Universidad Autónoma de Madrid

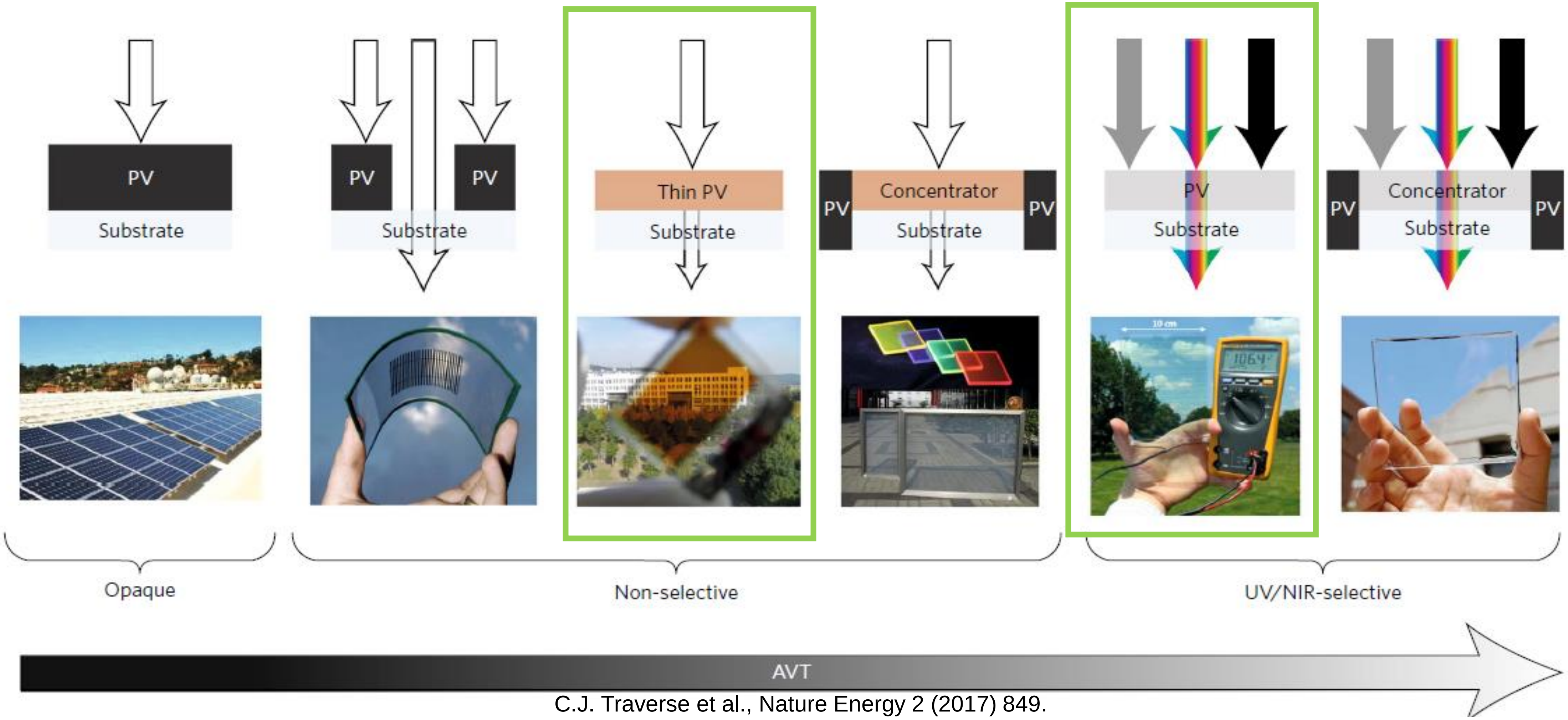
(SEMI)-TRANSPARENT KESTERITE-BASED SOLAR CELLS

RAQUEL CABALLERO
UNIVERSIDAD AUTÓNOMA DE MADRID
Applied Physics Department

 raquel.caballero@uam.es

Challenges facing society today: to supply low-cost, environmentally friendly energy sources that can meet the growing demands of an expanding population ⇒ **Photovoltaic** (PV) power has the potential.
It is necessary to extent the use of PV in our daily lifes ⇒ **Building Integrated Photovoltaic (BIPV)** concepts.

Towards transparent solar cells

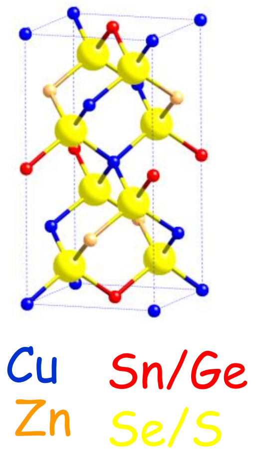


C.J. Traverse et al., Nature Energy 2 (2017) 849.

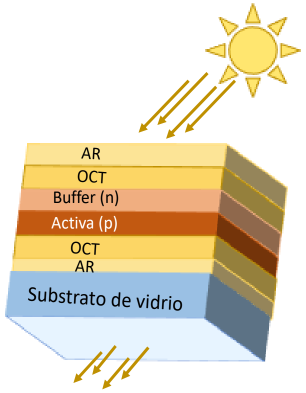
But, it is necessary to have efficient, **stable** and low-cost solar cells ⇒ **Inorganic thin film solar cells.**

Kesterite-type material, $Cu_2Zn(Sn,Ge)(S,Se)_4$ as alternative to chalcopyrite (CIGSe), to be used as absorber of the solar cells. Why is kesterite attractive?

- Earth abundant and low-toxicity elements.
- High optical absorption coefficient.
- Tuneable band gap energy: $Cu_2ZnSnSe_4$ (E_g = 1.0 eV); Cu_2ZnSnS_4 (E_g = 1.6 eV).
  $Cu_2GeSnSe4$ (E_g = 1.4 eV); Cu_2ZnGeS_4 (E_g = 2.2 eV).
- p-type conductivity.



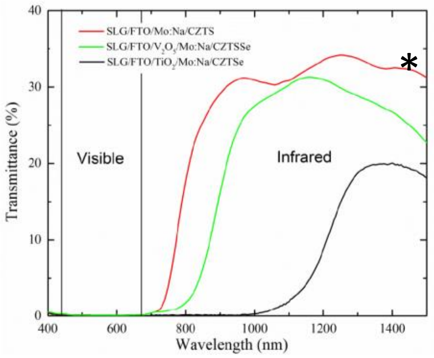
Record efficiency: 12.6 % and 8.5 % for CZTSSe and CZGSe-based solar cells respectively, grown on Mo back substrate.

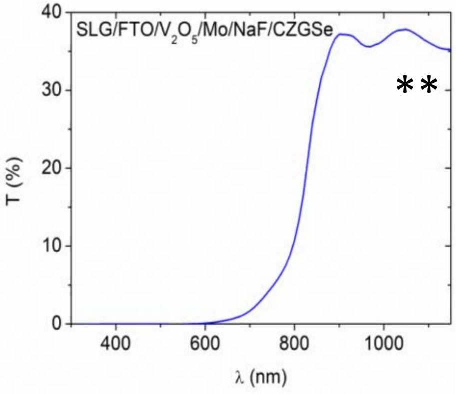


Challenge: as transparent as possible without decreasing device efficiency.

Different layers of the PV device: TCO, AR coating, active layer (p), buffer layer (n).

Transparent back contact (Transmittance and resistivity). Fabrication of nm transition metal oxides/TCO.





FTO/**MoO_x**

MoO_x (nm)	**2**	**4**	**5**
$T_{600\ nm}$ (%)	73	78	79
ρ(Ω/sq)	6.7	7.0	7.4

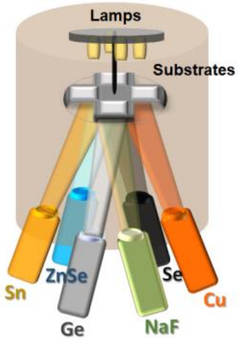
*I. Becerril-Romero, PhD thesis, Univ. Barcelona, 2019.

** R, Caballero, submitted for publication J. Phys. Mater.

Collaboration with Institute of Optic, CSIC.

FTO/10 nm V_2O_5/12 nm Mo/6 nm NaF

Active layer (CZGSe, CZGSSe)



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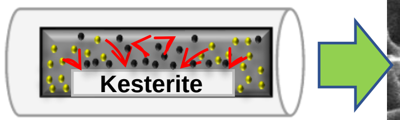
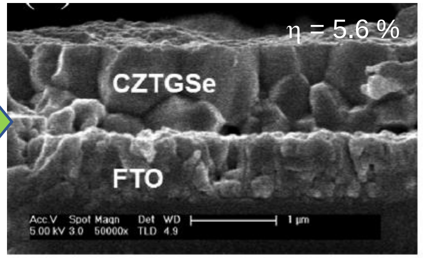


Cross-sectional SEM



A. Ruiz-Perona et al, Solar Energy 206 (2020) 555.

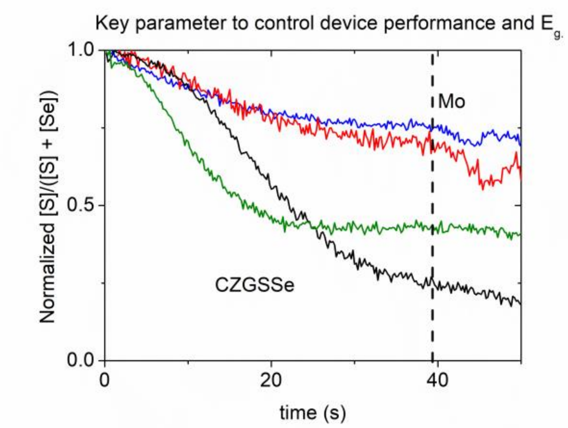
Co-evaporation + annealing (S/Se)

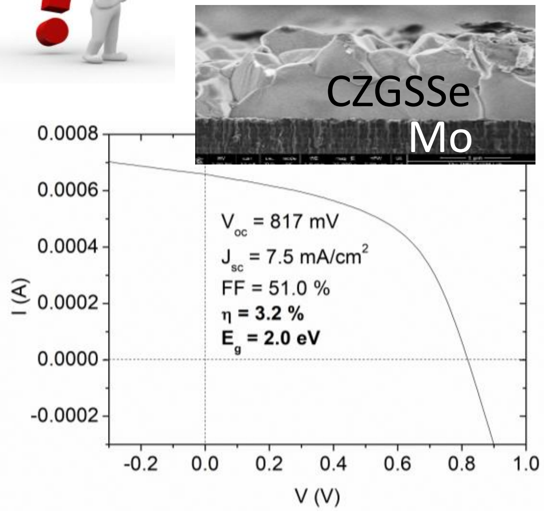
On FTO

η (%)	**5.6**	**5.2**	**3.1**	**2.7**	**1.5**
E_g (eV)	1.28	1.47	1.73	1.86	1.91

How to increase T?

1. ↑ $E_g \Rightarrow$ ↑ T (CZGSSe).
2. ↓ Thickness of CZGSSe.





A. Ruiz-Perona, Master Thesis, UAM, 2020.

Investigation in progress:

- Reduction of the thickness of kesterite layer to 100 nm:

  - Control during the co-evaporation process.
  - **Chemical etching and surface treatments**, maintaining the properties of the material.

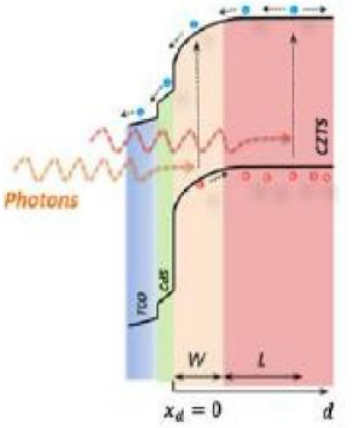
→ Investigation by AFM, SEM, XPS, TEM…

A lot to do:

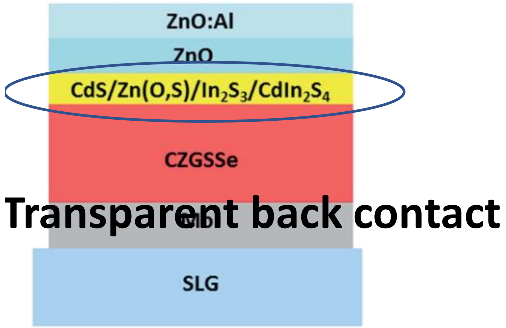
- To enhance the band-alignment between CZGSSe (p) and buffer layer (n) (reduction of interface recombination).

- Optimization of the window layer (TCO) and addition of AR-coating.

New research line: New UV-selective inorganic thin film solar cells.



Y. Ren et al, Phys. Stat. Solidi A 212 (2015) 2889-2896.



T. Schnabel et al., RCS Adv. 7 (2017) 40105.

COLLABORATIONS WITH CIVIS UNIVERSITIES ARE WELCOME!

In the frame of the Master of Advanced Materials, Nanotechnology and Photonic:

- **2 Master thesis are about this investigation this course.**
- **Subject: Materials for solar applications.**

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THANK YOU
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INFINITE CELL
INFINITE-CELL:
INTERNATIONAL COOPERATION FOR THE DEVELOPMENT OF COST-EFFICIENT KESTERITE/C-SI THIN FILM NEXT GENERATION TÁNDEM SOLAR CELLS