

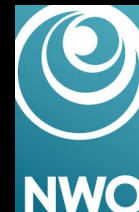
Advancing Solar Energy Conversion through Materials Science

Prof. Monica Morales-Masis

m.moralesmasis@utwente.nl



European Research Council
Established by the European Commission



Focus Session: Basic Science for Sustainable Development
Physics@Veldhoven
April 4th 2023

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INSTITUTE FOR NANOTECHNOLOGY

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OF TWENTE.

About me: a career in physics with a strong focus on materials science

Education

BSc-Physics



MSc-Physics



PhD-Physics



Postdoc

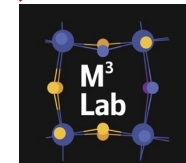
Team Leader



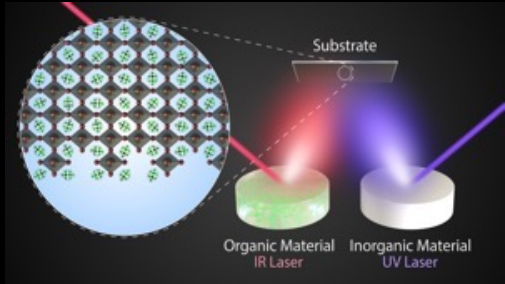
Professor



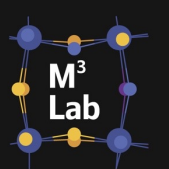
Visiting scientist



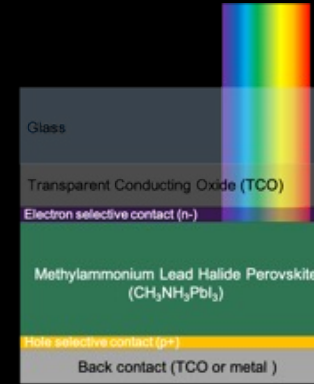
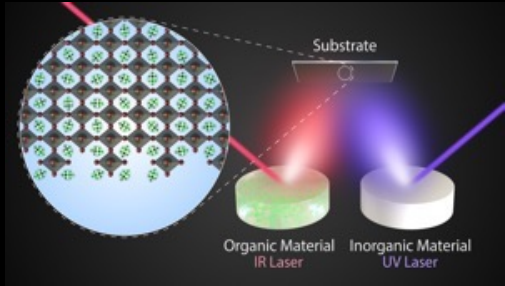
Strong focus on
controlled synthesis
of materials



M³: Making Optoelectronic Materials that Matter



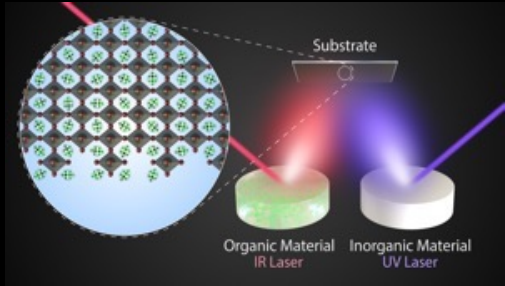
Strong focus on controlled synthesis of materials



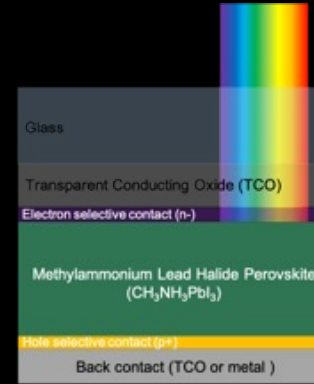
Materials with tunable electrical and optical properties to optimize existing and enable new applications.

M³: Making Optoelectronic Materials that Matter

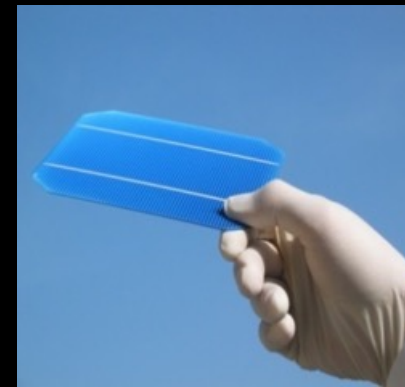
Strong focus on controlled synthesis of materials



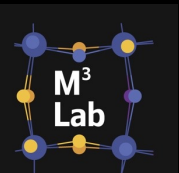
M³: Making Optoelectronic Materials that Matter

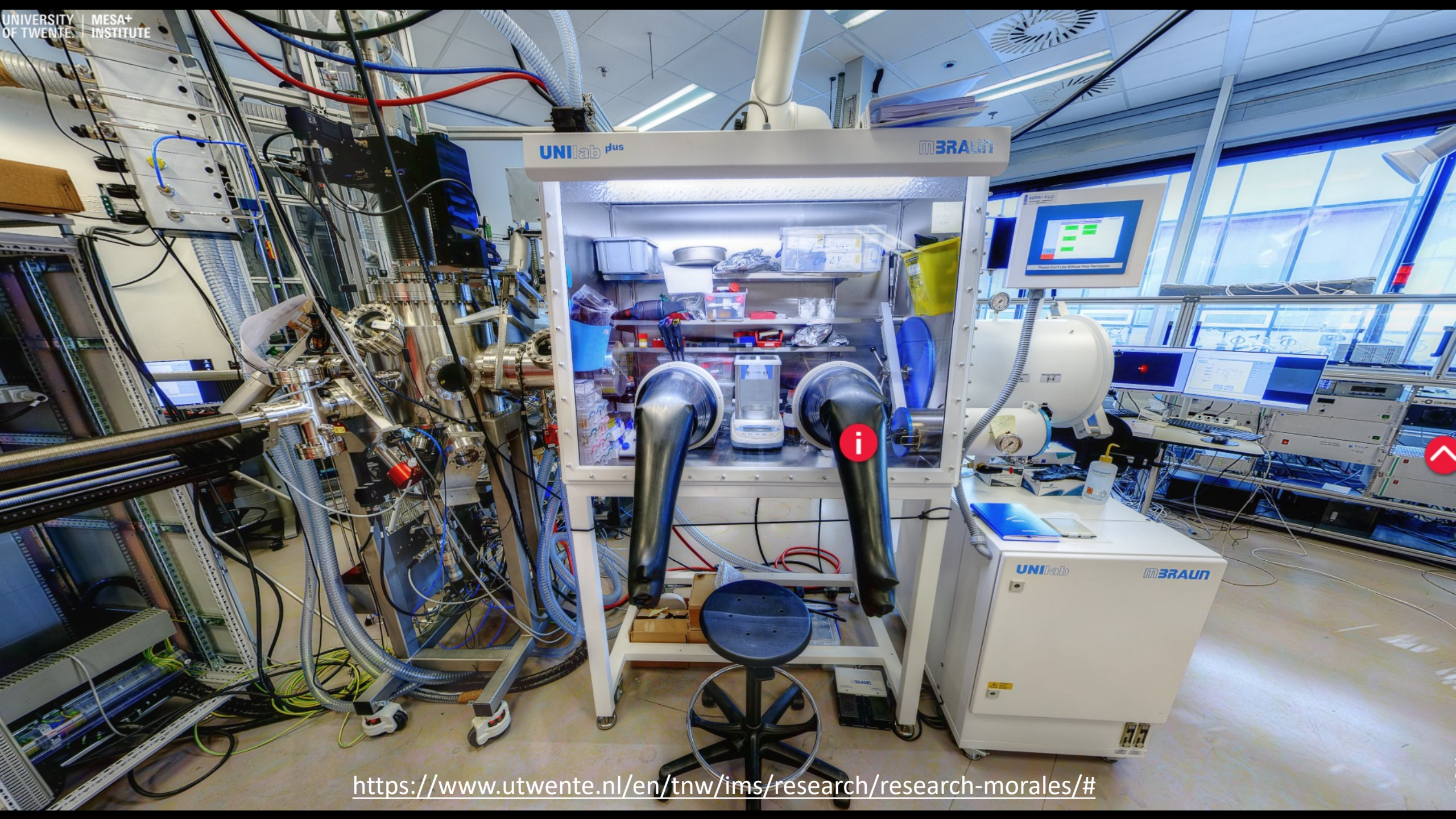


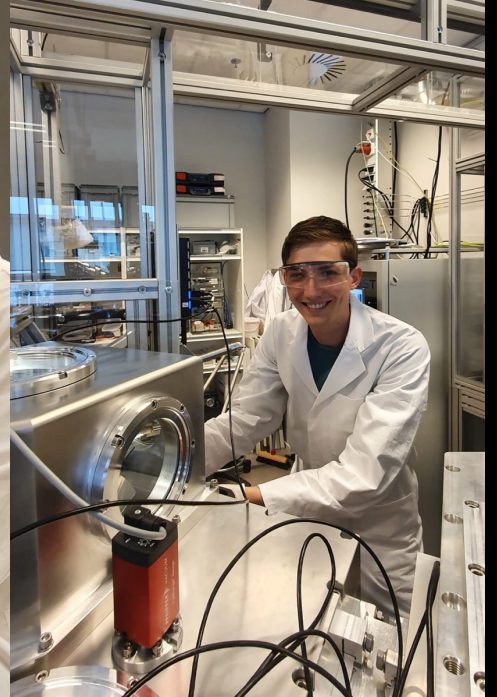
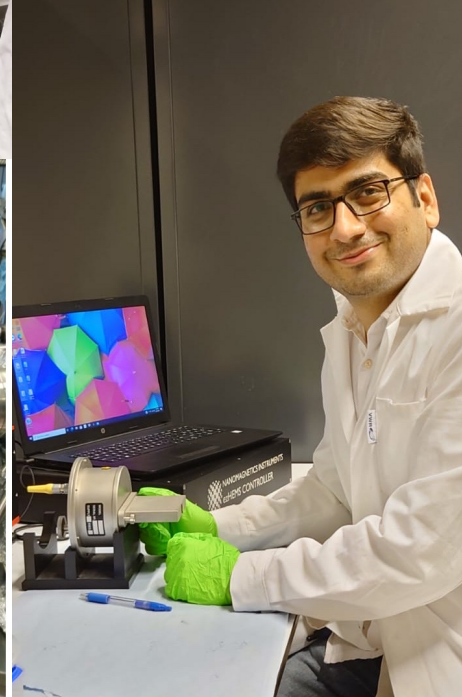
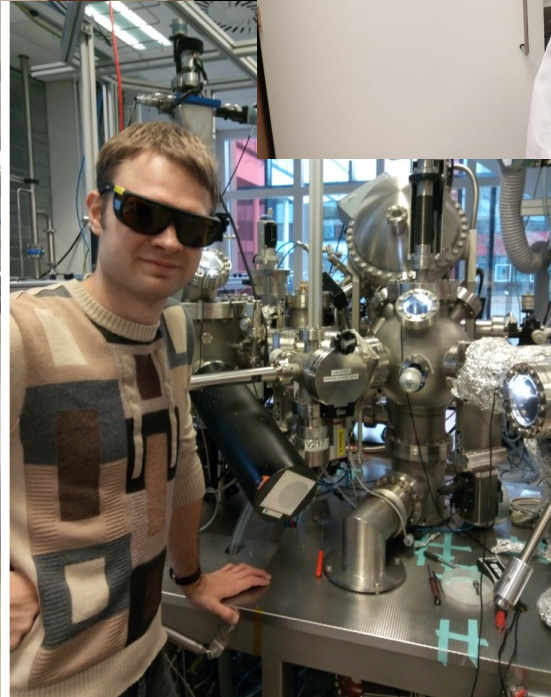
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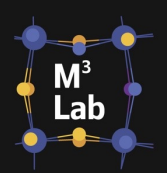
Enhance efficiency and functionality in emerging and established solar cells.
Earth-abundant, Toxic-free materials



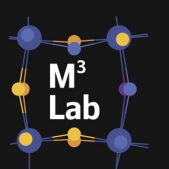




The M³ team



Why Materials for Solar Cells?



Solar energy

- Photovoltaics: the fastest growing energy technology in the world today and an important tool for mitigating climate change.



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POLICY FORUM | RENEWABLE ENERGY



Terawatt-scale photovoltaics: Transform global energy



Nancy M. Haegel, Harry Atwater Jr., Teresa Barnes, Christian Breyer, Anthony Burrell, Yet-Ming C...
+ See all authors and affiliations

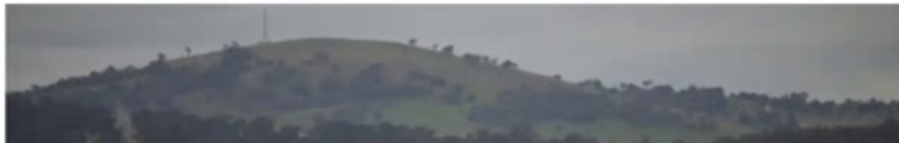
Science 31 May 2019:
Vol. 364, Issue 6443, pp. 836-838
DOI: 10.1126/science.aaw1845



Energy

'Insanely cheap energy': how solar power continues to shock the world

Australian smarts and Chinese industrial might made solar power the cheapest power humanity has seen - and no one saw it coming



Royce Kurlmelovs

@RoyceRk2

Sat 24 Apr 2021 21:00 BST

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pv magazine

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World has installed 1TW of solar capacity

The world has installed its first terawatt of hardware on Earth to generate electricity directly from the sun.

MARCH 15, 2022 **JOHN FITZGERALD WEAVER**

Global power demand ~ 20 TW

“Global installed solar PV capacity exceeded **500 GW** at the end of 2018, and an additional 500 GW is projected to be installed by 2022-2023, bringing us to the era of TW-scale PV”

“...**solar supplies 3% of the world's electricity**. Our official forecast is that it will be 23% by 2050, but that's completely underestimated...”

~90% of global PV installations are crystalline Silicon!



Crystalline silicon PV:
modules are now affordable, efficient, reliable and dominant in
the global PV market

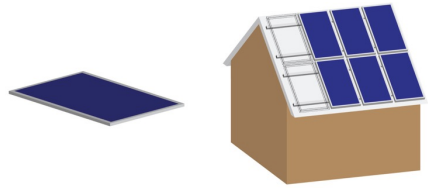
Do we actually need other PV technologies?

Sustainability! (low carbon footprint, recyclability, etc)

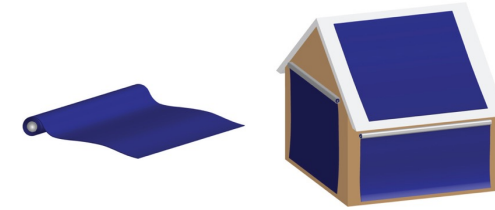
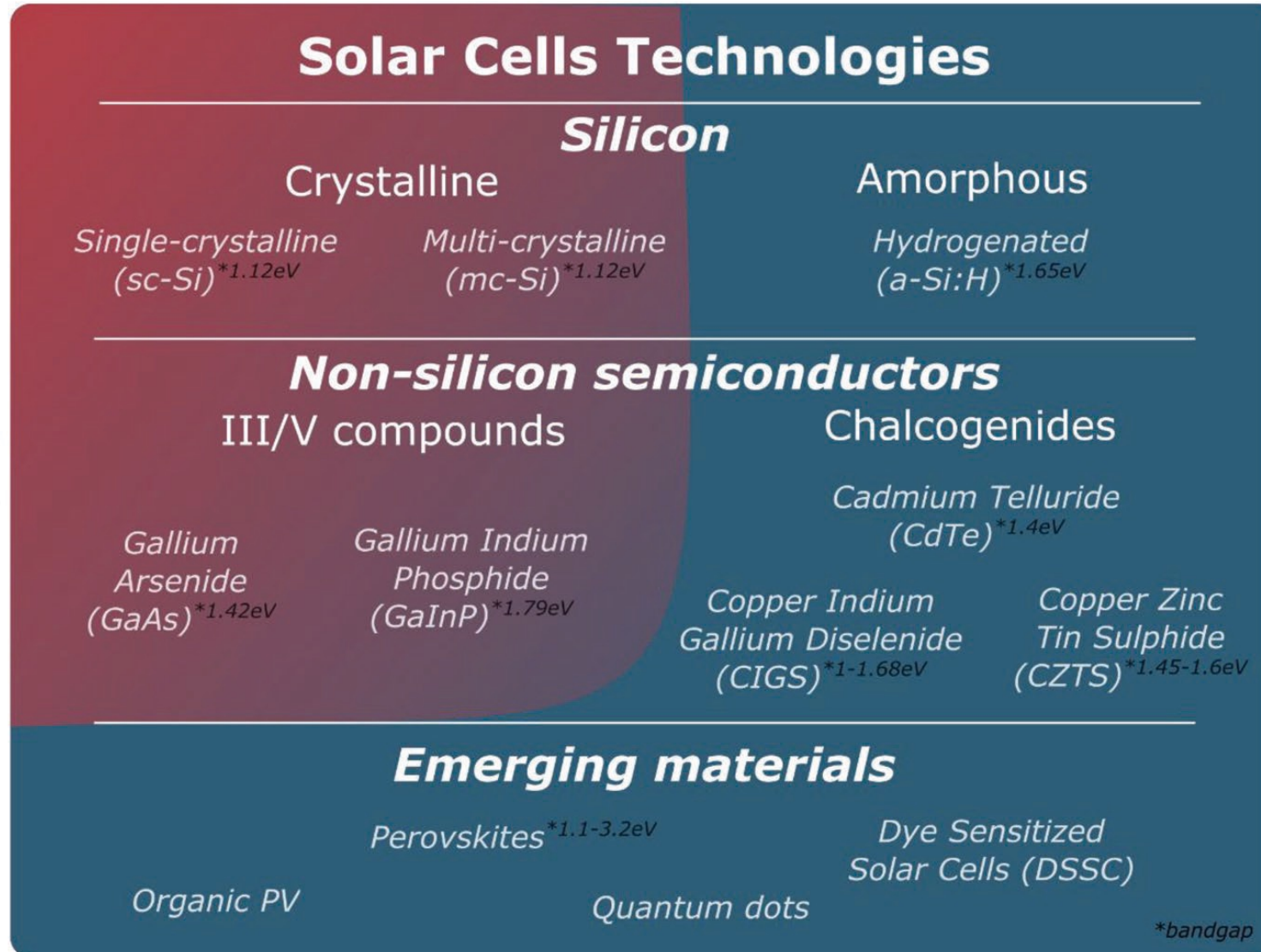
Efficiency (e.g. less m²)

Seamless integration of PV everywhere (VIPV, BIPV, wearables, etc)

Main solar photovoltaic technologies...



Wafer



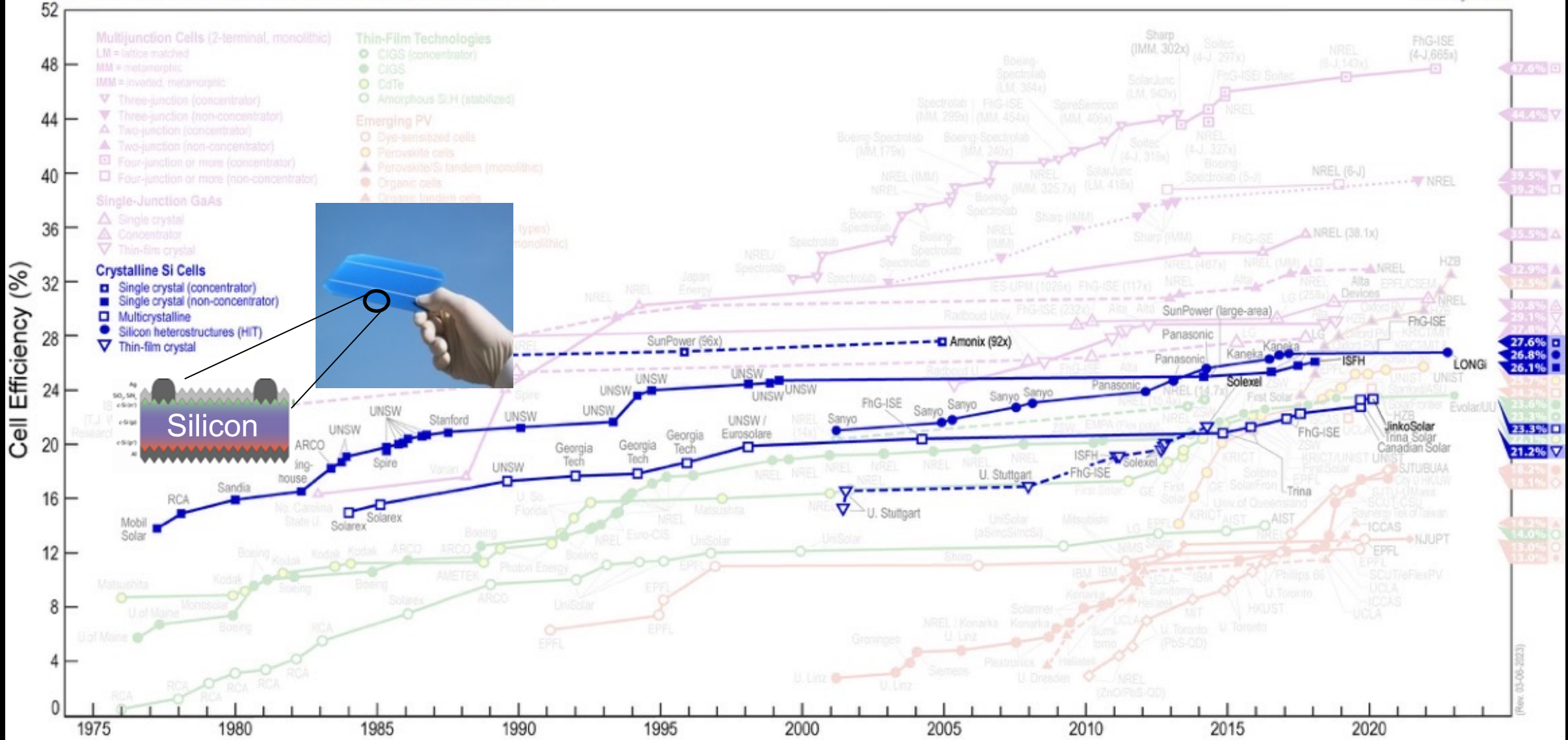
Thin films

- Low CO₂ footprint
- Reduce use of materials
- Opportunities for new Earth abundant materials
- Avoid critical and toxic materials

*bandgap

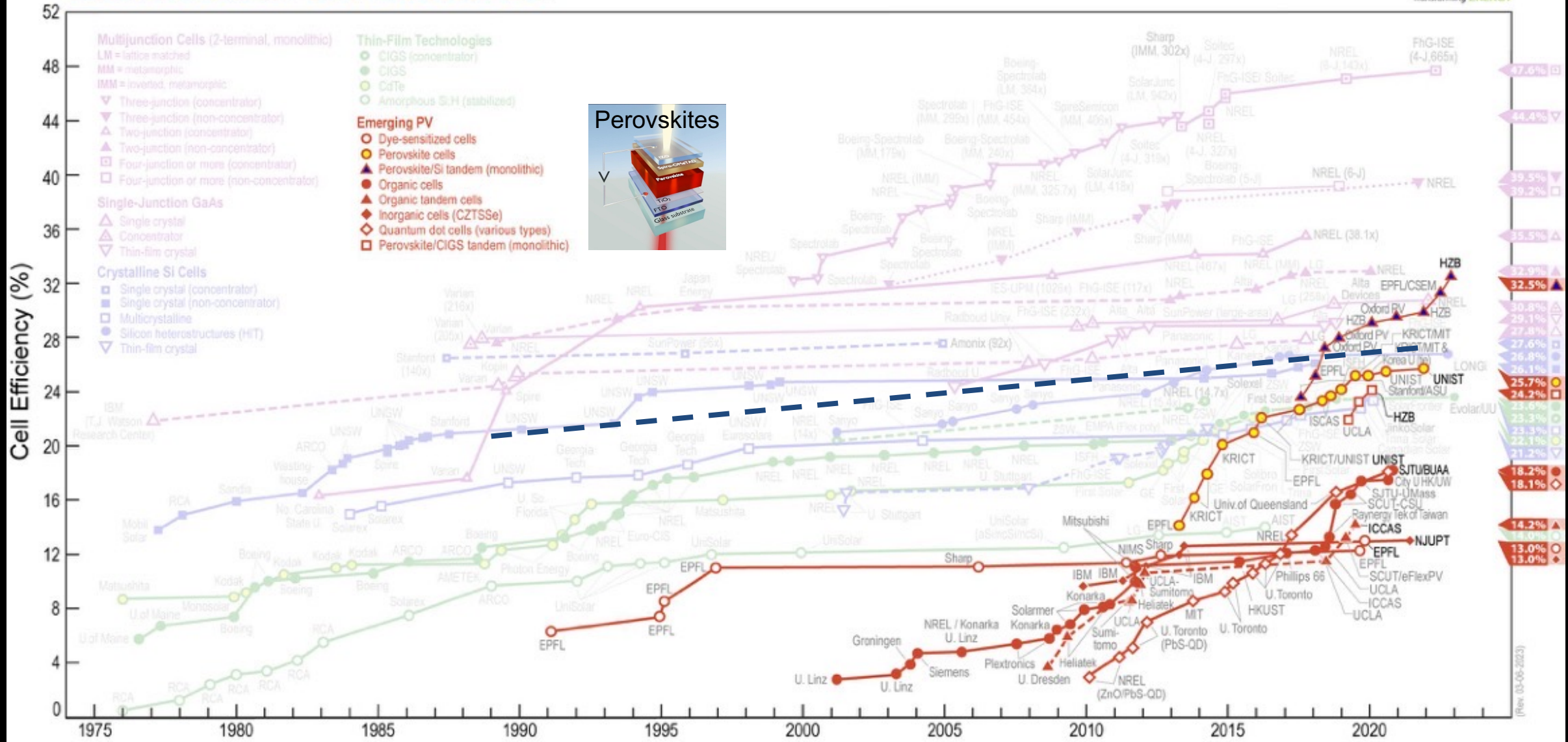
Solar Cell (certified) record efficiency chart

Best Research-Cell Efficiencies

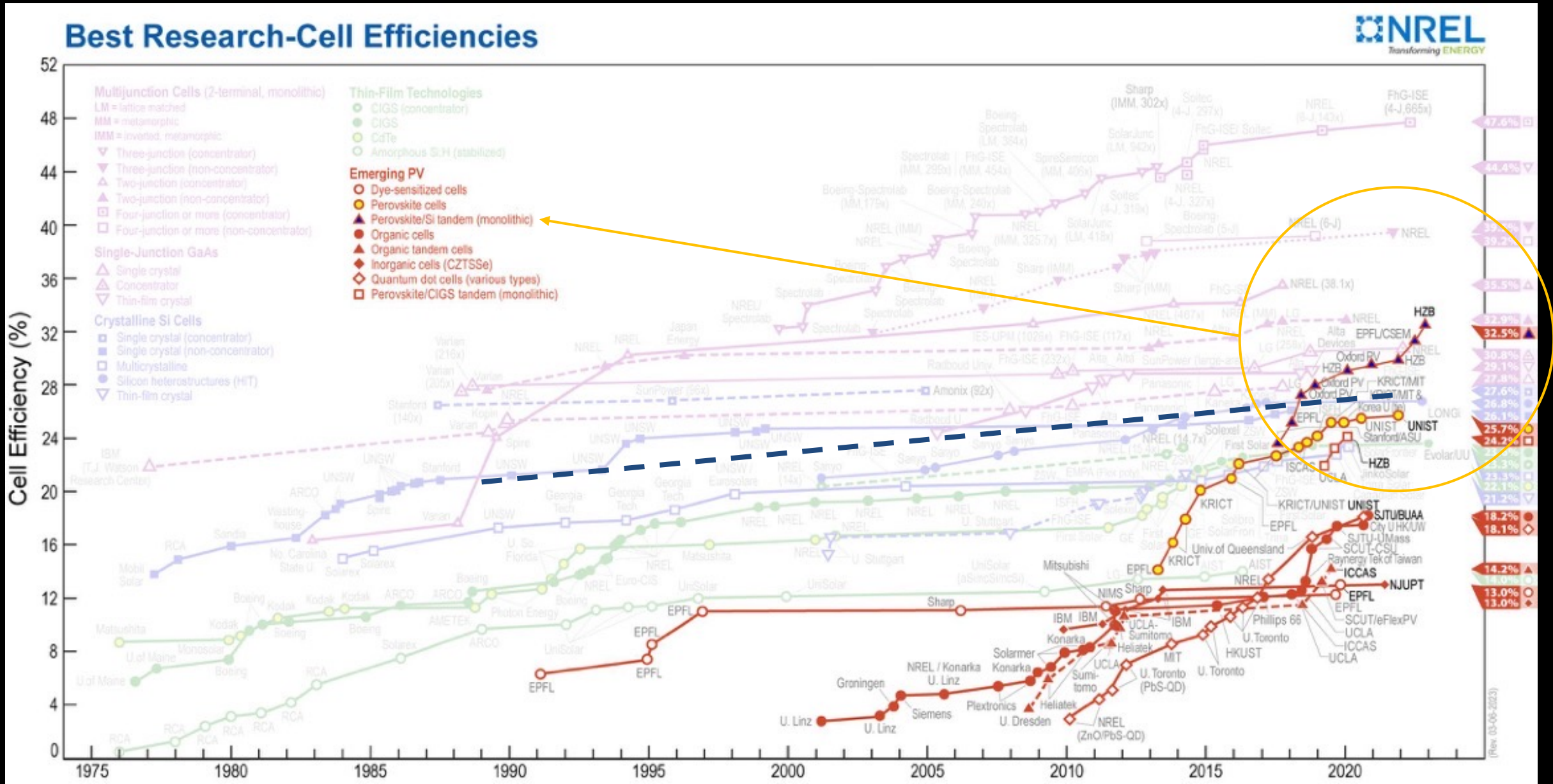


Solar Cell (certified) record efficiency chart

Best Research-Cell Efficiencies



Solar Cell (certified) record efficiency chart



Interesting challenges for materials science:
 New materials with properties on par with those used in record devices **but**
 made of **non-toxic, non-critical raw materials**

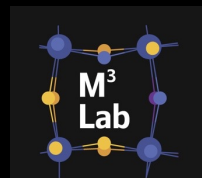
Periodic Table of the Elements

| | | | | | | | | | | | | | | | | | |
|---------------------------------|---------------------------------|----------------------------------|-------------------------------------|-------------------------------------|----------------------------------|-----------------------------------|----------------------------------|----------------------------------|------------------------------------|-----------------------------------|------------------------------------|----------------------------------|---------------------------------|-----------------------------------|-----------------------------------|----------------------------------|---------------------------------|
| 1 1IA 1A | 2 IIA 2A | | | | | | | | | | | 13 IIIA 3A | 14 IVA 4A | 15 VA 5A | 16 VIA 6A | 17 VIIA 7A | 18 VIIIA 8A |
| 1 H Hydrogen 1.008 | | | | | | | | | | | | | | | | | 2 He Helium 4.003 |
| 3 Li Lithium 6.941 | 4 Be Beryllium 9.012 | | | | | | | | | | | 5 B Boron 10.811 | 6 C Carbon 12.011 | 7 N Nitrogen 14.007 | 8 O Oxygen 15.999 | 9 F Fluorine 18.998 | 10 Ne Neon 20.180 |
| 11 Na Sodium 22.99 | 12 Mg Magnesium 24.305 | 3 IIIB 3B | 4 IVB 4B | 5 VB 5B | 6 VIB 6B | 7 VIIB 7B | 8 VIII 8 | 9 VIII 8 | 10 VIII 8 | 11 IB 1B | 12 IIB 2B | 13 Al Aluminum 26.982 | 14 Si Silicon 28.086 | 15 P Phosphorus 30.974 | 16 S Sulfur 32.066 | 17 Cl Chlorine 35.453 | 18 Ar Argon 39.948 |
| 19 K Potassium 39.098 | 20 Ca Calcium 40.078 | 21 Sc Scandium 44.956 | 22 Ti Titanium 47.867 | 23 V Vanadium 50.942 | 24 Cr Chromium 51.996 | 25 Mn Manganese 54.938 | 26 Fe Iron 55.845 | 27 Co Cobalt 58.933 | 28 Ni Nickel 58.693 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.38 | 31 Ga Gallium 69.723 | 32 Ge Germanium 72.631 | 33 As Arsenic 74.922 | 34 Se Selenium 78.971 | 35 Br Bromine 79.904 | 36 Kr Krypton 83.799 |
| 37 Rb Rubidium 85.468 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.906 | 40 Zr Zirconium 91.224 | 41 Nb Niobium 92.906 | 42 Mo Molybdenum 95.95 | 43 Tc Technetium 98.907 | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.906 | 46 Pd Palladium 106.42 | 47 Ag Silver 107.868 | 48 Cd Cadmium 112.414 | 49 In Indium 114.818 | 50 Sn Tin 118.710 | 51 Sb Antimony 121.760 | 52 Te Tellurium 127.6 | 53 I Iodine 126.904 | 54 Xe Xenon 131.294 |
| 55 Cs Cesium 132.905 | 56 Ba Barium 137.328 | 57-71 Lanthanide Series | 72 Hf Hafnium 178.49 | 73 Ta Tantalum 180.948 | 74 W Tungsten 183.84 | 75 Re Rhenium 186.207 | 76 Os Osmium 190.23 | 77 Ir Iridium 192.217 | 78 Pt Platinum 195.085 | 79 Au Gold 196.967 | 80 Hg Mercury 200.592 | 81 Tl Thallium 204.383 | 82 Pb Lead 207.2 | 83 Bi Bismuth 208.980 | 84 Po Polonium [209] | 85 At Astatine [209] | 86 Rn Radon 222.018 |
| 87 Fr Francium 223.029 | 88 Ra Radium 226.025 | 89-103 Actinide Series | 104 Rf Rutherfordium [261] | 105 Db Dubnium [262] | 106 Sg Seaborgium [266] | 107 Bh Bohrium [264] | 108 Hs Hassium [269] | 109 Mt Meitnerium [278] | 110 Ds Darmstadtium [281] | 111 Rg Roentgenium [280] | 112 Cn Copernicium [285] | 113 Nh Nihonium [286] | 114 Fl Flerovium [289] | 115 Mc Moscovium [288] | 116 Lv Livermorium [293] | 117 Ts Tennessine [294] | 118 Og Oganesson [294] |
| | | 57 La Lanthanum 138.905 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.243 | 61 Pm Promethium 144.913 | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.925 | 66 Dy Dysprosium 162.500 | 67 Ho Holmium 164.930 | 68 Er Erbium 167.259 | 69 Tm Thulium 168.934 | 70 Yb Ytterbium 173.055 | 71 Lu Lutetium 174.967 | |
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Critical raw materials

toxic

| | | | | | | | | | |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|
| Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|



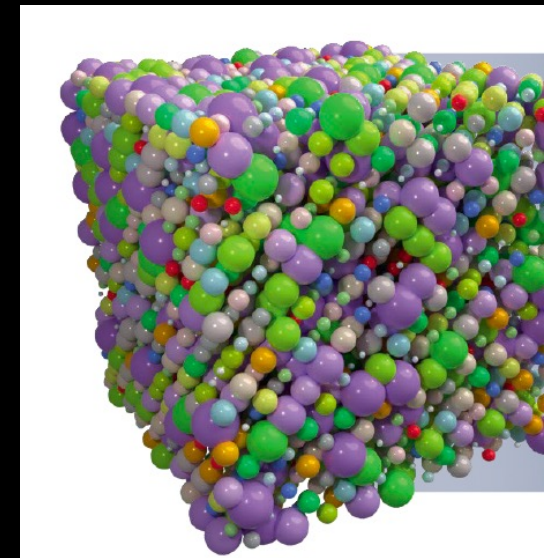
Interesting challenges for materials science: Great opportunities for **Materials Design** joining experimental and computational efforts

Only 118 elements on the period table, but huge number of materials combinations possible

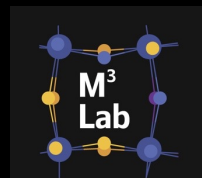
Chemical complexity in materials therefore increasing!

Periodic Table of the Elements

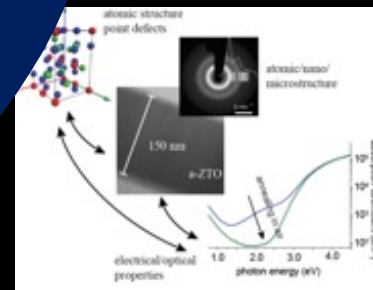
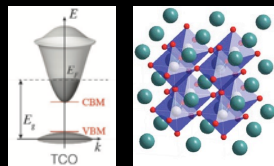
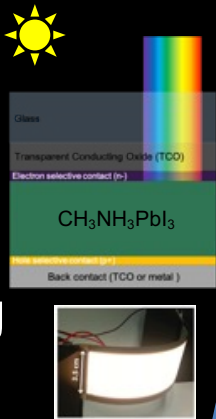
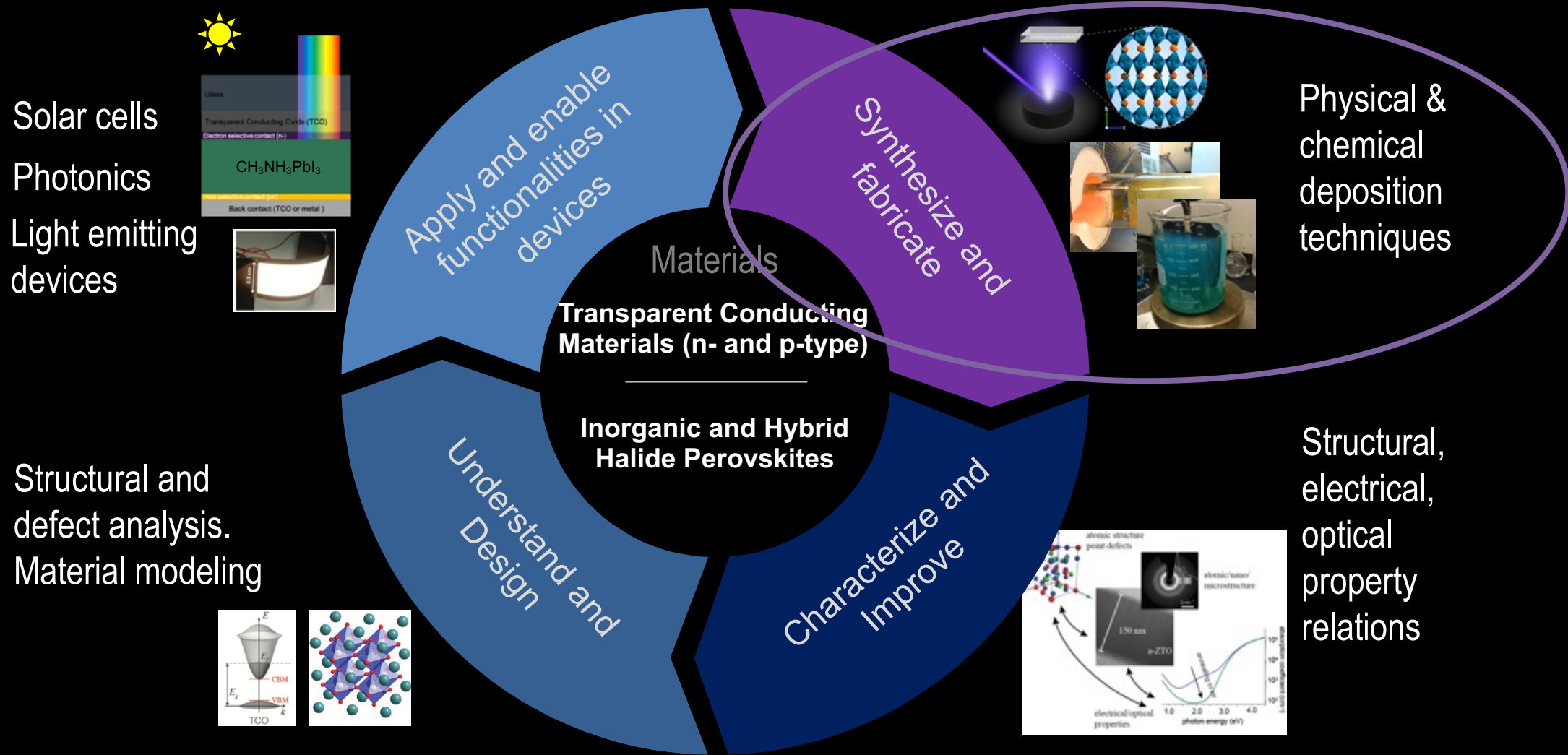
| | | | | | | | | | | | | | | | | | |
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<https://doi.org/10.1038/s43588-023-00412-7>

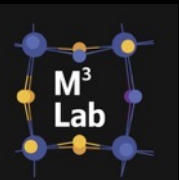


Our contribution to the field: Optoelectronic Thin Film Materials

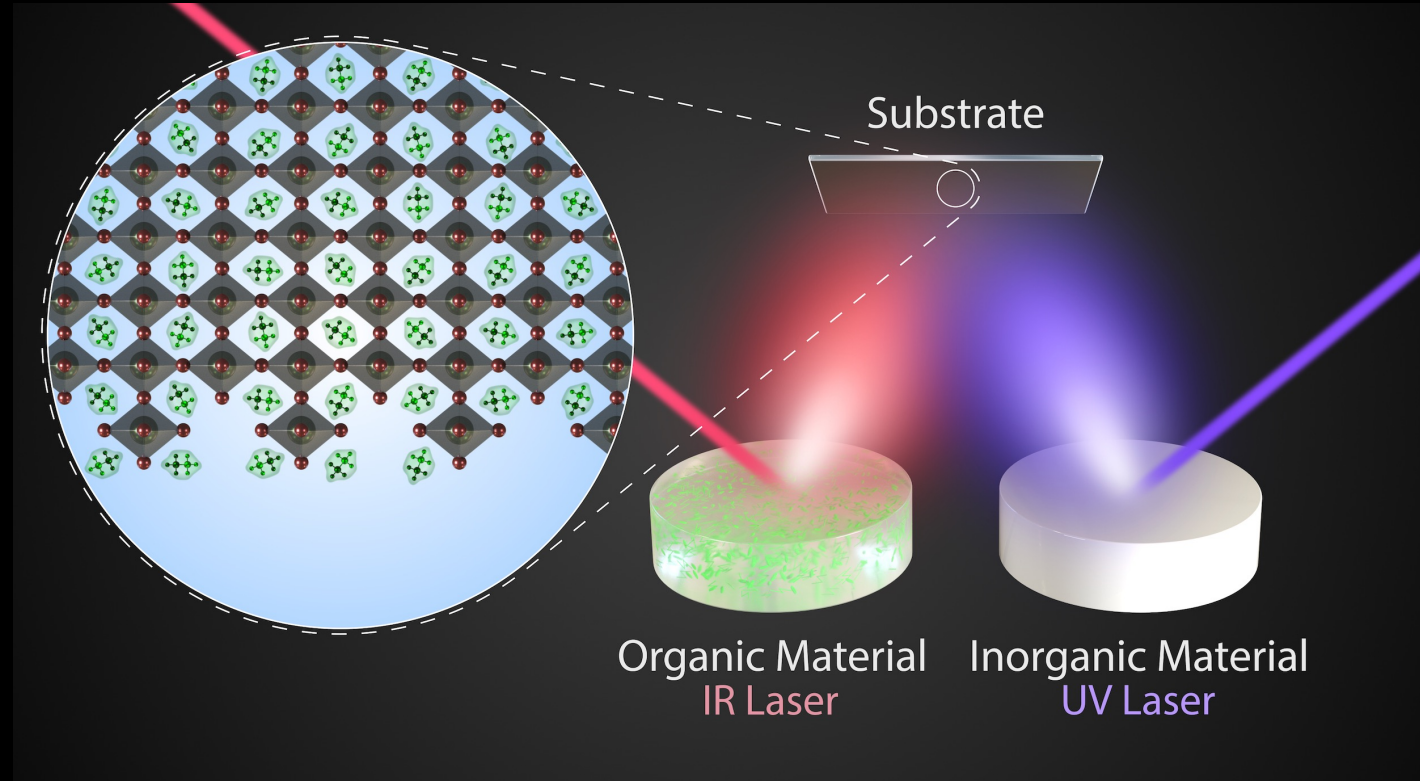
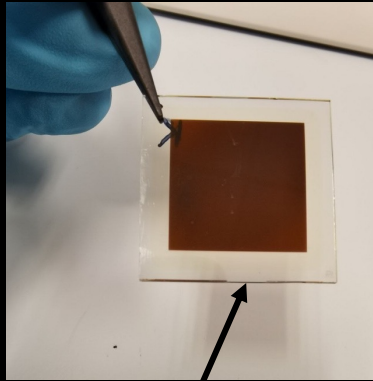


Reviews

Morales-Masis M., et al. *Adv. Electron Mat.* Vol.3 (2017)
 Fioretti A., Morales-Masis M. *J. Phot. Energy* (2020)
 Soto-Montero T., Soltanpoor W., M.MM. invited. *APL Mat* (2020)

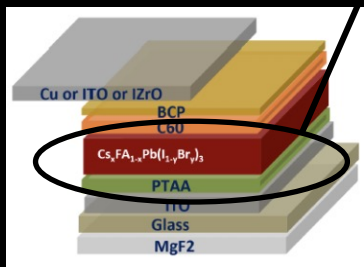


A versatile thin film deposition technique for **complex material compositions**: case of hybrid halide perovskites for solar cells



European Research Council
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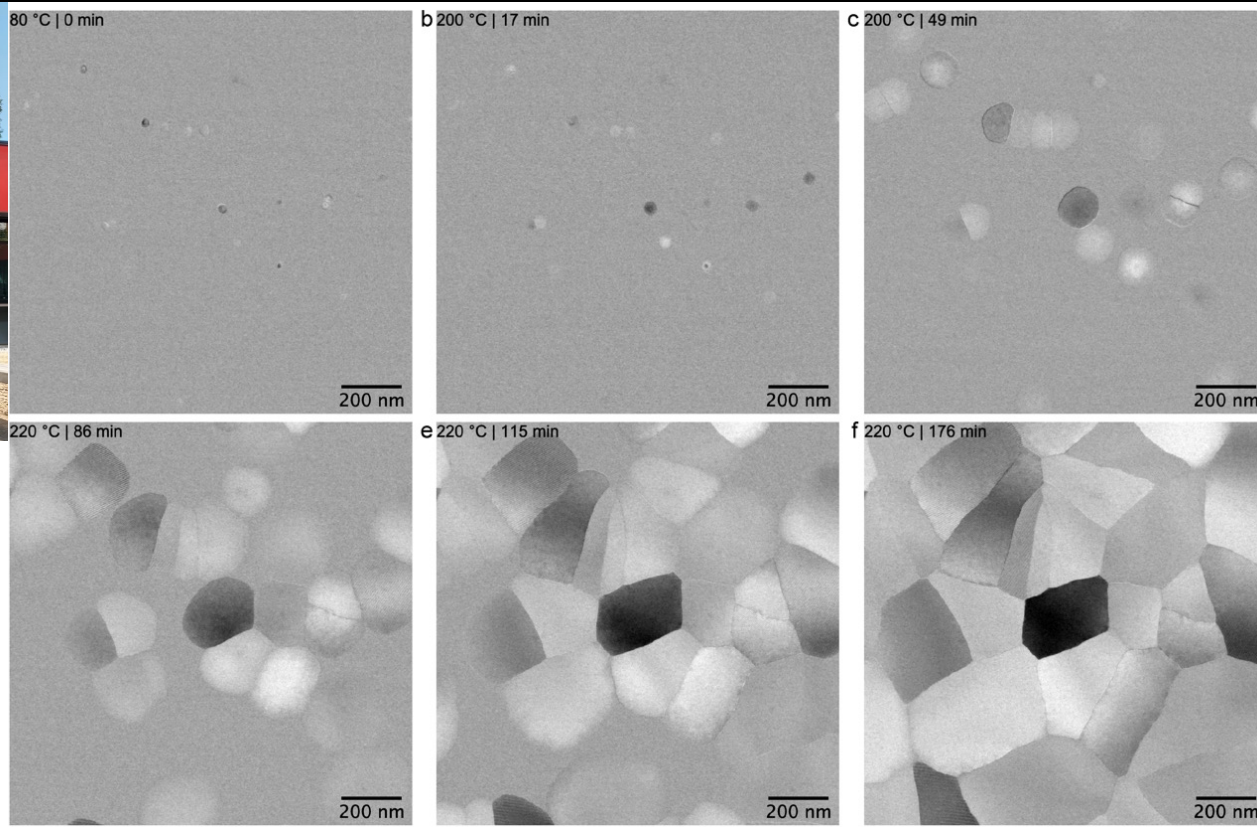
CREATE



Thin film solar cell stack



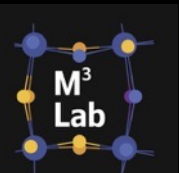
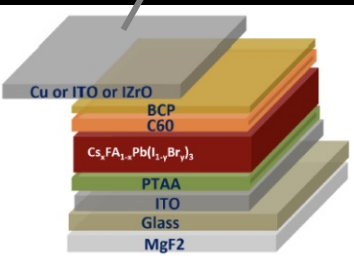
Development of transparent electrodes for solar cells



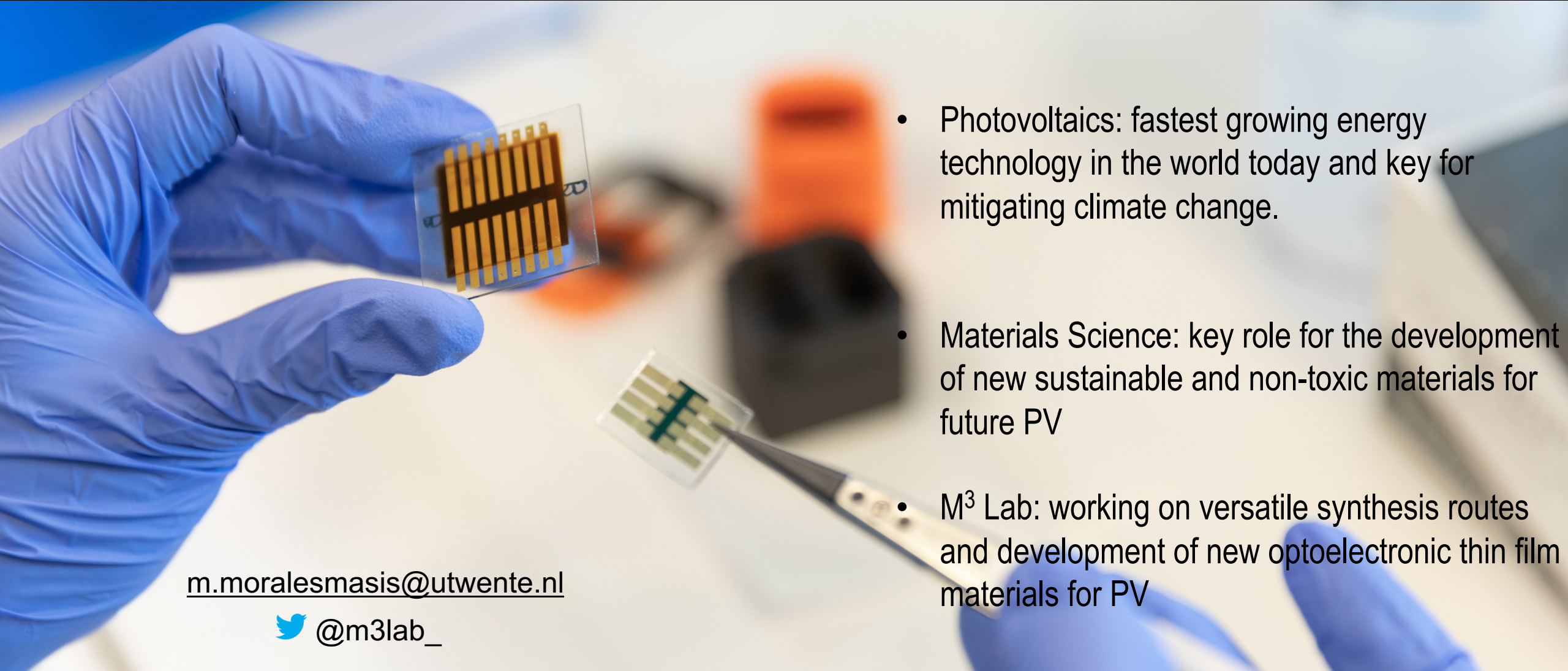
In-situ crystallization of a Zr-doped In_2O_3 transparent electrode:

Improve performance with microstructure control

Reducing thickness of the electrodes to reduce the use of indium in SCs




Summary



- Photovoltaics: fastest growing energy technology in the world today and key for mitigating climate change.
- Materials Science: key role for the development of new sustainable and non-toxic materials for future PV
- M³ Lab: working on versatile synthesis routes and development of new optoelectronic thin film materials for PV

m.moralesmasis@utwente.nl

 @m3lab_

Big PV Initiatives in NL

SolarNL

Solarlab.nl



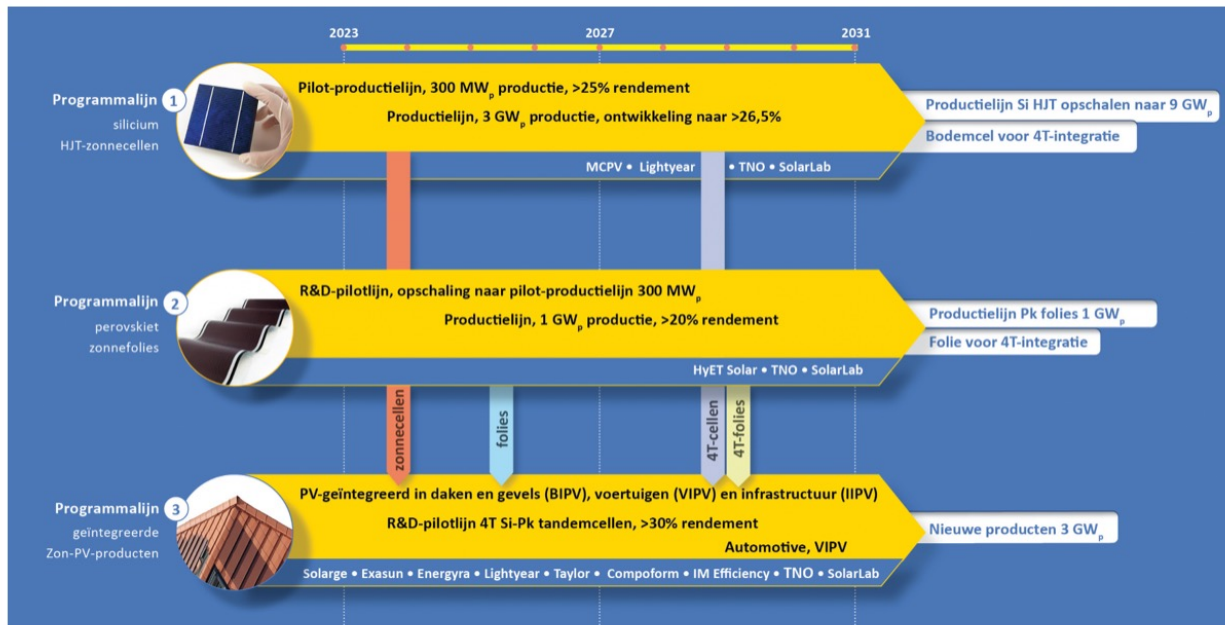
Si HJT cell factory



Flexible solar foils



Lightweight/integrated



This Growth Fund proposal aims to create the necessary innovative PV technologies and industrial basis in the Netherlands to capture economic value of billions of euros for decades to come. In addition, this 'local manufacturing', using short lines from supply to markets, will generate multiple environmental benefits and reinforce strategic autonomy in our energy supply. On all these points, the proposal is fully aligned with the currently accelerating momentum towards new industrial public policies on EU level.