PVK/Si 3T-HBT solar cell

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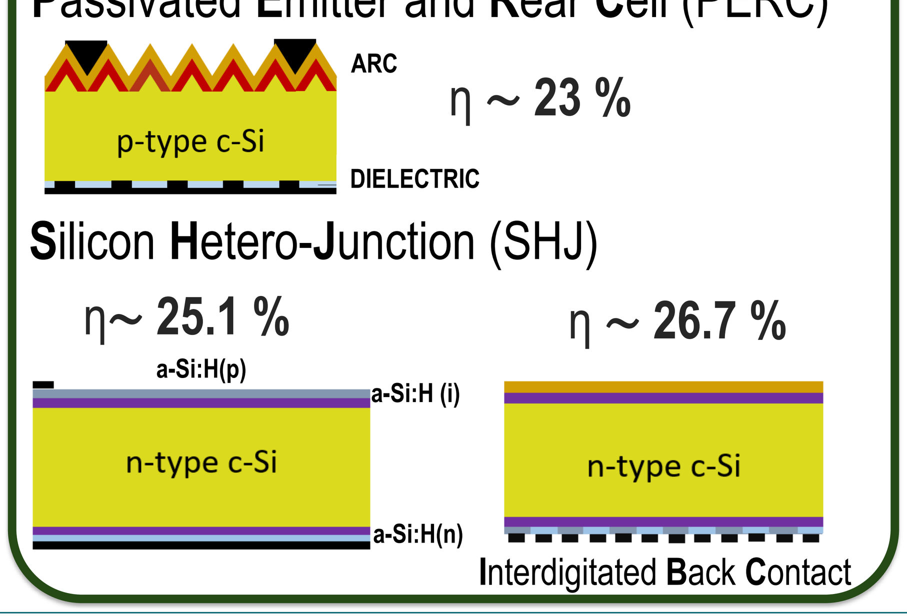
ScuDo Scuola di Dottorato – Doctoral School
WHAT YOU ARE, TAKES YOU FAR

XIV Cycle

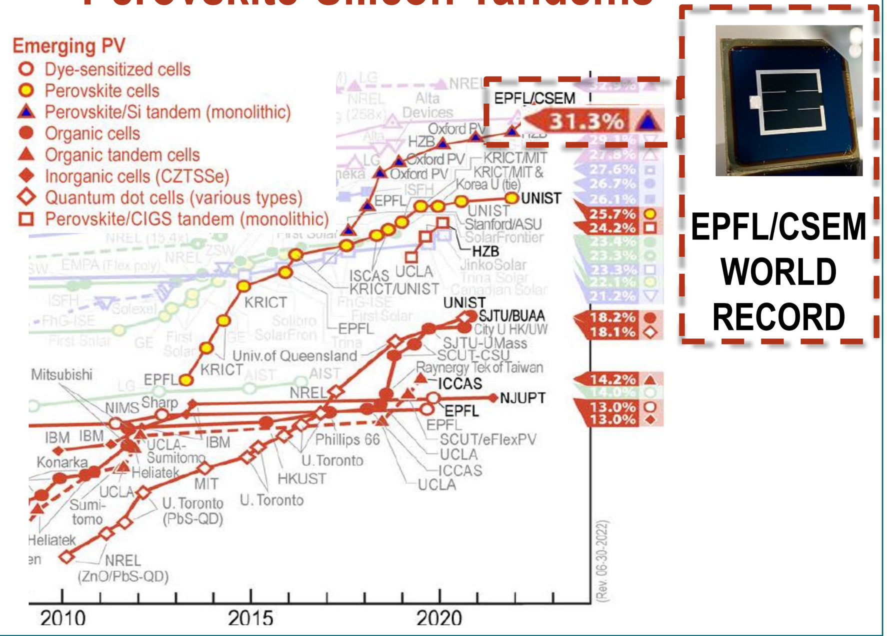
Research context and motivation

Crystalline Silicon solar cell η < 29 %
Until 2030… Upper bound

Passivated Emitter and Rear Cell (PERC)

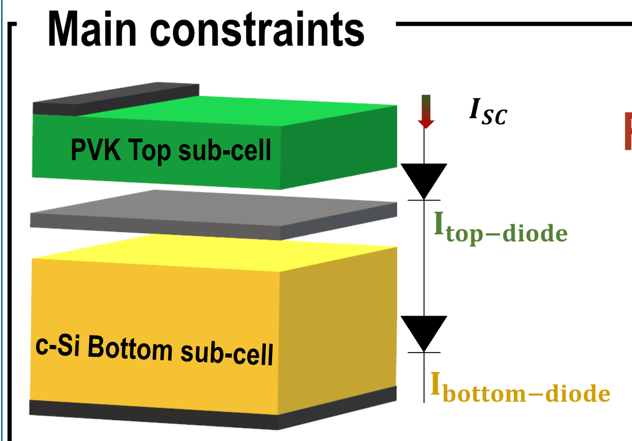


Perovskite-Silicon Tandems



Addressed research questions/problems

Main constraints



→ Tunnel Junction Recombination Layer

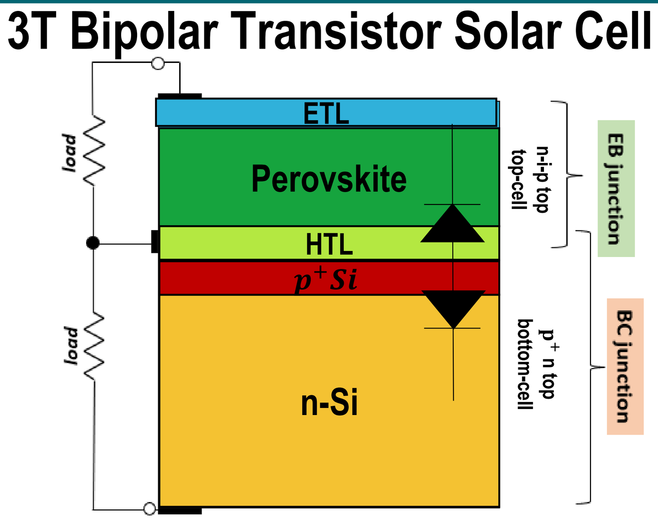
Needed to allow the **current flow** between the **two sub-cells**.

→ Current matching constraint

$$I_{SC} = \min[I_{top-diode} \div I_{bottom-diode}]$$

- In order to **maximize** the output **power**, the two sub-cells should generate the **same photo-current**
- **Sensitive** to spectral variations in outdoor operation

3T Bipolar Transistor Solar Cell

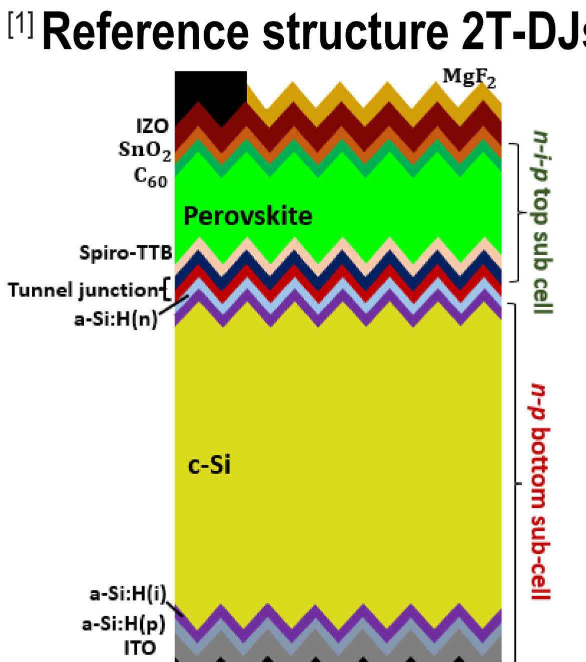


Two subcells (Emitter/Base and Base/Collector) electrically connected through the **common base** layer.

The generated electrical power is extracted at **two independent loads**

Novel contribution

[1] **Reference structure 2T-DJsc**

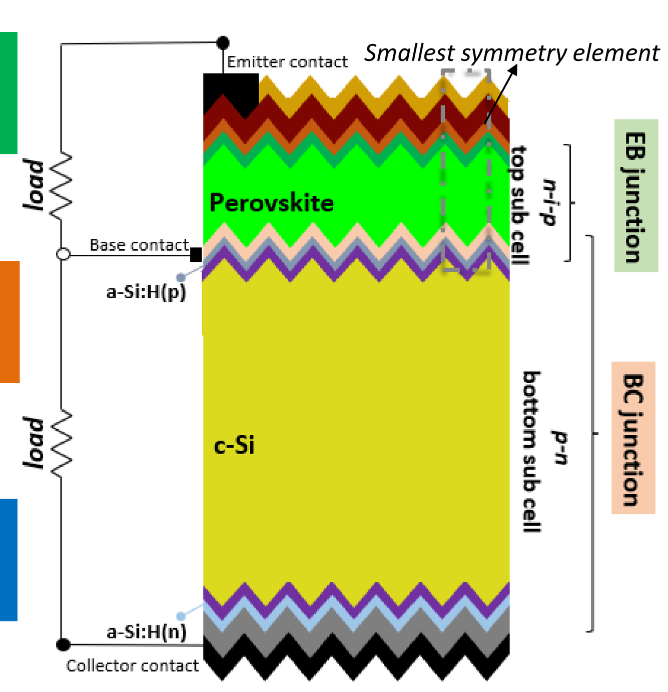


Remove **n++/p++ tunnel junction**

Replace **n-p bottom sub-cell with p-n one**

Add **Base metal contact**

3T-HBTsc



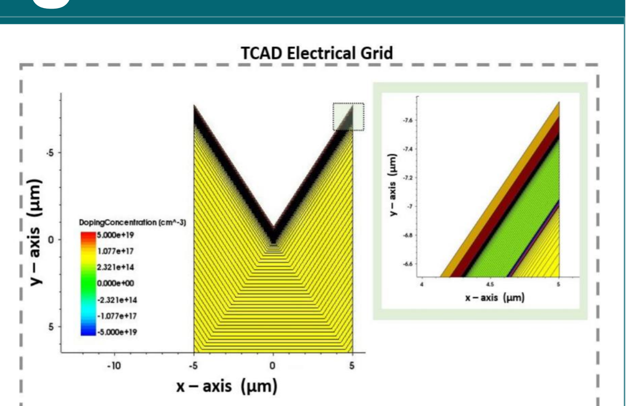
[1] Sahli, F., Werner, J., Kamino, B.A. *et al.* Fully textured monolithic perovskite/silicon tandem solar cells with 25.2% power conversion efficiency. *Nature Mater* **17**, 820–826 (2018). https://doi.org/10.1038/s41563-018-0115-4

Adopted methodologies

- **Normal** incidence & input optical power of AM1.5G
- **Hybrid optical model →**

Transfer Matrix Method (**TMM**) for **Interference effect** through the subwavelength multi-layered media.

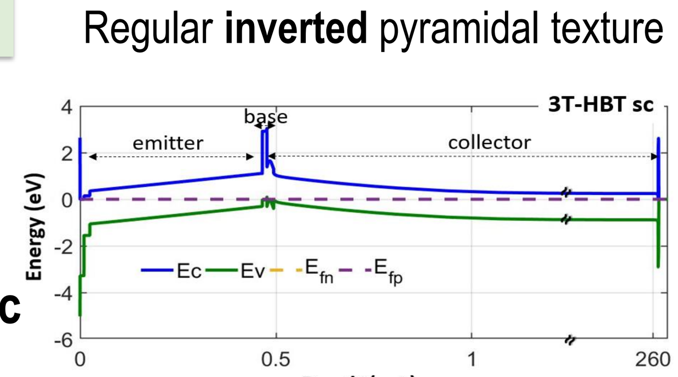
Monte Carlo RayTracing for **Scattering effects** at the textured surfaces



Regular **inverted** pyramidal texture

Electrical Model

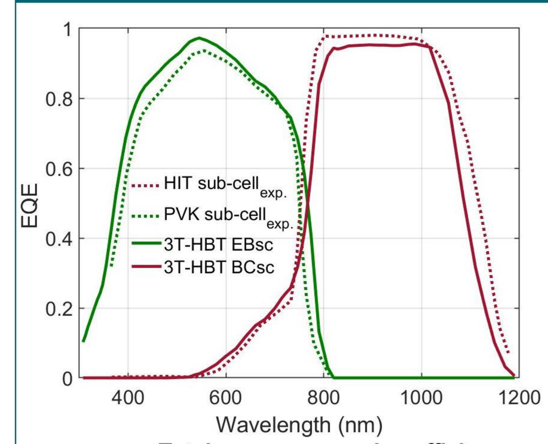
- **Radiative** recombination
- **SRH** and **Auger** recombination in c-Si layer
- **Perovskite** material **modelled** as a classical **inorganic** semiconductor

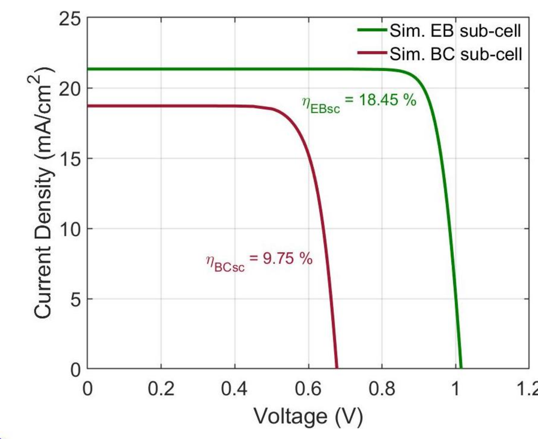


List of attended classes

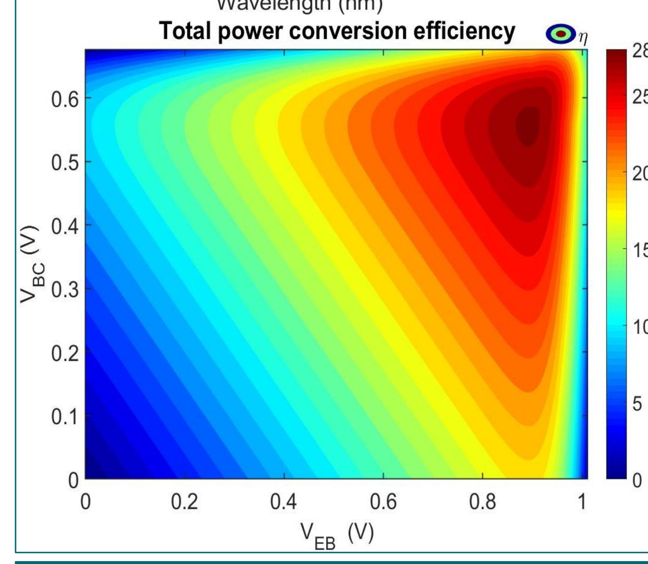
01UAYOQ – CAD of semiconductor devices(14/2/2020, 6 CFU)
02IUGKG – Il metodo Monte Carlo(4/6/2020, 6 CFU)
01UIYRV – Physics-based modeling of semiconductor devices (1/4/2020, 3 CFU)
01UMEKG – Principles of deep learning (18/9/2020, 4 CFU)
01UMEKG – Programmazione scientifica avanzata in matlab (25/5/2020, 4 CFU)
02LWHRV – Communication(23/7/2020, 1 CFU)
01UNYRV – Personal branding (22/6/2021, 1 CFU)
01RISRV – Public speaking(23/7/2020, 1 CFU)
01UNXRV – Thinking out of the box (22/6/2021, 1 CFU)
01SWPRV – Time management (21/7/2020, 1 CFU)
01SWQRV – Responsible research and innovation, the impact on social challenges(21/6/2021, 1 CFU)
02RHORV – The new Internet Society: entering the black-box of digital innovations(13/10/2020,1 CFU)

Result





The **high bandgap** of the Spiro-TTB and a-Si:H layers prevent the **transistor action** between the EB and BC junctions biased up to their MPP.



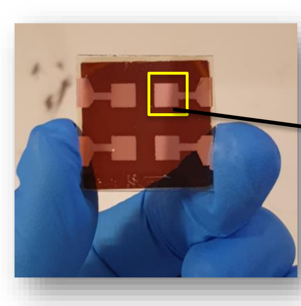
Carrier injection through the base is **negligible** at least up to the **maximum power point**

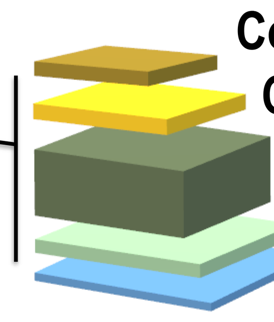
The **sub-cells** work **independently** → Efficiency is maximized

The **3T-HBTSC** achieves a **high efficiency** of **28.2 %**, equivalent to that of a **2T-DJSC**

Long visit to CHOSE (polo solare organico)

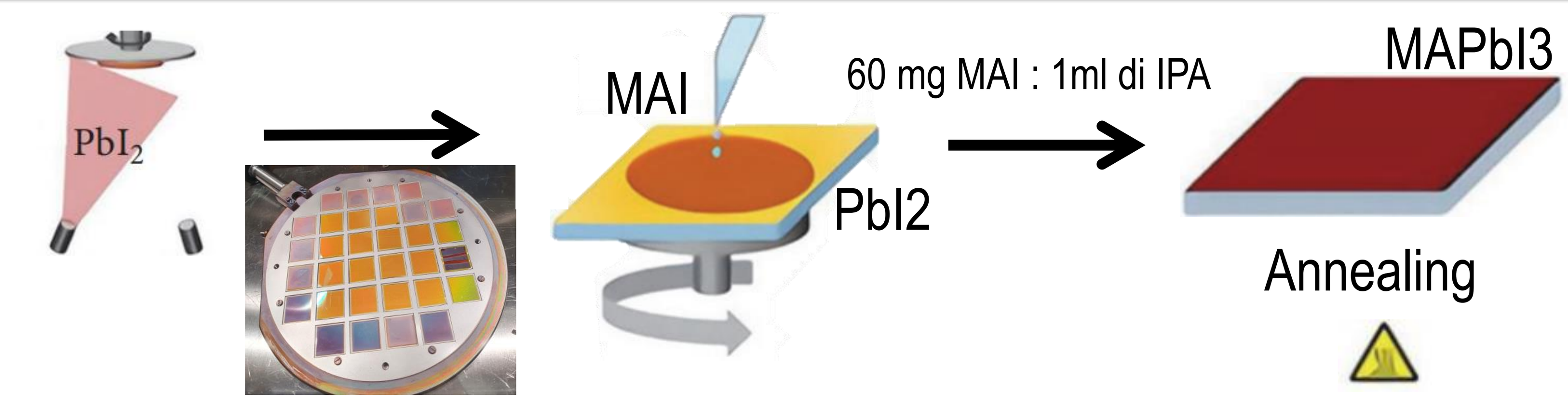
Main Topic: fabrication of a p-i-n Perovskite solar cell

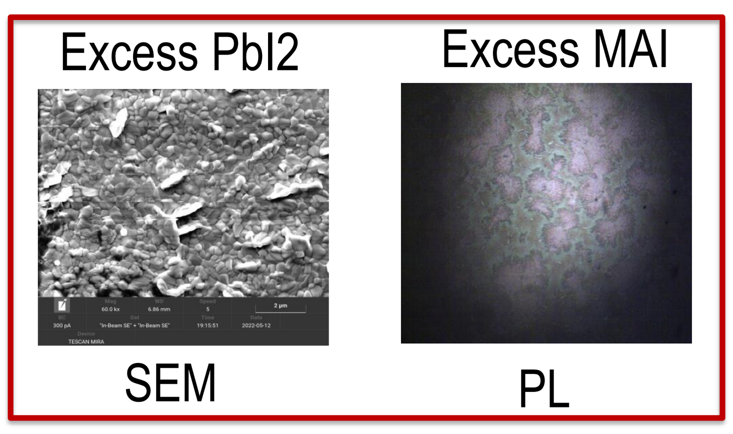




Copper – metal evaporation -
C60/PCB – organic evaporation -
MAPbI3 *
PTAA – spin coating -
Glass/ITO

* **Hybrid deposition process**: **Evaporation** of PbI2 + **spin coating** of precursors

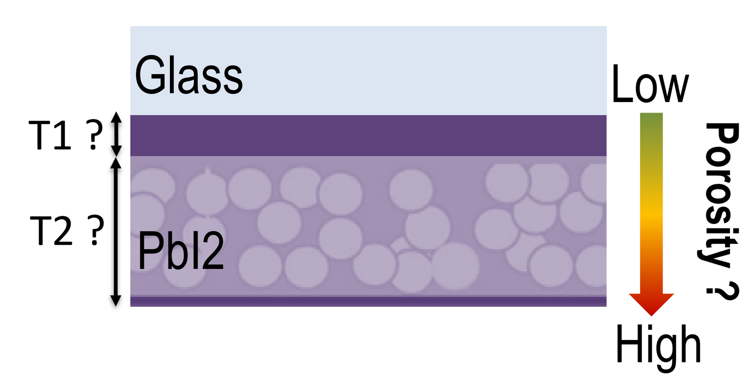




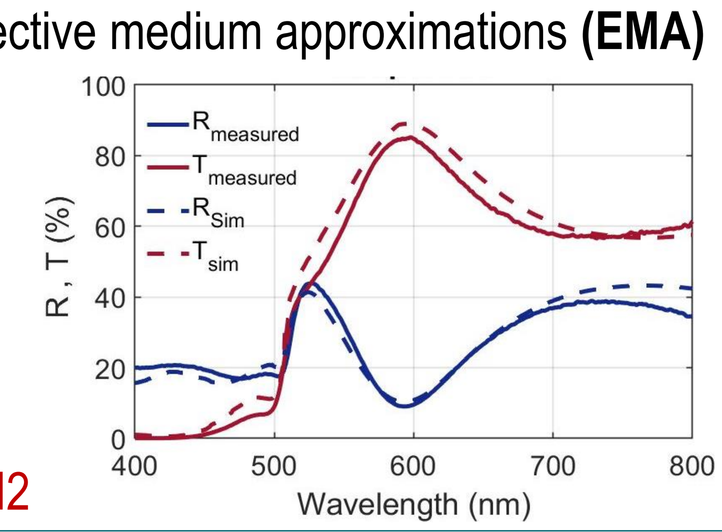
Porosity of the **PbI2** is a **key** for complete conversion

…How can we estimate it ?

→ Optical Simulations to support experimental study
General Transfer Matrix Method (**GTMM**) + Effective medium approximations **(EMA)**



Need of n,k parameter of compact evaporated PbI2



Future work

- ❑ PhD thesis & Article submission
- ❑ Fabrication of HBT PVK/Si solar cell with small-area prototypes on planar and textured Si substrates in collaboration with Università Tor Vergata (Roma)

Submitted and published works

- Gruginskie, N., Cappelluti, F., Bauhuis, G., Tibaldi, A., GILIBERTI, G., Mulder, P., ... & Schermer, J. (2021). Limiting mechanisms for photon recycling in thin-film GaAs solar cells. *Progress in Photovoltaics: Research and Applications*, *29*(3), 379-390.
- GILIBERTI, Gemma, et al. Modeling of three-terminal heterojunction bipolar transistor solar cells. In: 2020 International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD). IEEE, 2020. p. 43-44.
- GILIBERTI, Gemma; MARTÍ, Antonio; CAPPELLUTI, Federica. Perovskite-Si solar cell: a three-terminal heterojunction bipolar transistor architecture. In: 2020 47th IEEE Photovoltaic Specialists Conference (PVSC). IEEE, 2020. p. 2696-2699.
- MARTÍ, A., et al. Cuaderno abierto para la simulación de células solares de tres terminales de tipo transistor bipolar de heterounion. In: CIES2020-XVII Congresso Ibérico e XIII Congresso Ibero-americano de Energia Solar. LNEG-Laboratório Nacional de Energia e Geologia, 2020. p. 23-31.
- GILIBERTI, Gemma; CAPPELLUTI, Federica. Physical simulation of perovskite/silicon three-terminal tandems based on bipolar transistor structure. In: Physics, Simulation, and Photonic Engineering of Photovoltaic Devices XI. SPIE, 2022. p. 1199602