Perovskite & chalcogenide, a marriage made in heaven?

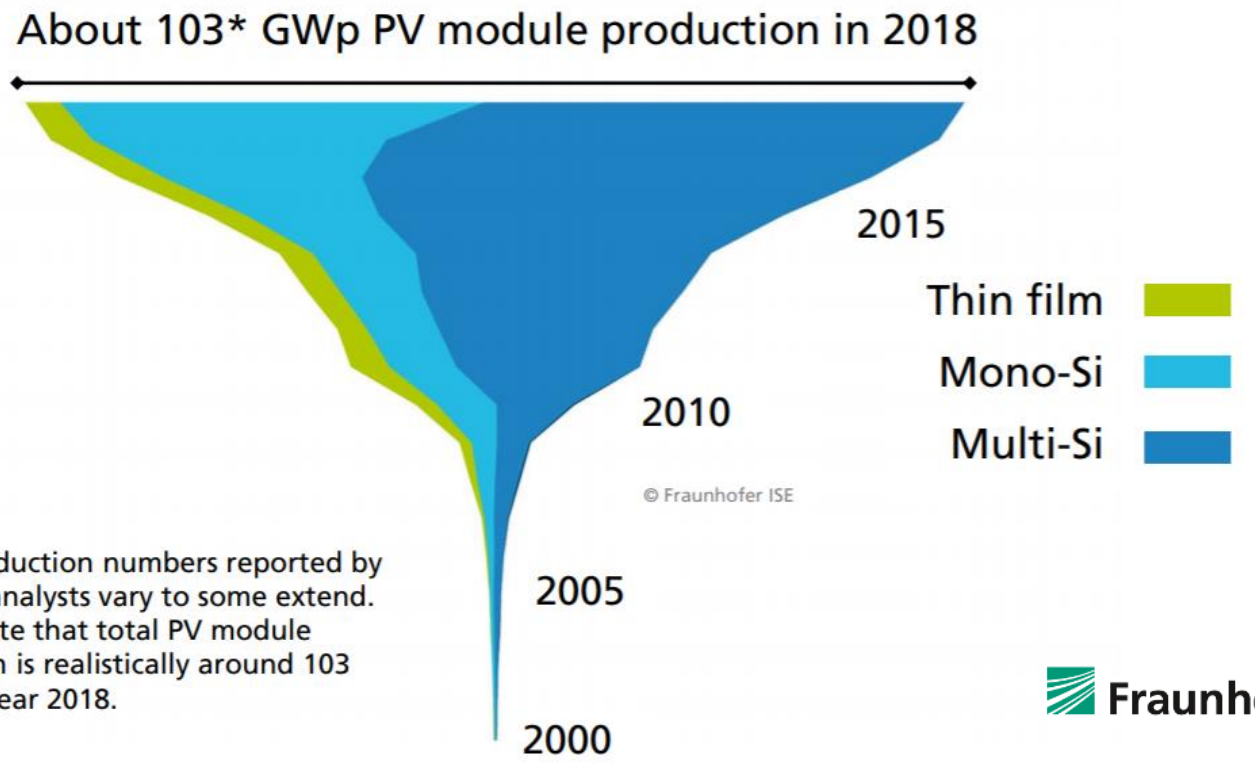
Bart Vermang, June 11th 2020

OUTLINE

1. Commercial thin film PV
2. Good match for perovskite
3. All thin-film tandem PV

PV – Annual production by technology, worldwide (GWp)

PV report, ISE Fraunhofer



*2018 production numbers reported by different analysts vary to some extend. We estimate that total PV module production is realistically around 103 GWp for year 2018.

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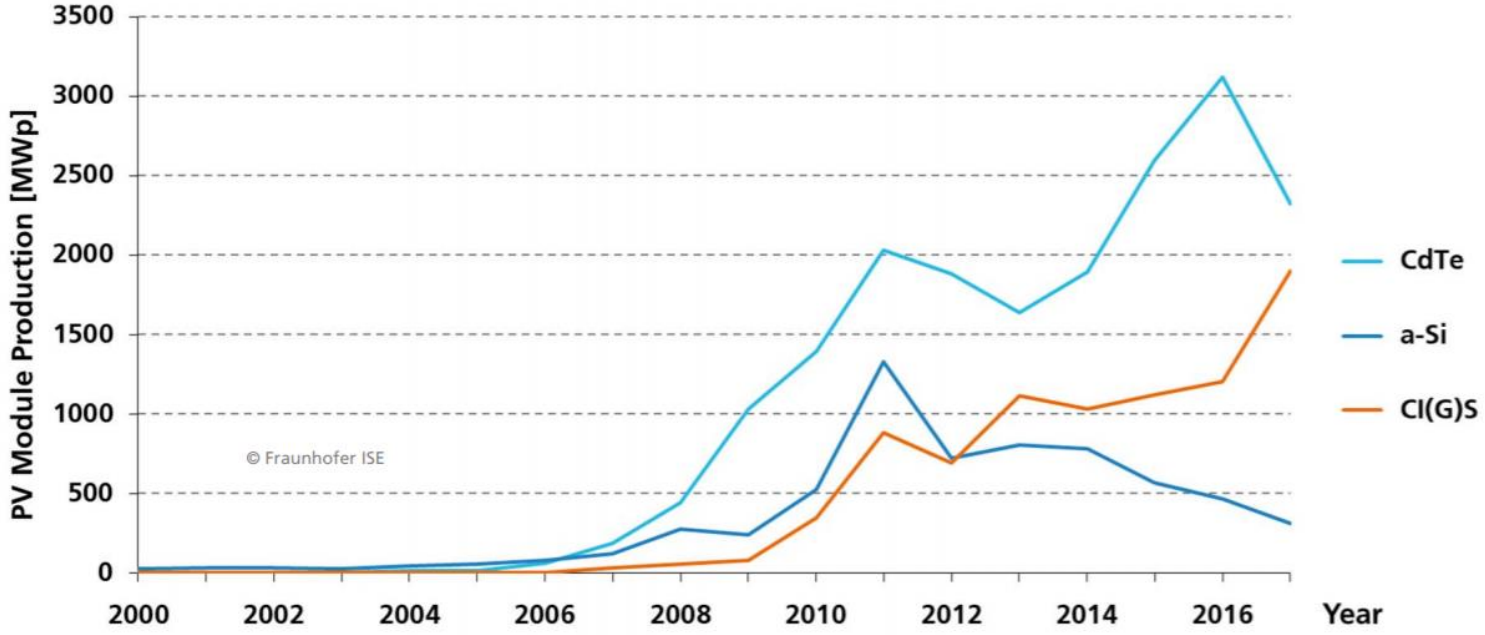
Thin-film PV – Annual global PV module production

PV report, ISE Fraunhofer



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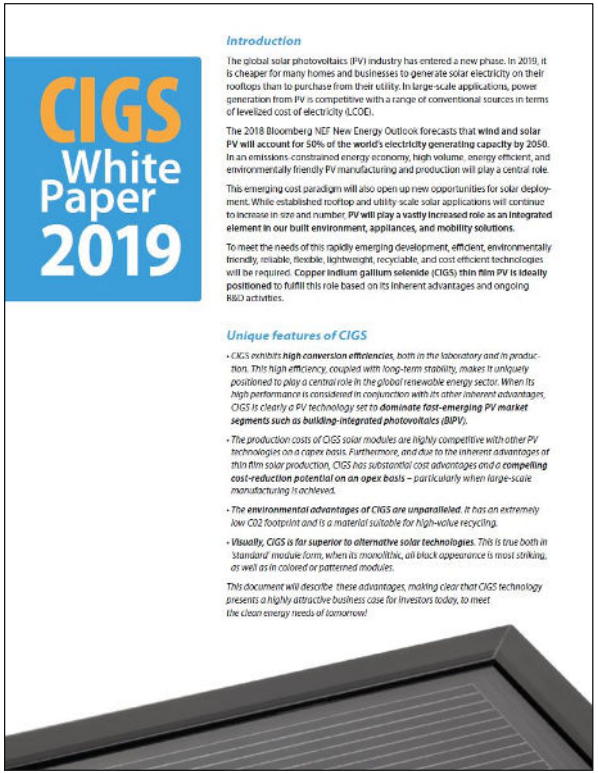
CIGS thin-film PV – White paper initiative

https://cigs-pv.net/

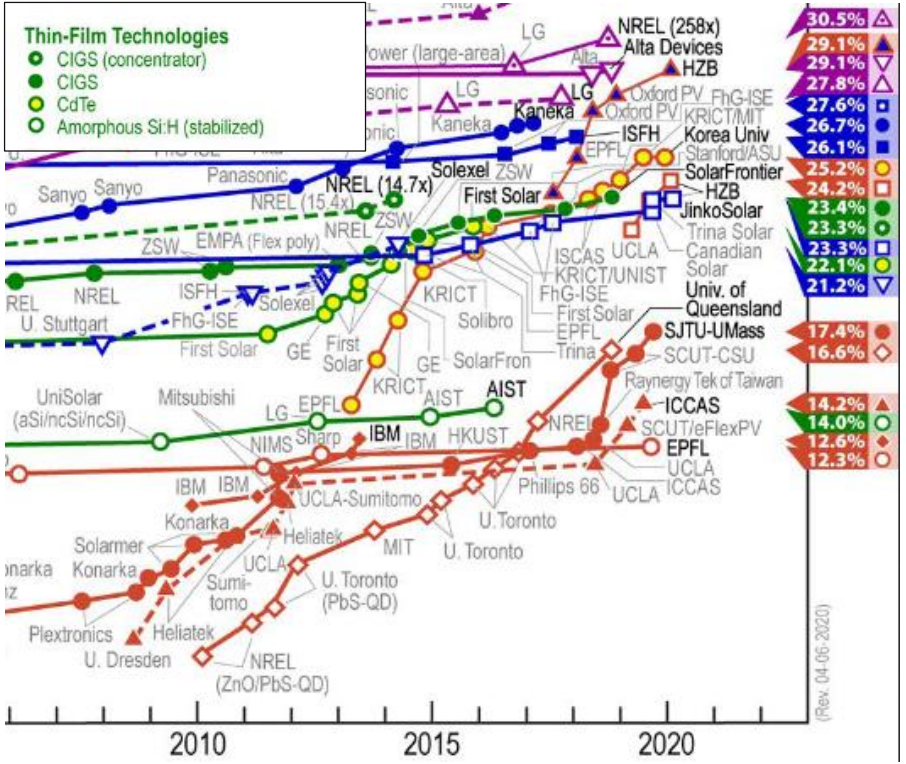


- Intrinsic advantages of thin-film technologies + high efficiency, energy yield and reliability
- Utility scale, rooftop and BIPV applications, colored, patterned and/or flexible products
- Fully vertically integrated, low-cost production on a GW scale
- Low material consumption, short energy payback times, low carbon footprint

CIGS thin-film PV – Single-junction status

Solar cell efficiency tables; DOI: 10.1002/pip.3228

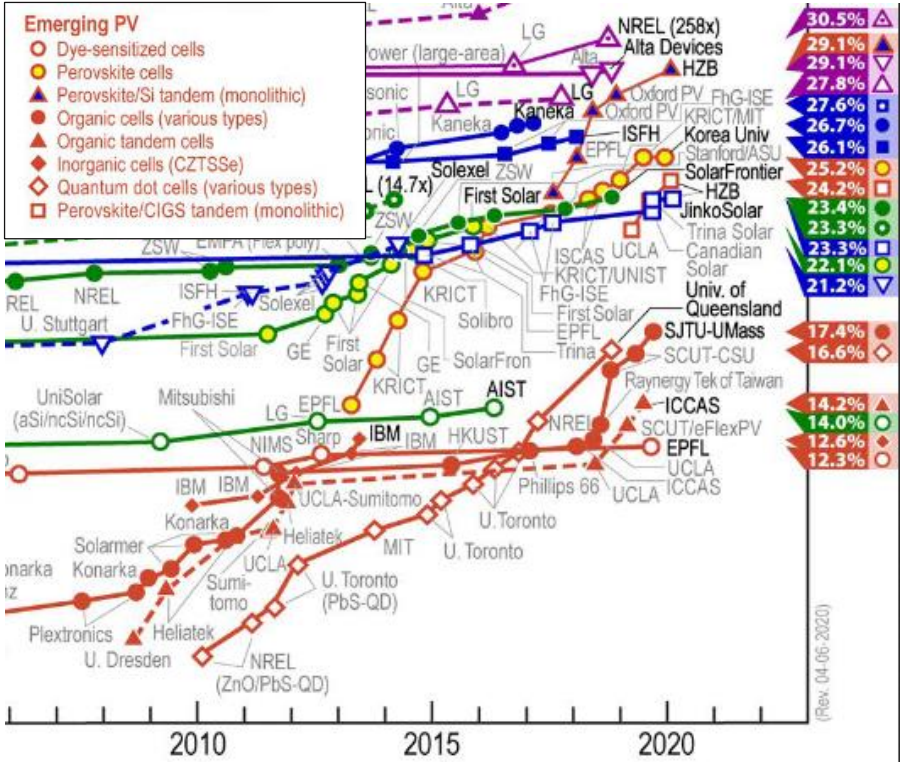
- Cell level
  - Efficiency = 23.4 %
  - V_{OC} = 0.734 V
  - J_{SC} = 39.6 mA/cm^2
  - FF = 80.4 %
- Module level
  - Efficiency = 19.2 %
  - V_{OC} = 48.0 V
  - J_{SC} = 0.456 A
  - FF = 73.7 %



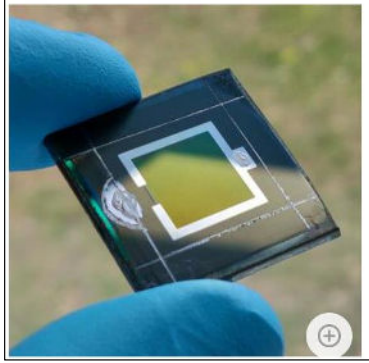
CIGS thin-film PV – Tandem status

Solar cell efficiency tables; DOI: 10.1002/pip.3228

- Monolithic / 2T
  - 0.5 to 1 cm^2
  - 24.16 %



Tandem solar cell world record: New branch in the NREL chart



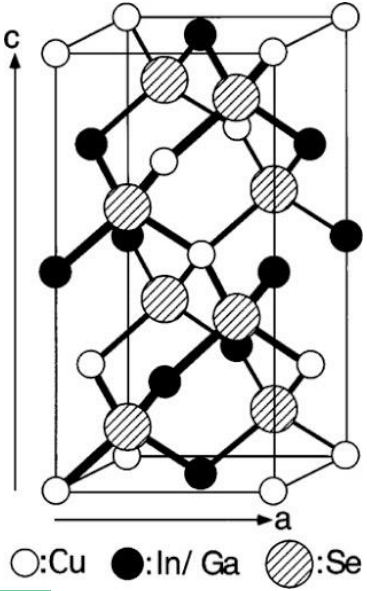
A special branch in the famous NREL-chart for solar cell world records refers to a newly developed tandem solar cell by HZB teams. The world-record cell combines the semiconductors perovskite and CIGS to a monolithic "two-terminal" tandem cell. Due to the thin-film technologies used, such tandem cells survive much longer in space and can even be produced on flexible films. The new tandem cell achieves a certified efficiency of 24.16 percent.

Tandem cells combine two different

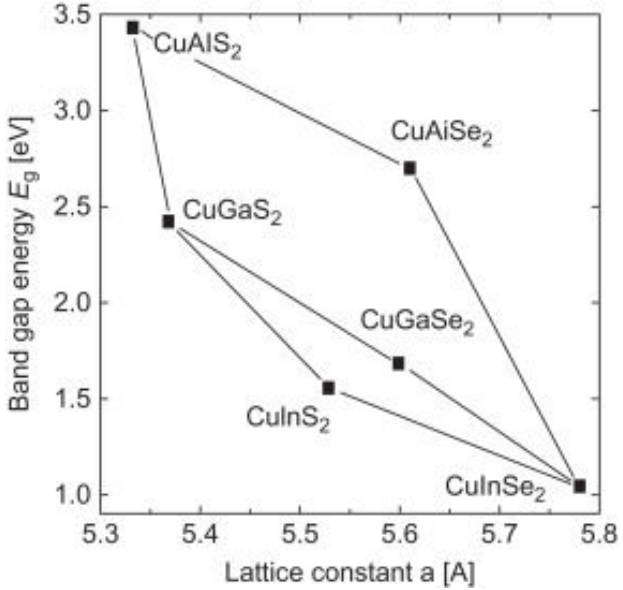
CIGS thin-film PV – Tunable bandgap

DOI: 10.1016/B978-0-12-809921-6.00010-0

- Chalcopyrite structure



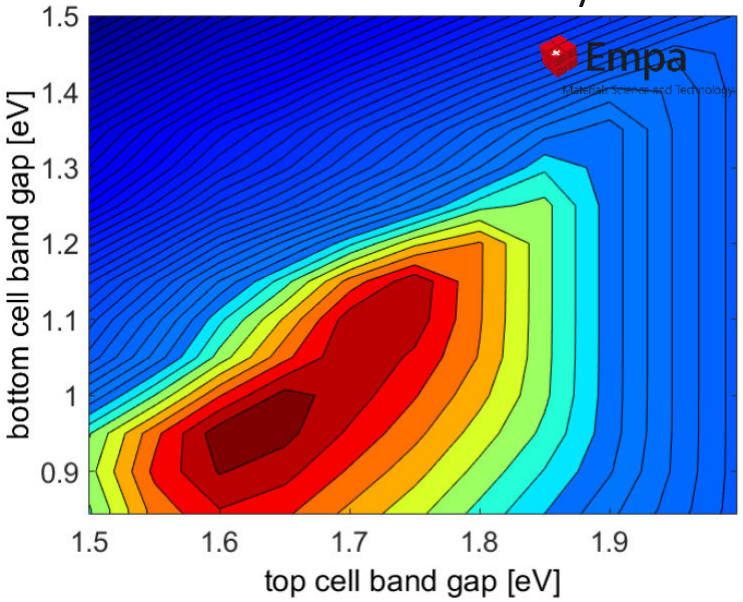
- Tunable bandgap



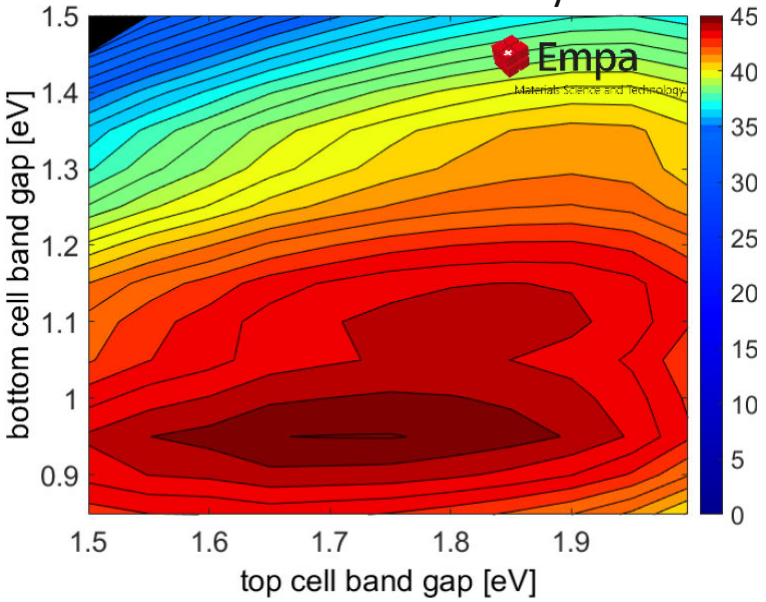
$CuInSe_2$ – High potential as bottom cell for tandem

Courtesy of EMPA; PhD thesis Thomas Feurer

2T tandem efficiency



4T tandem efficiency



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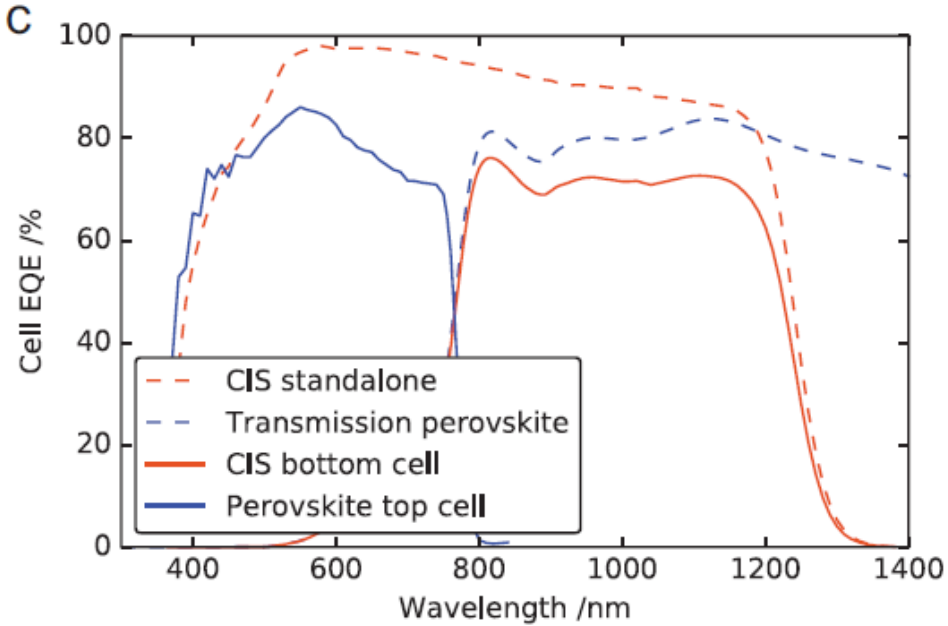
$CuInSe_2$ – High potential as bottom cell for tandem

Courtesy of EMPA; DOI: 10.1002/aenm.201901428

- Cell level
  - Efficiency = 19.2 %
  - V_{OC} = 0.609 V
  - J_{SC} = 42.3 mA/cm^2
  - FF = 74.6 %

Empa
Materials Science and Technology



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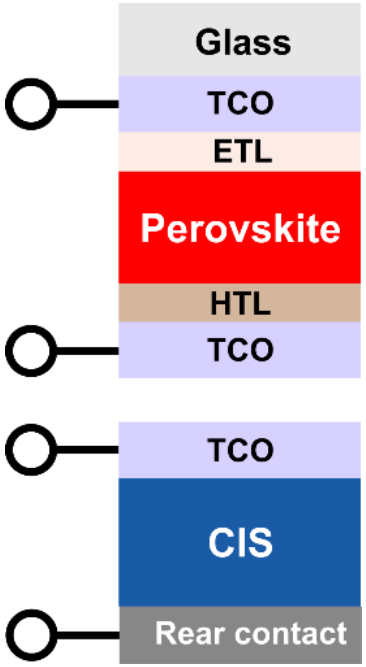
All thin-film perovskite on CIS tandem development

PERCISTAND

Very strong and complementary consortium



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TNO

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UHASSELT

Australian National University

NREL NATIONAL RENEWABLE ENERGY LABORATORY

All thin-film perovskite on CIS tandem development

PERCISTAND

LC-SC3-RES-1-2019-2020 - Next generation PV technologies

- Power conversion efficiency targets
  - ≥ 20 % semi-transparent perovskite
  - ≥ 10 % NIR-illuminated $CuInSe_2$
  - ≥ 30 % tandem cell
  - ≥ 25 % tandem module
- on glass.
- With high stability,
- high manufacturability,
- and at low cost and low environmental footprint.

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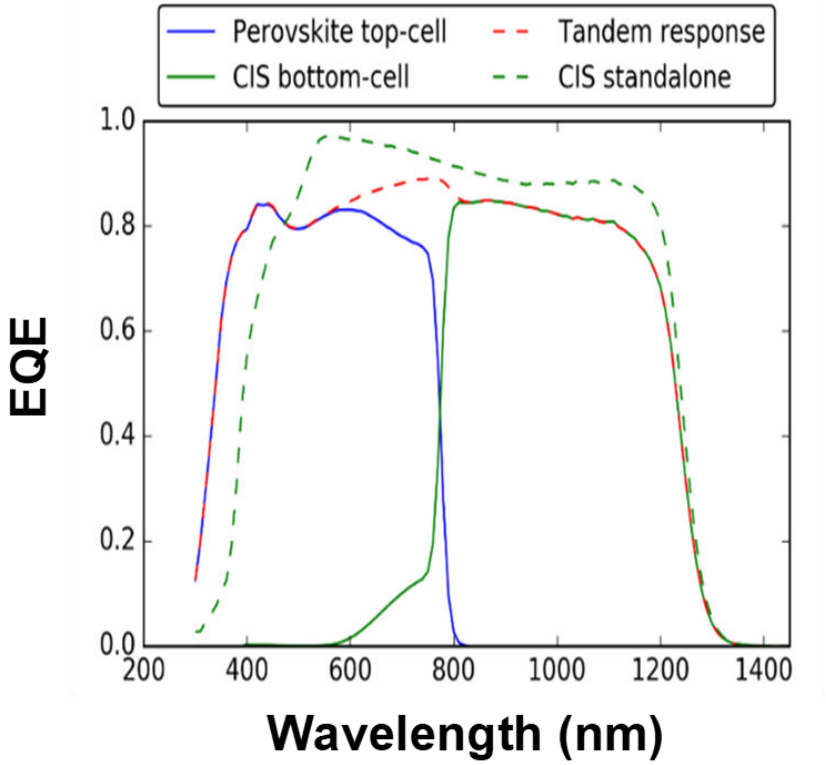
World record efficiencies guaranteed

Current status – 4T; Rigid; Cell

- Tandem efficiency = 25.0 %
  - Perovskite TOP
    - Efficiency = 16.9 %
    - V_{OC} = 1.034 V
    - J_{SC} = 20.79 mA/cm^2
    - FF = 79.8 %
  - CIS BOTTOM
    - Efficiency = 8.1 %
    - V_{OC} = 0.565 V
    - J_{SC} = 19.4 mA/cm^2
    - FF = 74.2 %
  - DOI: 10.1002/aenm.201901428



World record efficiencies guaranteed

Current status – 4T; Flexible; Cell

11 SEP **23% EFFICIENCY FOR FLEXIBLE CELLS – FOR REAL?**

PRESS RELEASE

SOLAR RESEARCH SOLLIANCE

RECORD BREAKING 23% EFFICIENCY PROVED FOR FLEXIBLE PEROVSKITE/CIGS-TANDEM

SOLLIANCE SOLAR RESEARCH AND MIASOLÉ HI-TECH CORP. ESTABLISH NEW WORLD RECORD CONVERSION EFFICIENCY WITH FLEXIBLE SOLAR CELLS.

Eindhoven (Netherlands) – 11 September 2019 – Just 9 months after the presentation of the first record breaking flexible solar cell, USA based MiaSolé Hi-Tech Corp and European Solliance Solar Research established a new world record power conversion efficiency of 23% on a flexible solar cell. The solar cell combines two thin-film solar cell technologies into a tandem solar cell stack: a top flexible semi-transparent perovskite solar cell with a bottom flexible copper indium gallium selenide (CIGS) cell.

Perovskite-on-chalcogenide, a marriage made in heaven?

Conclusions

- They are dating...

Courtesy of DREAMSTIME / MCT - www.inquirer.com

- ...but it looks promising!
  - Match
    - Lower bandgap perovskite
  - Very good results
    - 2T; rigid – 24.2 %
    - 4T; rigid – 25 %
    - 4T; flexible – 23 %
  - New EU projects
    - PERCISTAND – started
    - 2T; flexible – in the pipeline

Perovskite-on-chalcogenide tandem PV

Related Horizon 2020 work

- Uniting PV – Solar cell architecture optimization
  - ERC-2016-STG – ERC – Excellent Science

- SWInG / CUSTOM-ART – Replacing In, Ga
  - LCE-01-2014 - New knowledge and technologies
  - LC-SC3-RES-9-2020 – Next generation of thin film PV

- Tech4Win – Tandem to the extreme = UV + IR
  - LC-SC3-RES-2-2018 – Disruptive innovation in PV

Acknowledgements

Keep an eye on ...

- European Union's Horizon 2020 research and innovation programme, grant agreements
  - Nº 850937; PERCISTAND
  - Nº 715027; Uniting PV
  - Nº 952982; CUSTOM-ART
  - Nº 826002; Tech4Win

- Progress in PV tandem technology

Thank you!
Questions?

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