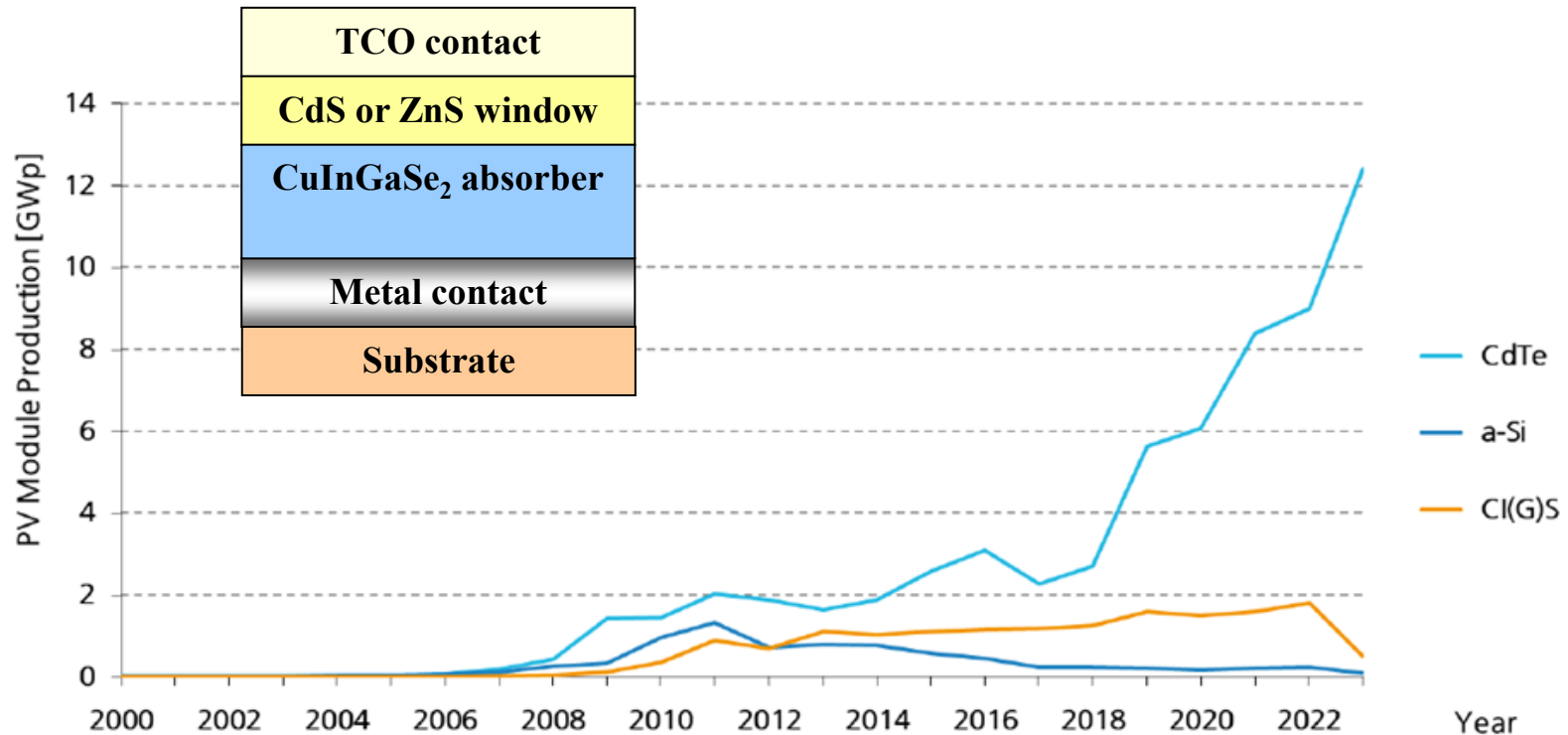
Flexible CIGS solar modules

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

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



Summary CIGS thin film technology



- 23.4% on glass (SolarFrontier, 2019)
- 22.2% on flexible polymer foil (Empa, 2022)
- 17.6% module efficiency (NICE Solar, 2019)

BUT: many CIGS companies went out of business (SolarFrontier, NICE solar, Solibro, Flisom,...) only a few remaining: AVANCIS (DE), Midsummer (Sweden)