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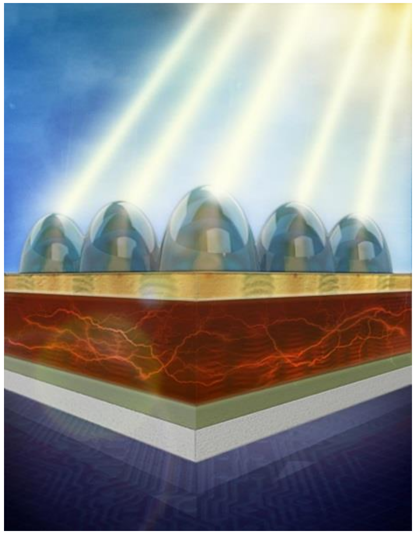

Design of photonic microstructures for optimum wave-optical light trapping in perovskite solar cells (PSCs)

MATERIAIS 2019

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CENIMAT-i3N

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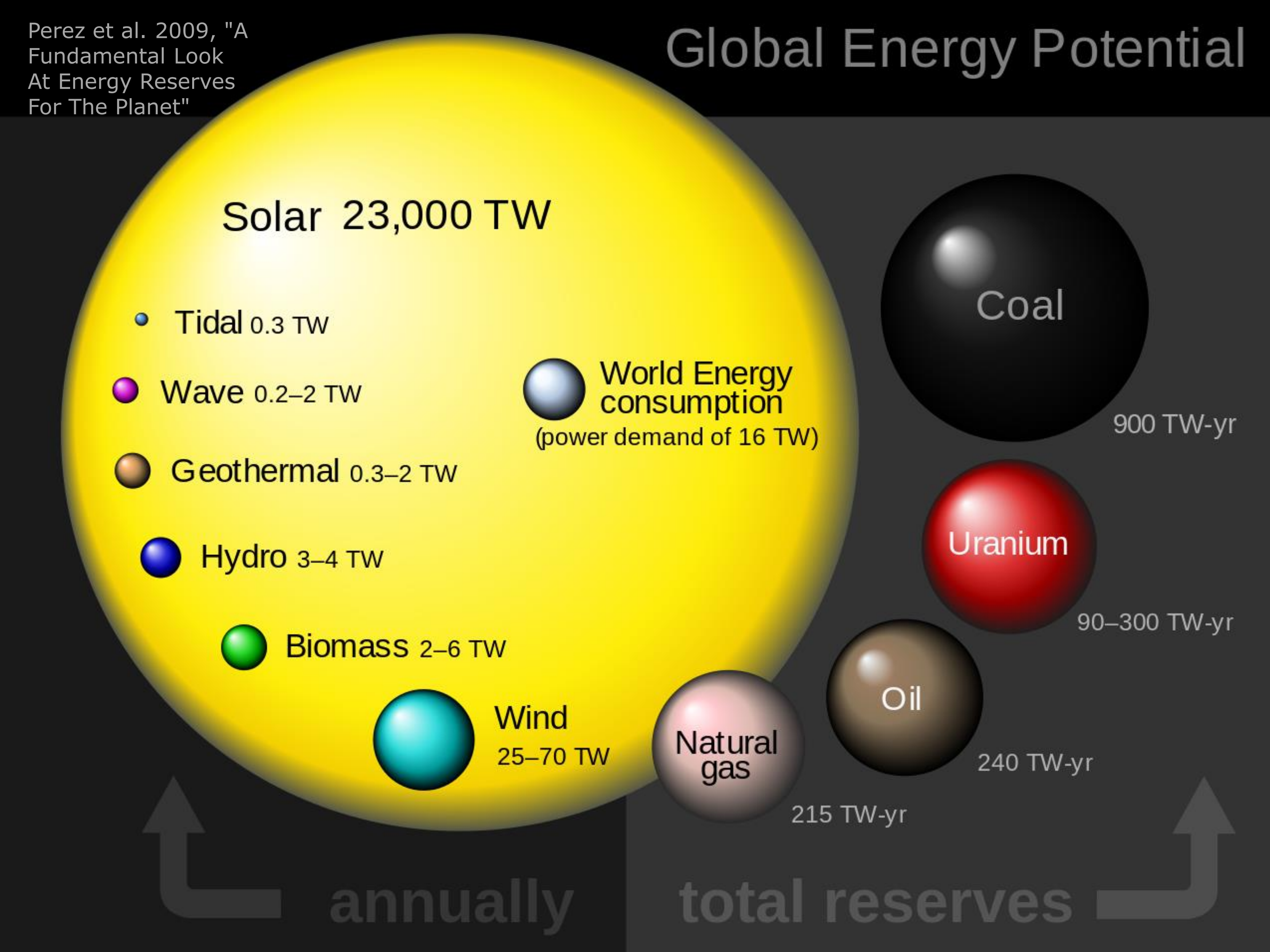
MATERIALS FOR A BETTER LIFE – NOVA UNIVERSITY OF LISBOA



Perez et al. 2009, "A Fundamental Look At Energy Reserves For The Planet"
Global Energy Potential
Solar 23,000 TW
Tidal 0.3 TW
Wave 0.2–2 TW
Geothermal 0.3–2 TW
Hydro 3–4 TW
Biomass 2–6 TW
Wind 25–70 TW
World Energy consumption
(power demand of 16 TW)
Coal
900 TW-yr
Uranium
90–300 TW-yr
Oil
240 TW-yr
Natural gas
215 TW-yr
annually
total reserves

State-of-the-art in PV

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Current Market Leader

Crystalline Si wafer-based solar cells

Record efficiency ~ 26%
Theoretical limit ~30%

Lower Cost

Higher Efficiency

New Generations

Thin-film wafer-free cells on inexpensive substrates **(recent record ~23.3% with Perovskites)**

Epitaxially-grown multi-junction cells with III-V materials under high sunlight concentration **(record efficiency ~45 %)**

State-of-the-art in PV

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Current Market Leader

- Theoretical limits almost reached! Efficiency cannot be improved further
- Still high price for most consumers
- No bendability/flexibility

Lower Cost

Higher Efficiency

New Generations

- **Insufficient light absorption** due to low thickness → *efficiency bottleneck!*

A new market for PV – **consumer electronics**

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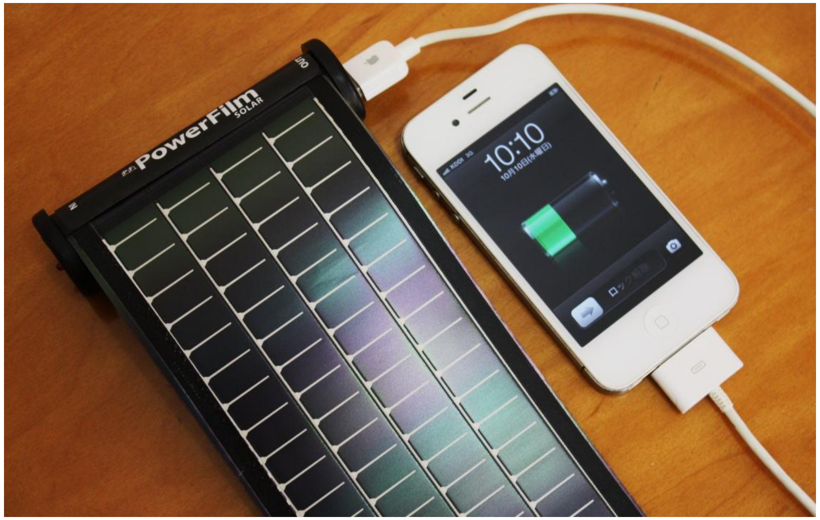
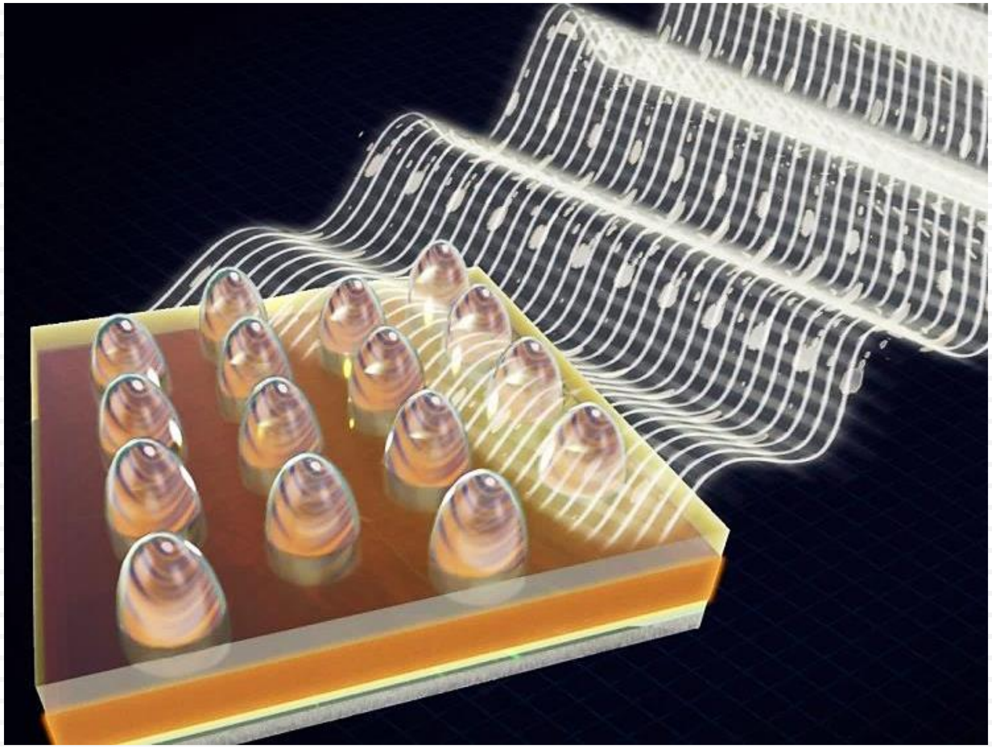
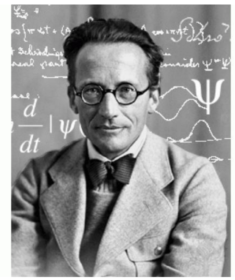
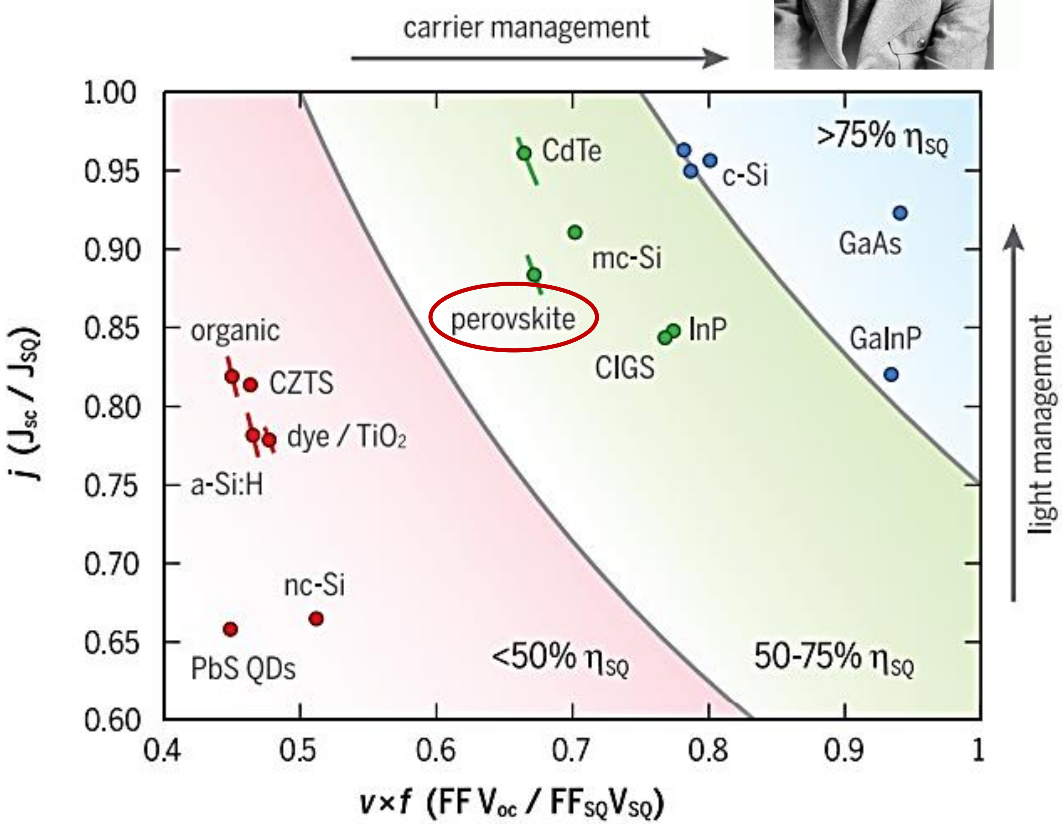


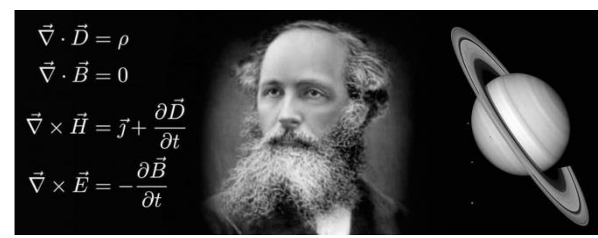
Light trapping with Wave Optics in PSCs



Motivation for light trapping in perovskite solar cells







A. Polman et al., Science (2016)

Advantages of dielectric photonics structures

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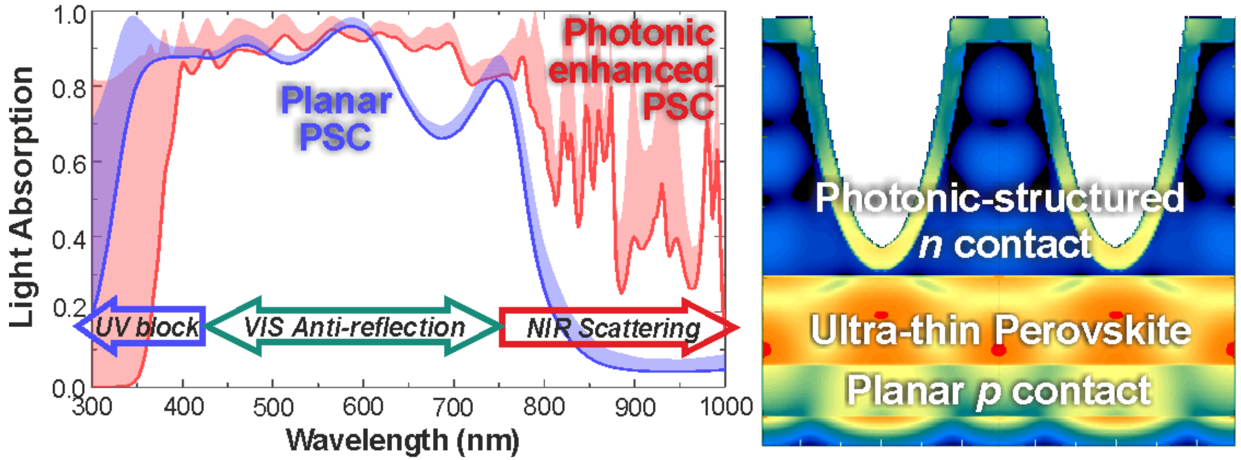
- Dielectric photonics structures able to block UV harmful radiation and can:

1) Suppress reflection
2) Concentrate their *near-field* light in the thin PV material
3) Enhance path length of light rays (*far-field*)
4) Increase angular acceptance



S. Haque et al., Nano Energy (2019)

Photonic-enhanced thin-film PSCs

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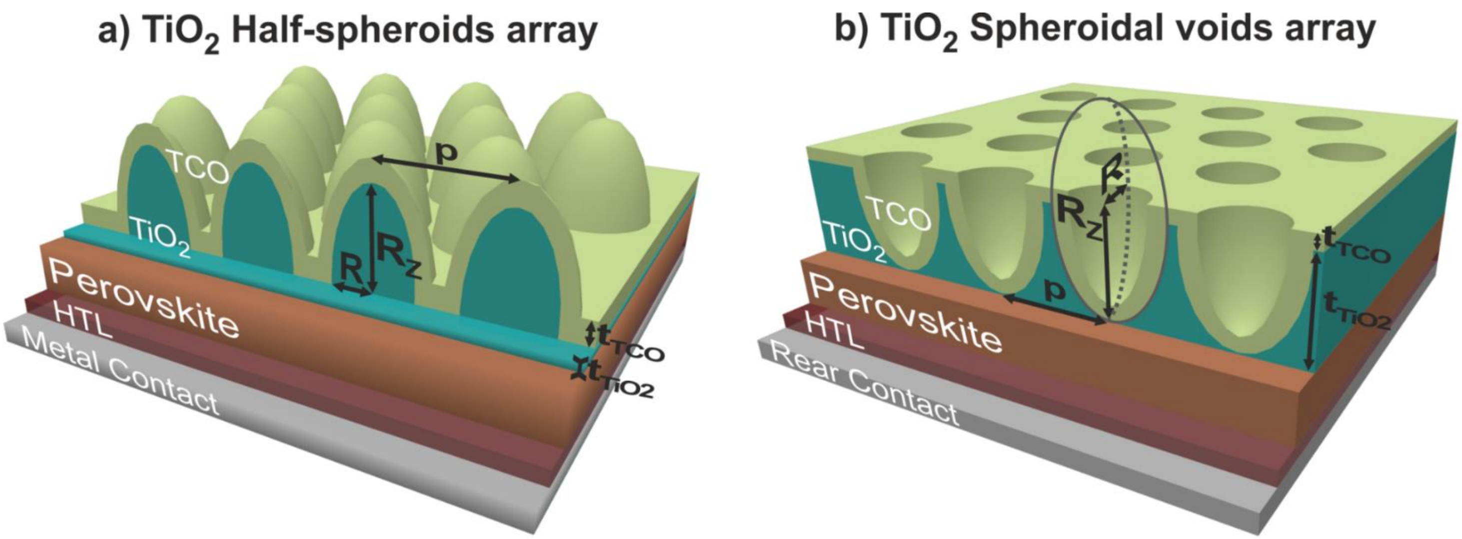

Solar cell base-structure (planar reference):

Ag electrode (80 nm) / Spiro-OMeTAD (150 nm) / Perovskite (250-500 nm) / TiO2 (20 nm) / ITO (50nm)

Photonic-enhanced PSCs with Domes

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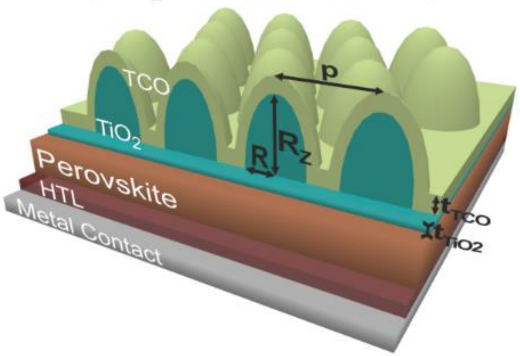
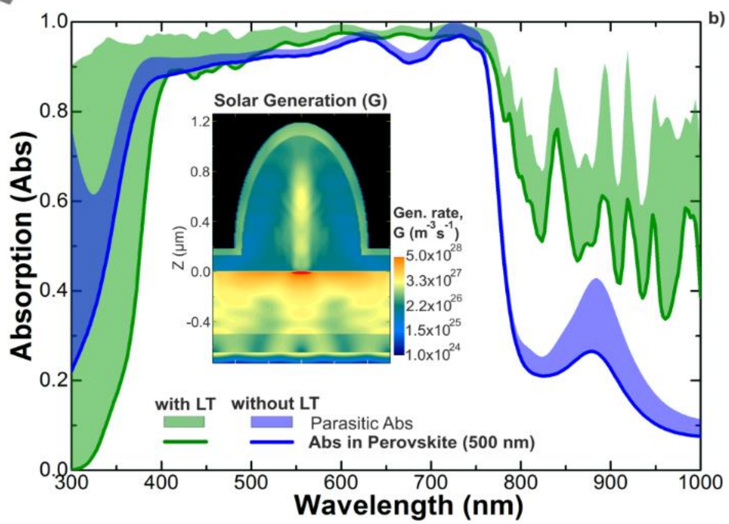
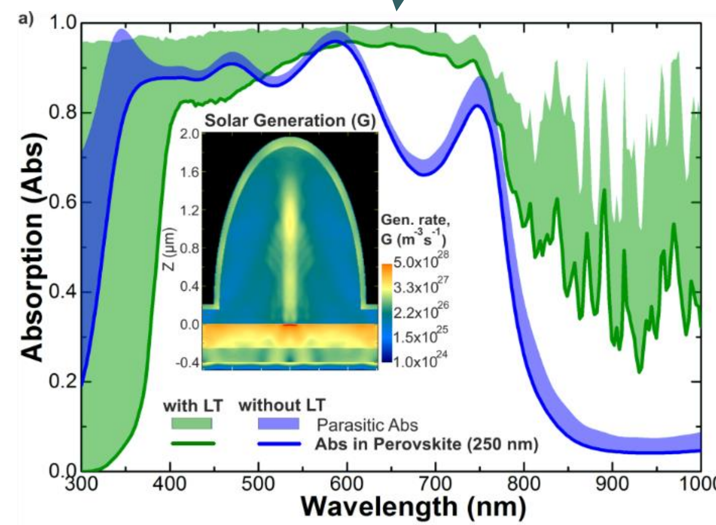
a) TiO_2 Half-spheroids array



Light Trapping Structure	**500 nm** Perovskite absorber	**250 nm** Perovskite absorber
	J_{PH} (mA/cm²)	**J_{PH} (mA/cm²)**
Planar ARC (Reference)	25.95	22.64
TiO_2 Domes array	30.56	28.00





Photonic-enhanced PSCs with Voids

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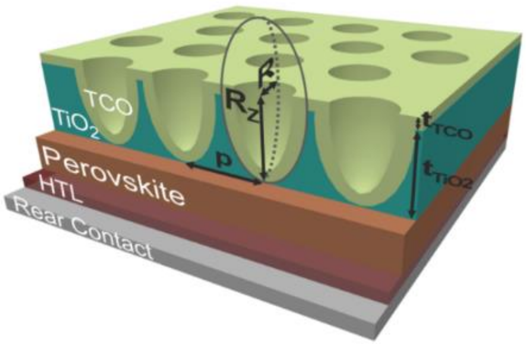
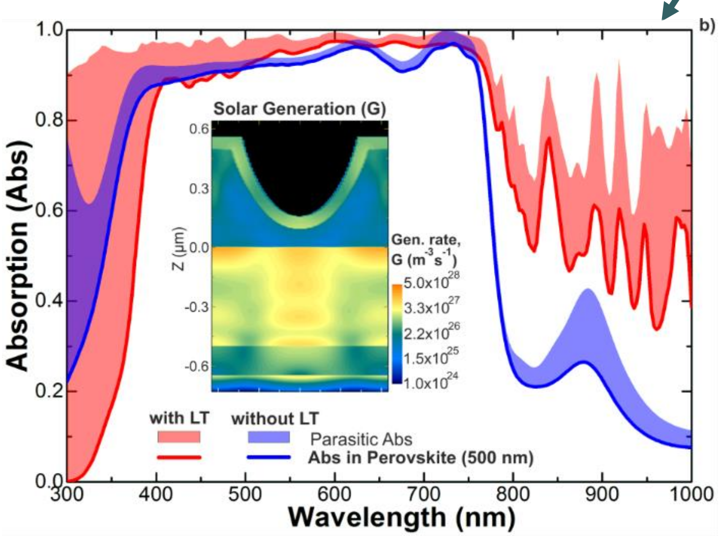
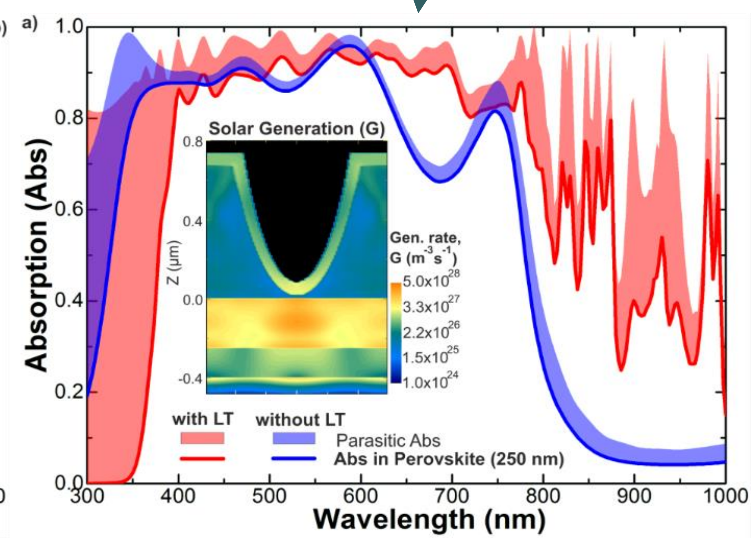
b) TiO_2 Spheroidal voids array



Light Trapping Structure	**500 nm** Perovskite absorber	**250 nm** Perovskite absorber
	J_{PH} (mA/cm²)	**J_{PH} (mA/cm²)**
Planar ARC (Reference)	25.9	22.6
TiO_2 Voids array	31.3	28.6





Geometrical optics limits

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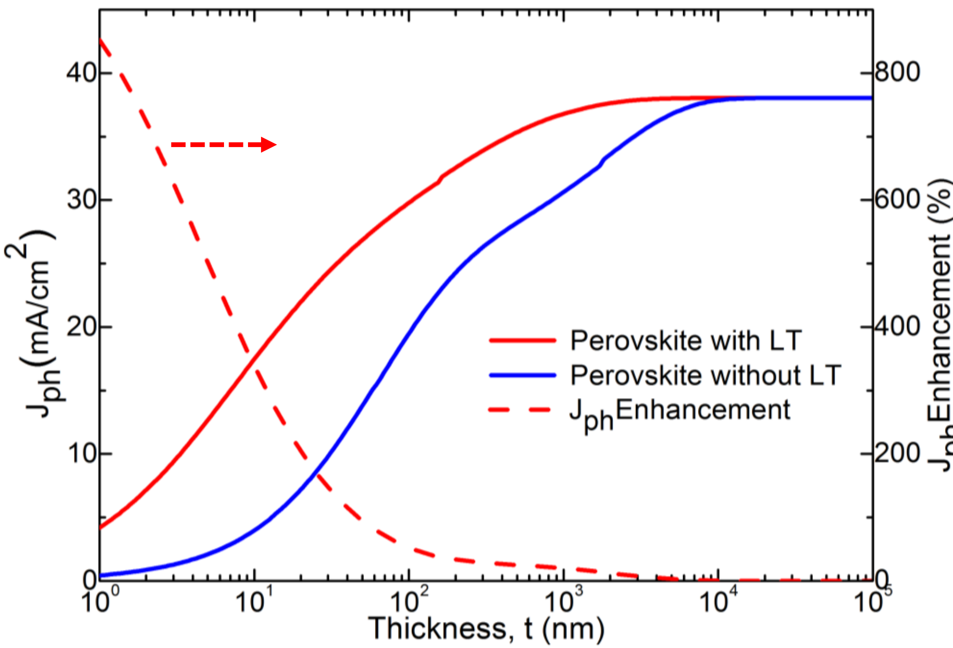
Light trapping (LT) in PSCs	500 nm Perovskite	250 nm Perovskite
	J_{PH} (mA/cm²)	J_{PH} (mA/cm²)
Planar ARC (Reference)	25.9	22.6
TiO_2 Voids array	31.3	28.6
Enhancement	21%	27%

Analytical Lambertian formalism	500 nm Perovskite	250 nm Perovskite
	J_{PH} (mA/cm²)	J_{PH} (mA/cm²)
Without light trapping (planar)	28.2	25.5
Lambertian light trapping	35.3	33.3
Enhancement	25%	31%

Lambertian (ray-optics) formalism applied to PSCs:



S. Haque et al., Nano Energy (2019)

Photonic-enhanced PSCs

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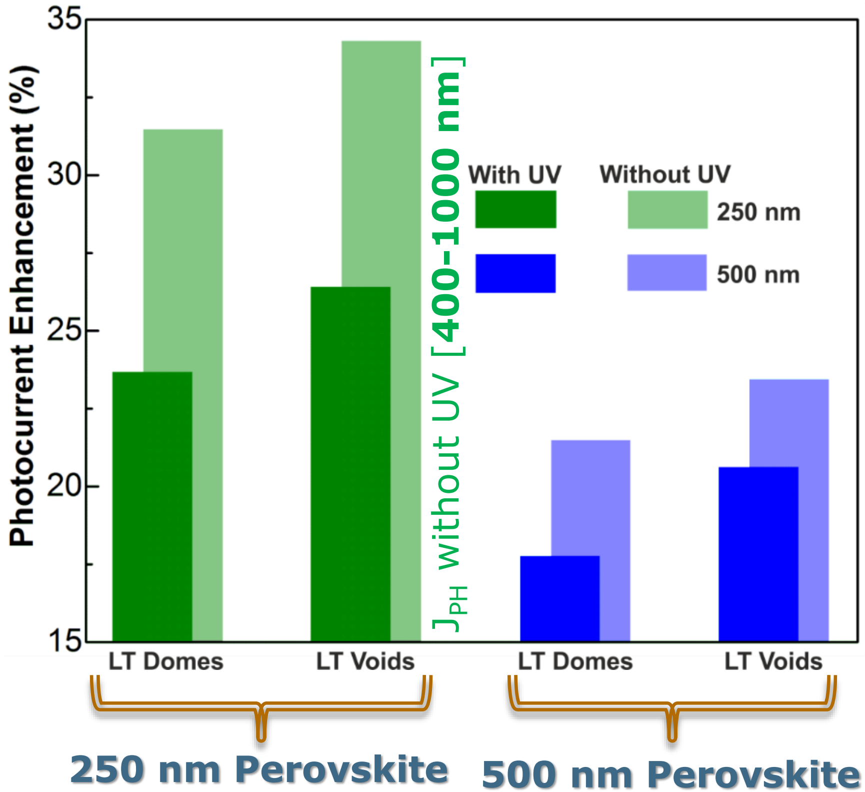

- **Main conclusions :**

- Attainable optical enhancements in PSCs are not so high as thin-film Si, but still important to **allow thickness reduction** (flexibility)

- Front photonic structures can **block UV** radiation and enhance red-NIR absorption → Besides optical improvements, we can have **stability improvements**

S. Haque et al., Nano Energy (2019)

Photonic-structured flexible PSCs

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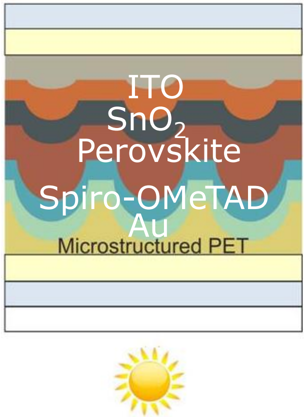
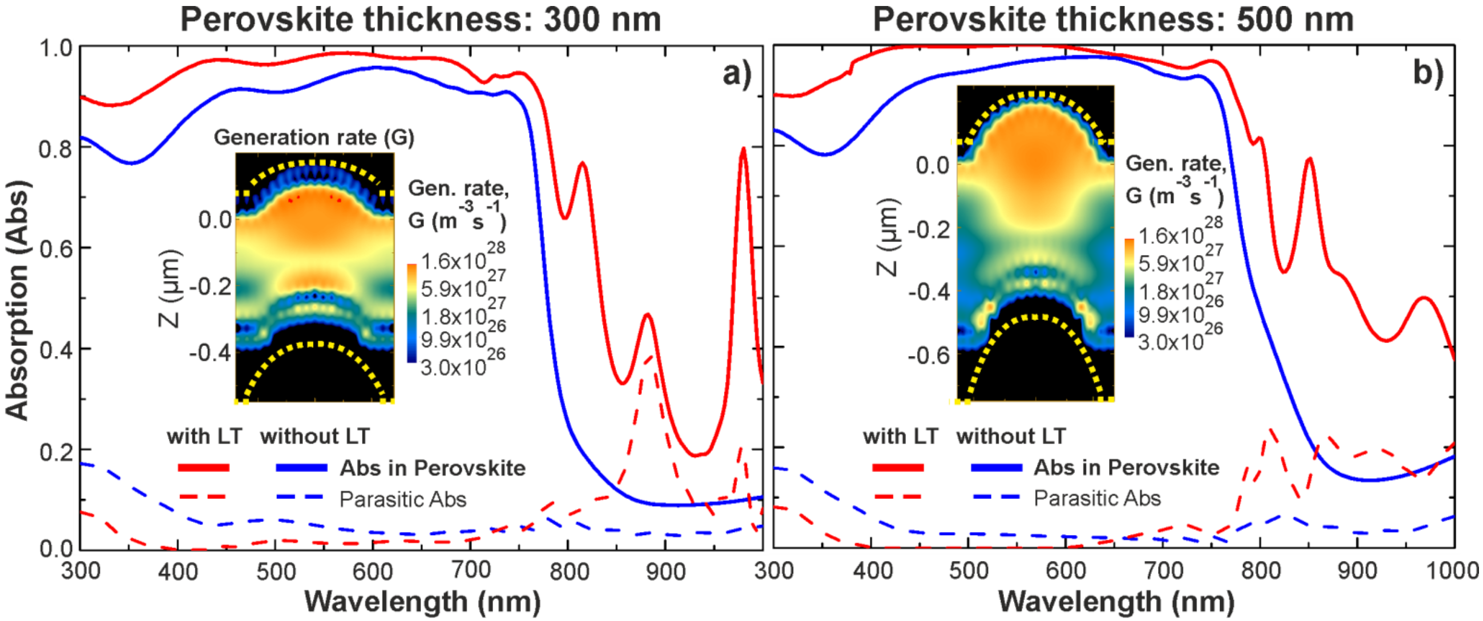
Photonic-structured PSCs





Solar cell base-structure (planar reference):

Au electrode (200 nm) / Spiro-OMeTAD (50 nm) / Perovskite (300-500 nm) / SnO_2 (25 nm) / ITO (50nm)

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Photo-current enhancement and omnidirectional angular response

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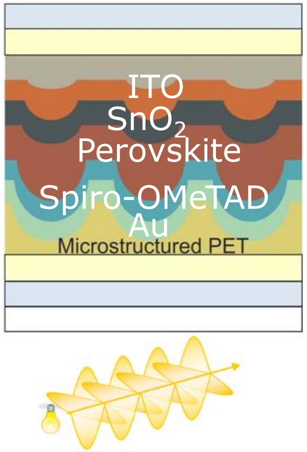
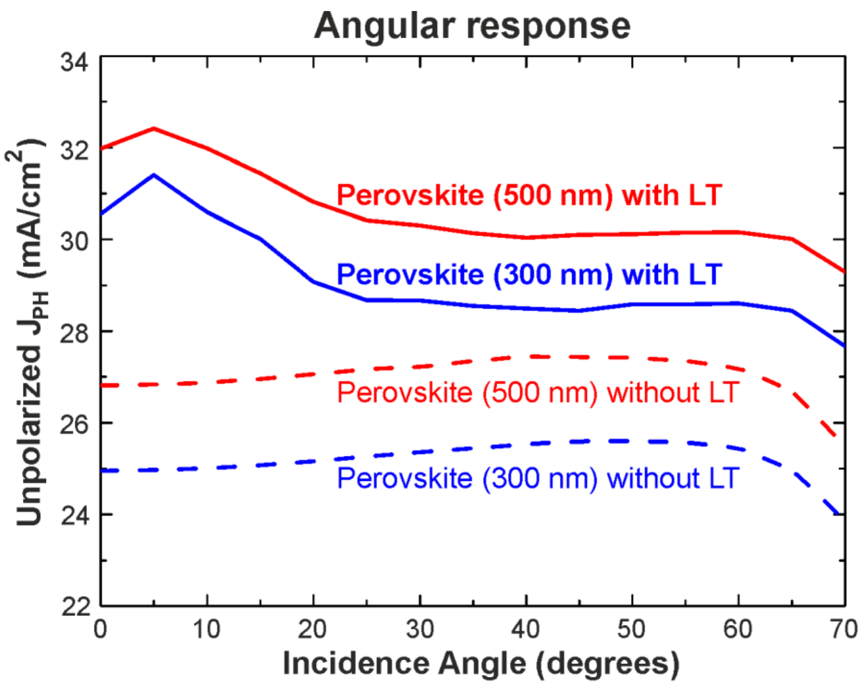
Photonic-structured PSCs in superstrate configuration



Light trapping (LT) in PSCs	500 nm Perovskite	300 nm Perovskite
	J_{PH} (mA/cm^2)	J_{PH} (mA/cm^2)
Planar ARC (Reference)	27.1	25.0
Photonic-structured PSCs	32.5	30.7
Enhancement	**20%**	**23%**
Lambertian Limits	25%	28%



S. Haque et al., Under Preparation

Thank you very much!

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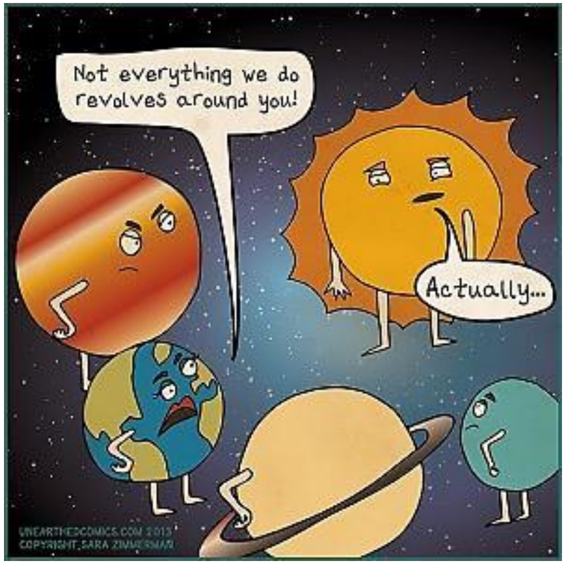

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