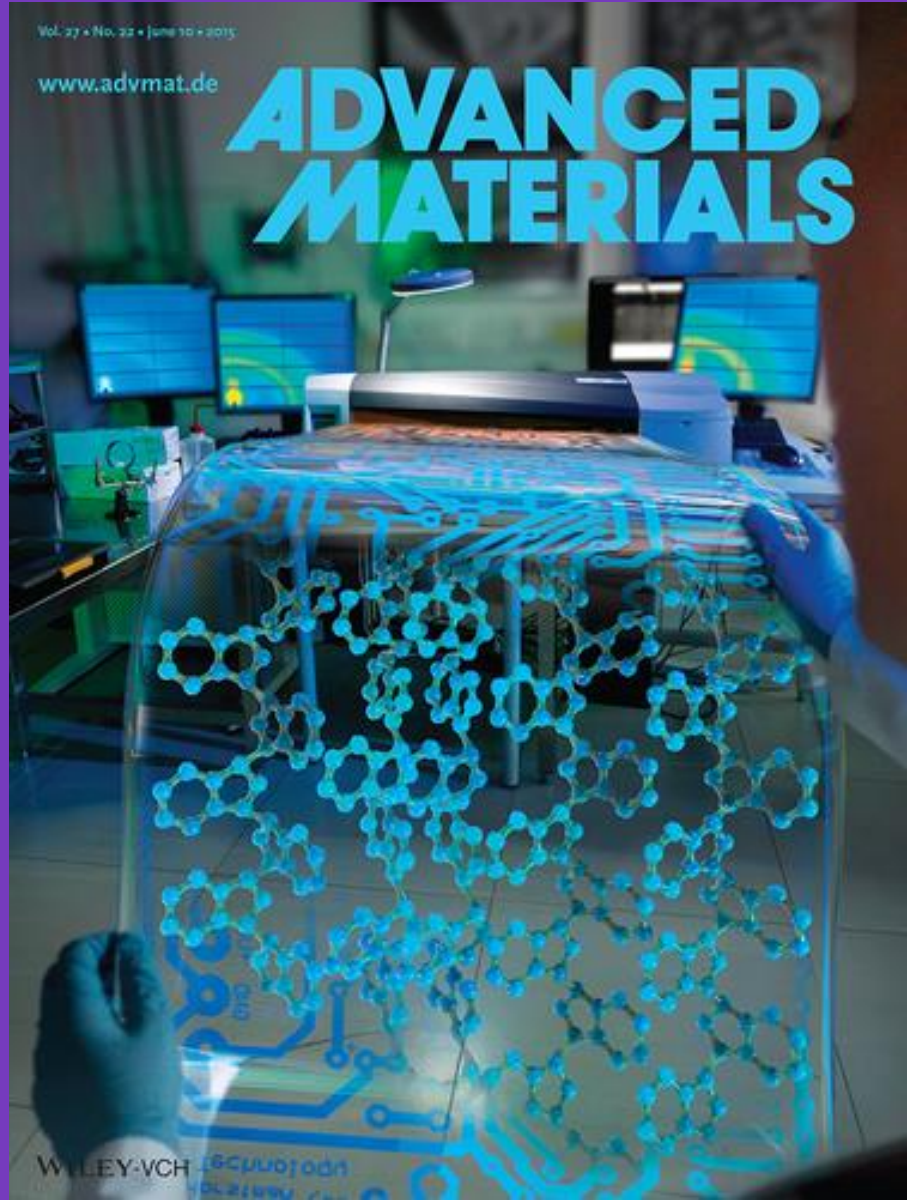
ELEC-E9210 Organic Electronics: Materials, Devices & Applications

Organic Photovoltaics II

Aalto University
School of Electrical
Engineering

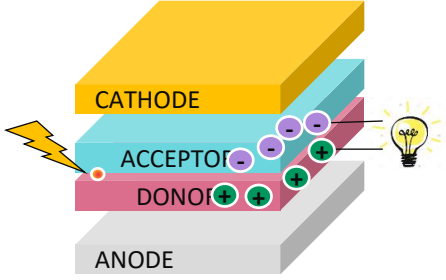
organicelectronics.aalto.fi



Organic Photovoltaics (OPV)

Last Class

- Organic photovoltaics (OPV): basic mechanisms and device structure
- Materials to achieve high efficiency of OPV



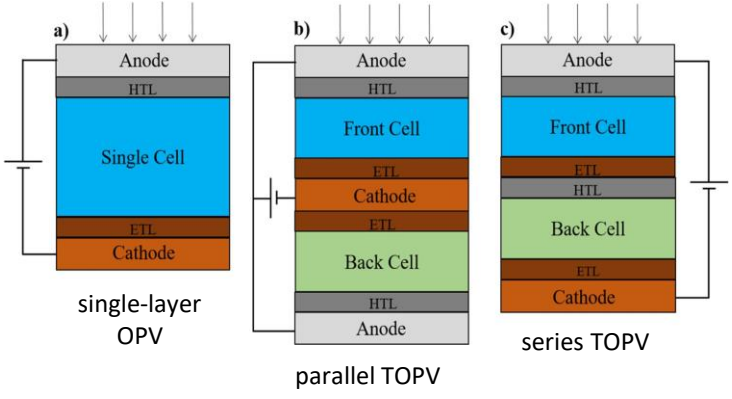
(O)PV devices ***convert light (sunlight)*** to *electrical energy*

Today´s Class

- Latest Trend in OPV and applications

Tandem Solar Cells to Boost Efficiency

Tandem organic photovoltaic (T-OPV) include ***two*** or ***more OPV devices, stacked on top of each other***



single-layer OPV

parallel TOPV

series TOPV

- series T-OPV are simpler to fabricate, with the same current though each cell, limiting the band gaps that can be used
- **monolithic growth** (cells are grown on top of each other and are connected through tunnel junctions)

Why *Tandem* solar cells?

- **cheap cells** (small/medium efficiencies)
- polymer-only T-OPV have EQE < 10% (expected 15%)
- semi-transparency

- combination of solar cells optimized in different part of the spectrum
  → increased efficiency

Challenges

- **layer compatibility**

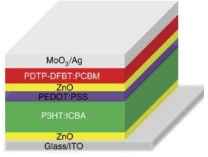
top cell must absorb part of solar light but also must be transparent to let light through so it can be absorbed by bottom cell

- **cell mismatch**

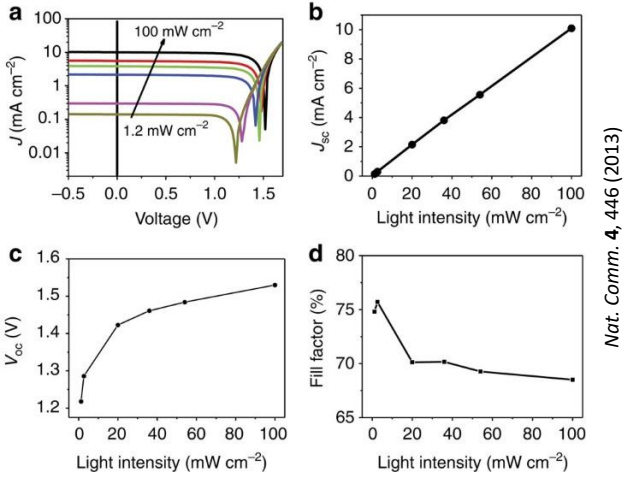
stacked cells are working at different voltages/currents

- **mechanical compatibility**

Tandem Solar Cells



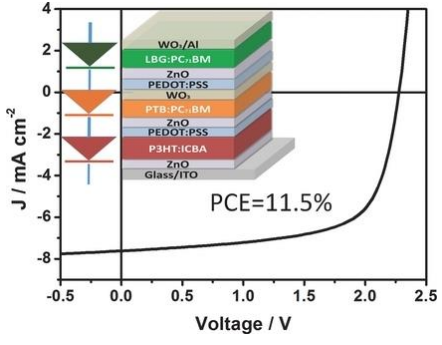
***Double* junction** | ***Triple* junction**

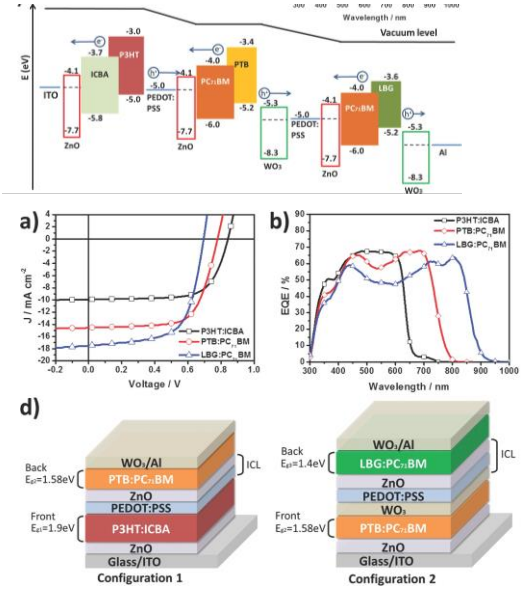


Nat. Comm. **4**, 446 (2013)

(**a**) *J*–*V* curve of T-OPV under different light intensity (1.2-100 mW/cm^2) (**b**–**d**) Variation of short circuit current (J_{SC}), open circuit voltage (V_{OC}), FF with different light intensity.

Energy diagram, (a) J-V curve and (b) EQE spectra of single-junction with (d) corresponding configurations of double junctions T-OPV





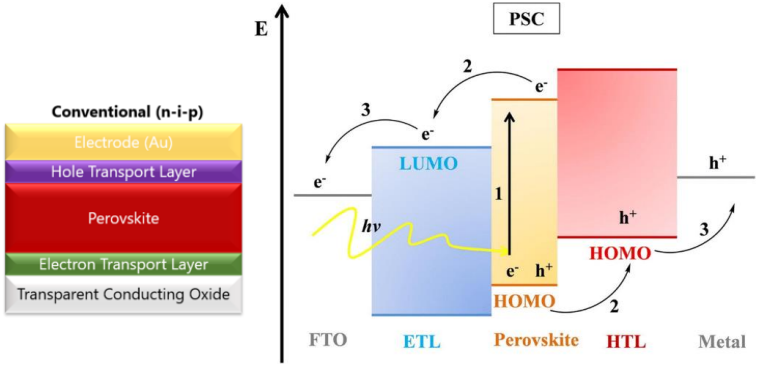
Adv. Mat. **26** (32), 5670 (2014)

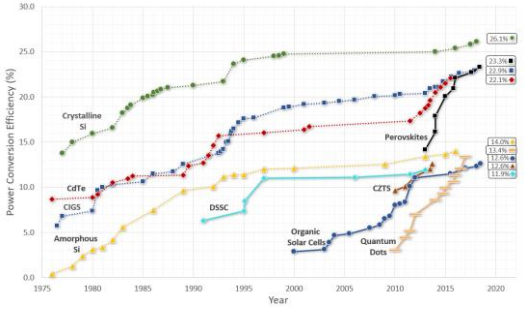
Triple junctions tandem organic solar cell exhibit an improved efficiency of 11.5%

Perovskite Solar Cells: Hybrid Approach

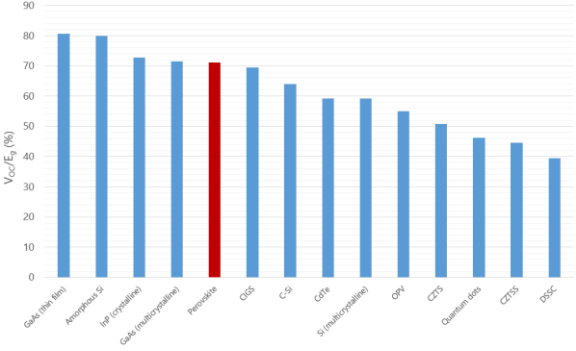
Often hybrid approaches offer multifunctional capabilities and enhanced performances

Perovskite is a mineral with the chemical formula $CaTiO_3$ (calcium titanium oxide). Compounds with similar structure to $CaTiO_3$ (ABX_3) are called *perovskites*





Perovskite solar cells have increased in power conversion efficiency at a fast rate compared to other types of photovoltaics

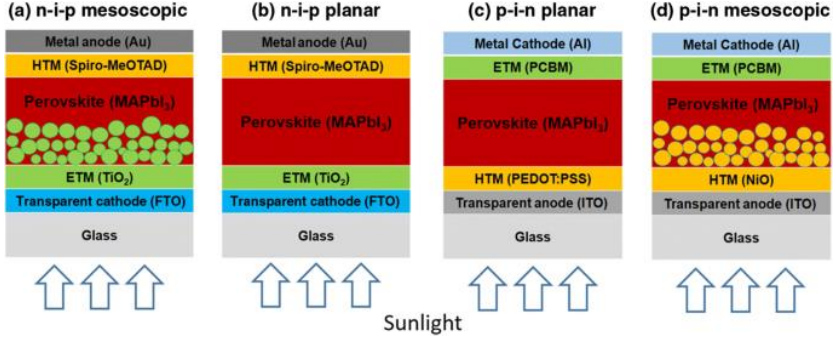


PSC are rapidly approaching *state-of-the-art* technologies (*i.e.* GaAs), but at a significantly lower cost.

Further reading Materials Today **18**(2), 65 (2015)

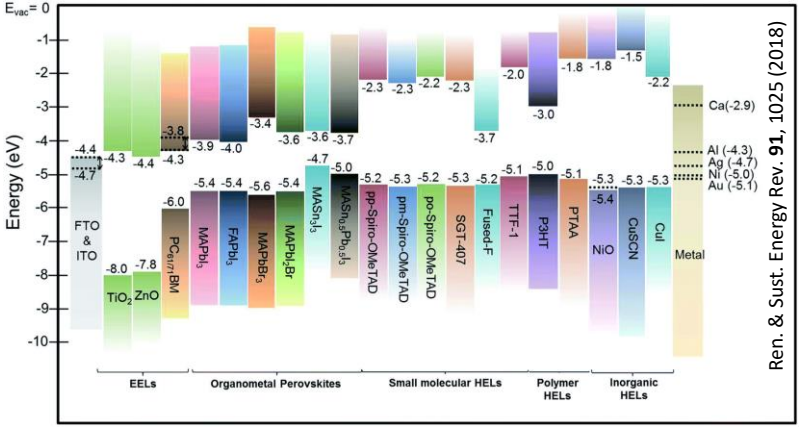
Perovskite Solar Cells Configuration

PSCs can be classified as regular (n-i-p) and inverted (p-i-n) structures depending on which ***transport (electron/hole) material is present on the exterior portion*** of the cell/encountered by incident light first.



Perovskite solar cells configurations: (a) *n-i-p* mesoscopic, (b) *n-i-p* planar, (c) *p-i-n* planar and (d) *p-i-n* mesoscopic

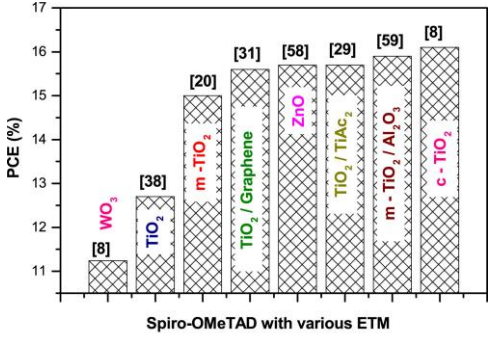
Mesoscopic and ***planar structures***: where mesoscopic structure incorporates a mesoporous layer whereas the planar structure consists of all planar layers.

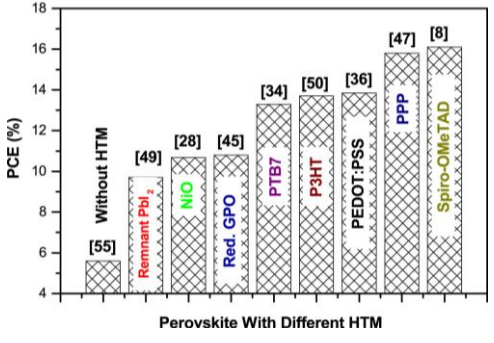


Energy levels of the various materials used as an *e*-transport material (ETM)(left), absorbers (middle) and *h*-transport materials (HTMs) (right) in perovskite solar cells.

Perovskite Solar Cells Performances

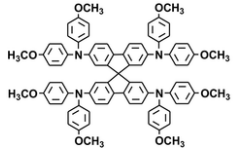
Best device performances for various ETMs and HTMs used in the preparation of perovskite solar cell



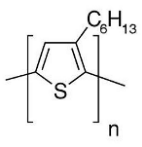


Renewable and Sustainable Energy Reviews **91**, 1025 (2018)

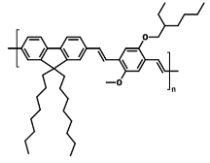
Spiro-OMe-TAD

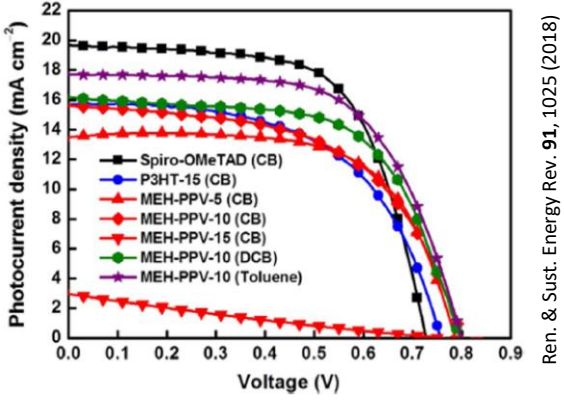


P3HT



MEH-PPV

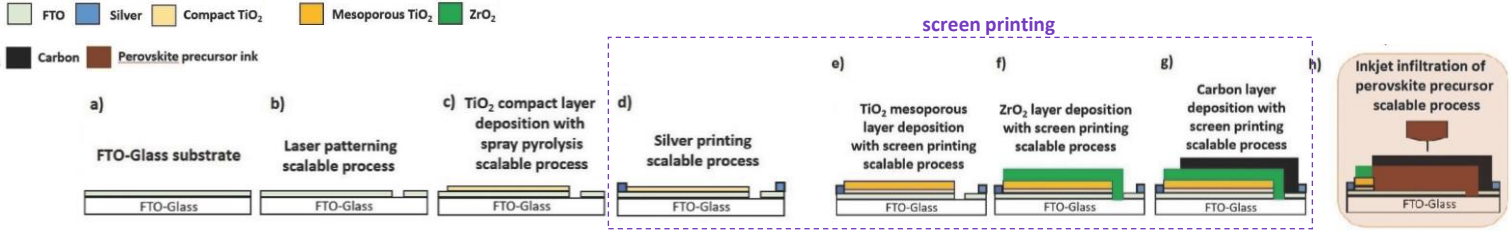


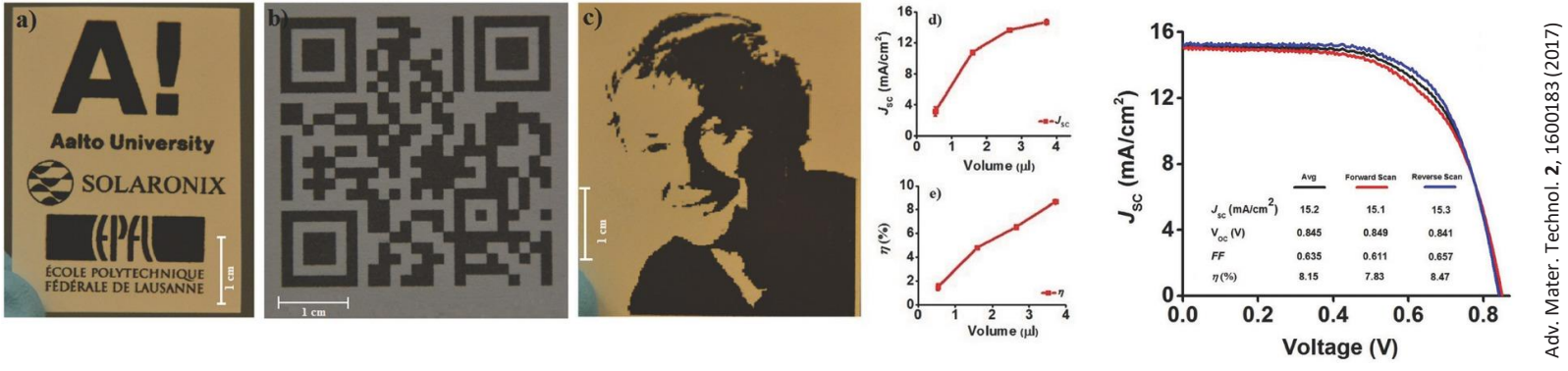


Ren. & Sust. Energy Rev. **91**, 1025 (2018)

The effect of various organic HTM on the collection of photocurrents from perovskite based solar cell. **Spiro-OMeTAD**-based (black), **P3HT** (blue) and **MEH-PVV** with different solvent.

Perovskite Solar Cells @Aalto



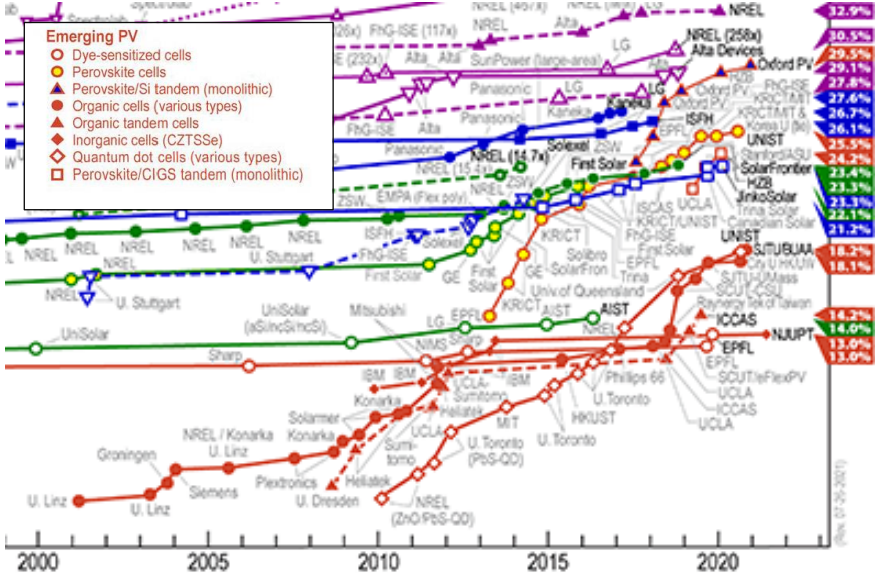


Adv. Mater. Technol. **2**, 1600183 (2017)

Stable inkjet printable perovskite precursor ink for (a) logos of different network partners, (b) QR code for Aalto University's website, (c) inkjet printing of bitmap image (permission from A. Herzog/EPFL), (d-e) solar cell performances as function of the perovskite precursor ink. (Right) *J–V* curve of a PSC (active area ~ 0.16 cm^2).

Organic Solar Cells: Future Impact

https://www.nrel.gov/pv/cell-efficiency.html



world record

National Renewable Energy Laboratory (NREL) maintains a chart of the highest confirmed conversion efficiencies for research cells for a range of photovoltaic technologies, plotted from 1976 to the present

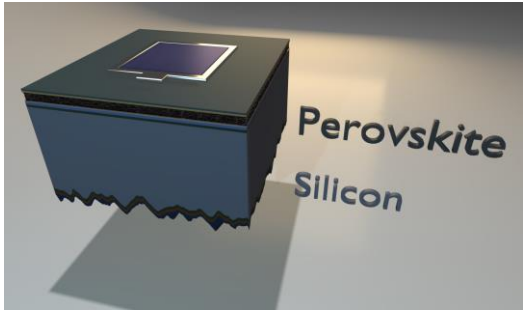
World Record: Perovskite Silicon Tandem Solar Cell

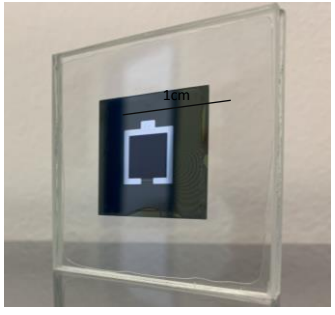
Perovskite Silicon Tandem Solar Cell

multiple stacks

Si absorption

hybrid organic/inorganic approach





- Si converts mostly the red portion of sunlight into electricity, while perovskite layer primarily uses the blue part
- tandem solar cell made of stacked Si/perovskite achieves significantly higher efficiency than individual cell

Tandem solar cell made of the semiconductors perovskite and silicon, that converts 29.15% of the incident light into electrical energy. This value has been officially certified by the CalLab of the Fraunhofer Institute for Solar Energy Systems (ISE). All processes are scalable for large surface areas.

30% efficiency is within reach

Press-Release
https://www.helmholtz-berlin.de/pubbin/news_seite?nid=21020;sprache=en;seitenid=1

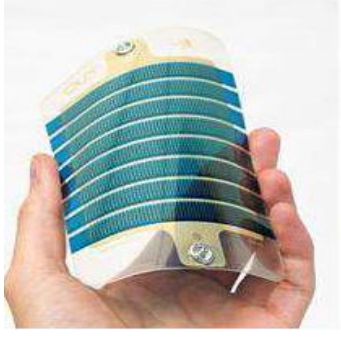
From Concept to Daily Life

semi or *total* transparency

Courtesy of M. Seri (CNR-ISOF)

From Concept to Daily Life (II)

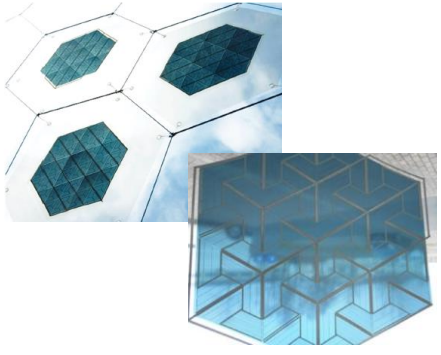
Lightness & Flexibility



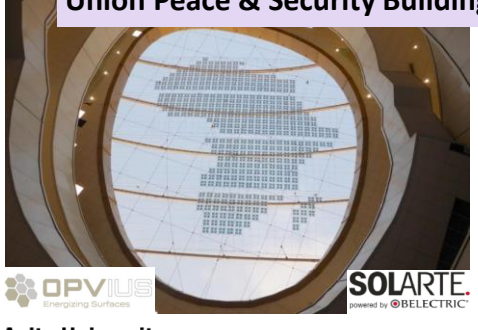
Aesthetic

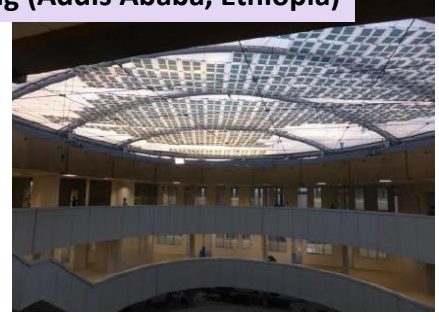
Organic Solar Cells Around Us

EXPO Milano 2015 (German Pavillon)



Union Peace & Security Building (Addis Ababa, Ethiopia)



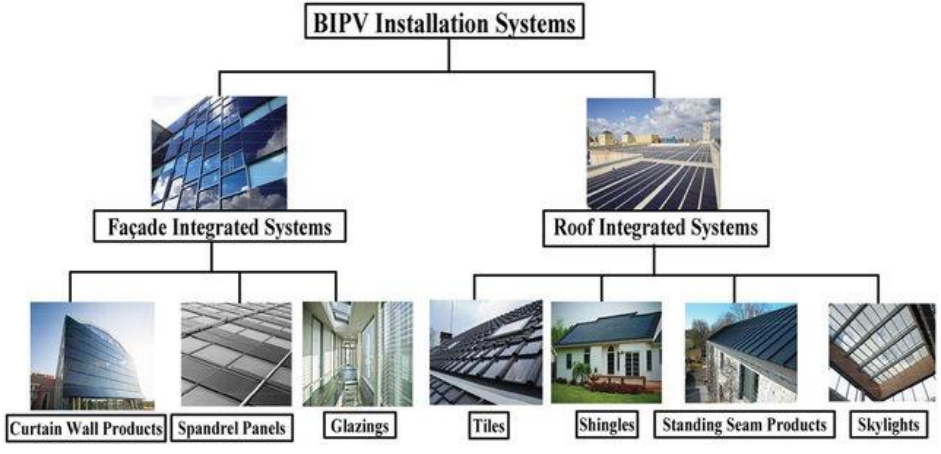


Largest Indoor Application
25mx20m, >70% light transmission

445 individual transparent OPV modules that powers the internal LED lighting of the building

Building Integrated Photovoltaics (BIPV)

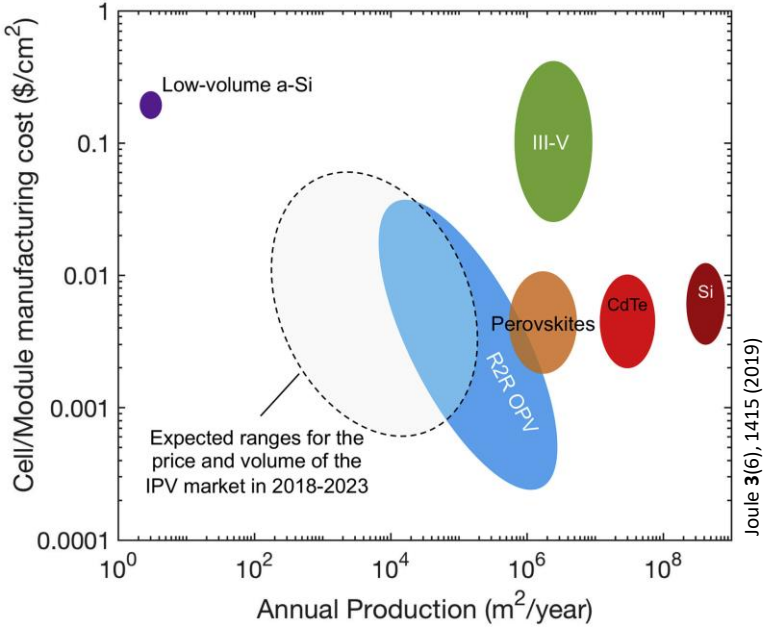
Building Integrated Photovoltaics (BIPV) system consists of integrating PV modules into the building envelope (*i.e.* roof, façade).
By simultaneously serving as building envelope material and power generator, BIPV systems can provide ***savings in materials*** and ***electricity costs***, reduce use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building



Commercial flexible see-through organic solar cell module. (Mitsubishi Chemical Corporation)

Building using OPV modules on the exterior walls and windows (Taisei Corporation)

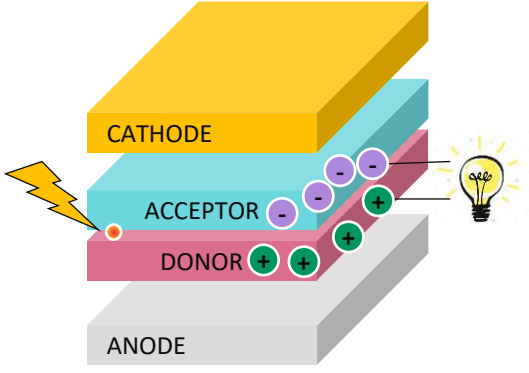
Organic Solar Cells & Market



Joule **3**(6), 1415 (2019)

Predicted (III-V, OPV, and perovskite) and actual (a-Si, CdTe, and Si) PV module manufacturing cost versus the annual production (m^2/year) for multiple cell types and manufacturing processes. Shaded region are the expected volume and maximum price point for the indoor PV market for the period 2018-2023.

Summary Today´s Class



- Organic photovoltaics (OPV): basic mechanisms and device structure
- Recent trends to enhance efficiency of OPV
- Applications in several fields

Interesting tutorial on perovskite solar cells:
https://www.cei.washington.edu/education/science-of-solar/perovskite-solar-cell/