Perovskite Architectures and Thermal Management for High Power and Durability

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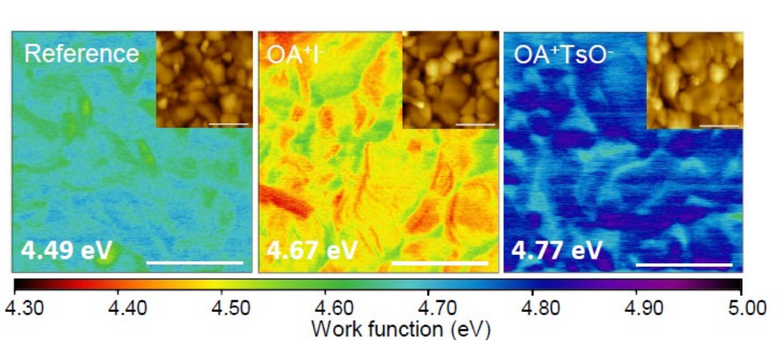

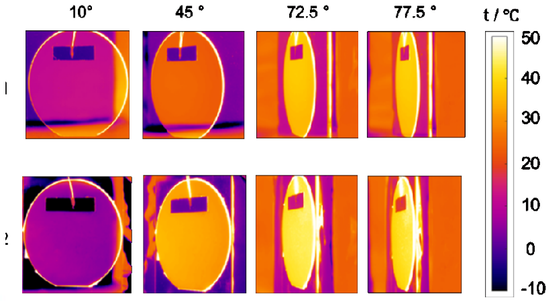

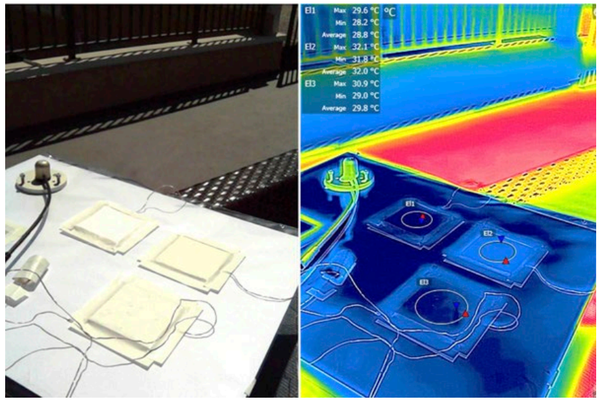

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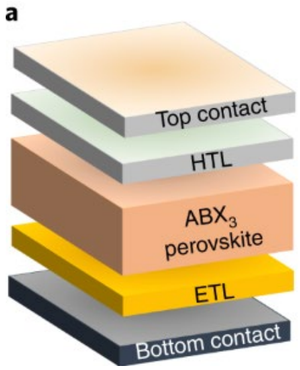
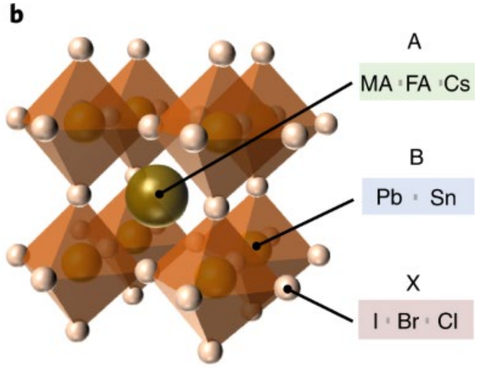
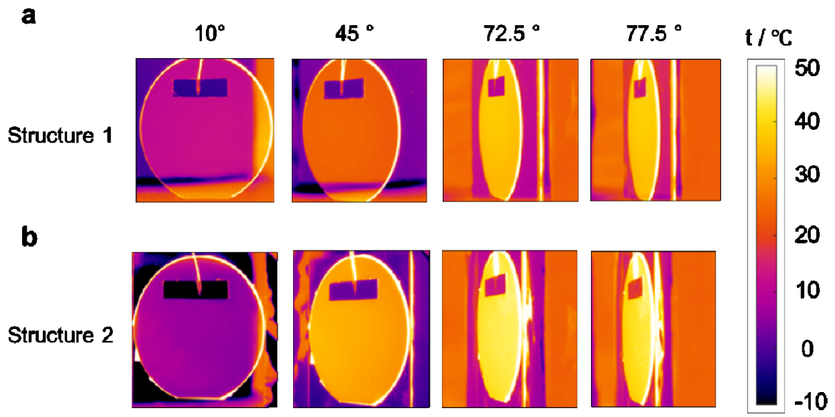
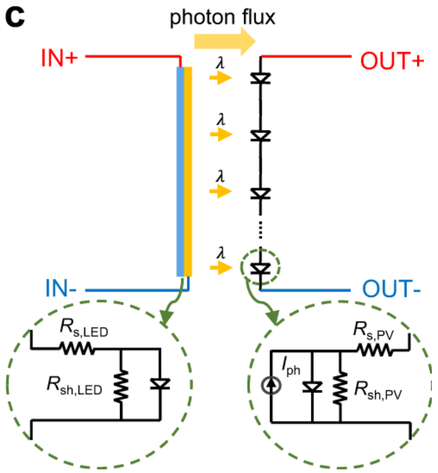
High specific power, durable PV systems: **Opportunities for different components**









I. PV material:

Perovskites exhibit potentially superior radiation durability in lightweight form factor

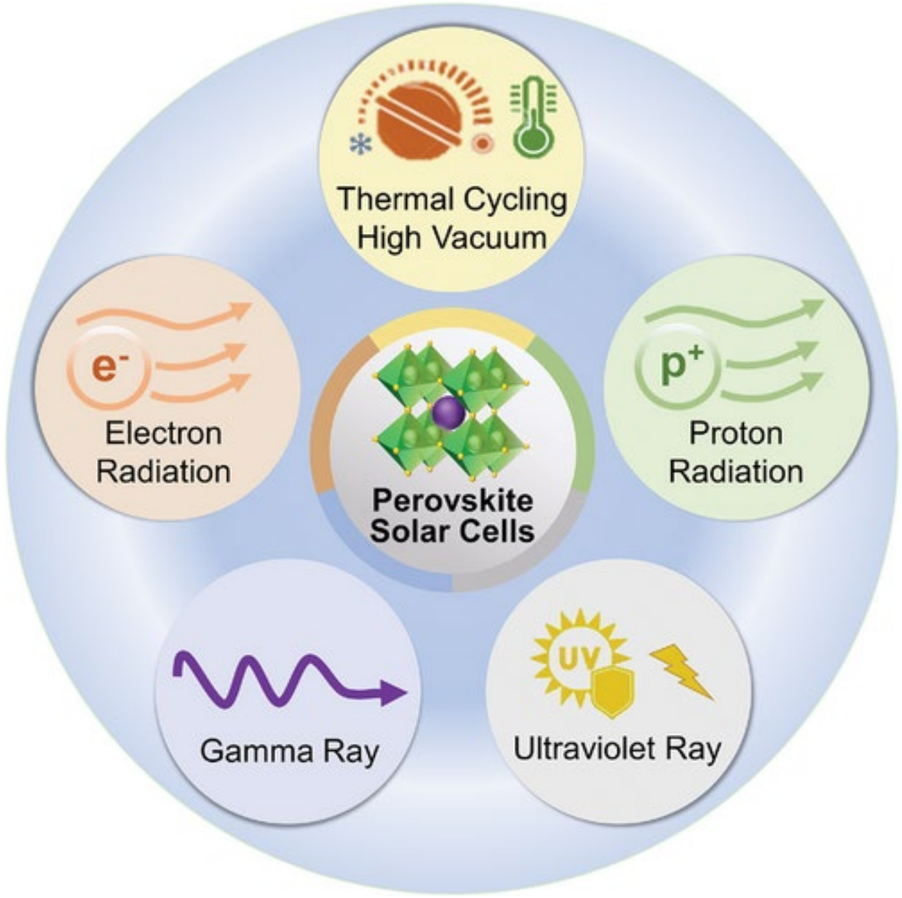
II. Module level:

Advances in photonics allow us to control thermal radiation and enable dramatically improved thermal management

III. Power electronics:

Lightweight photonic approaches for voltage conversion

Perovskites: An intriguing PV material for aerospace scenarios

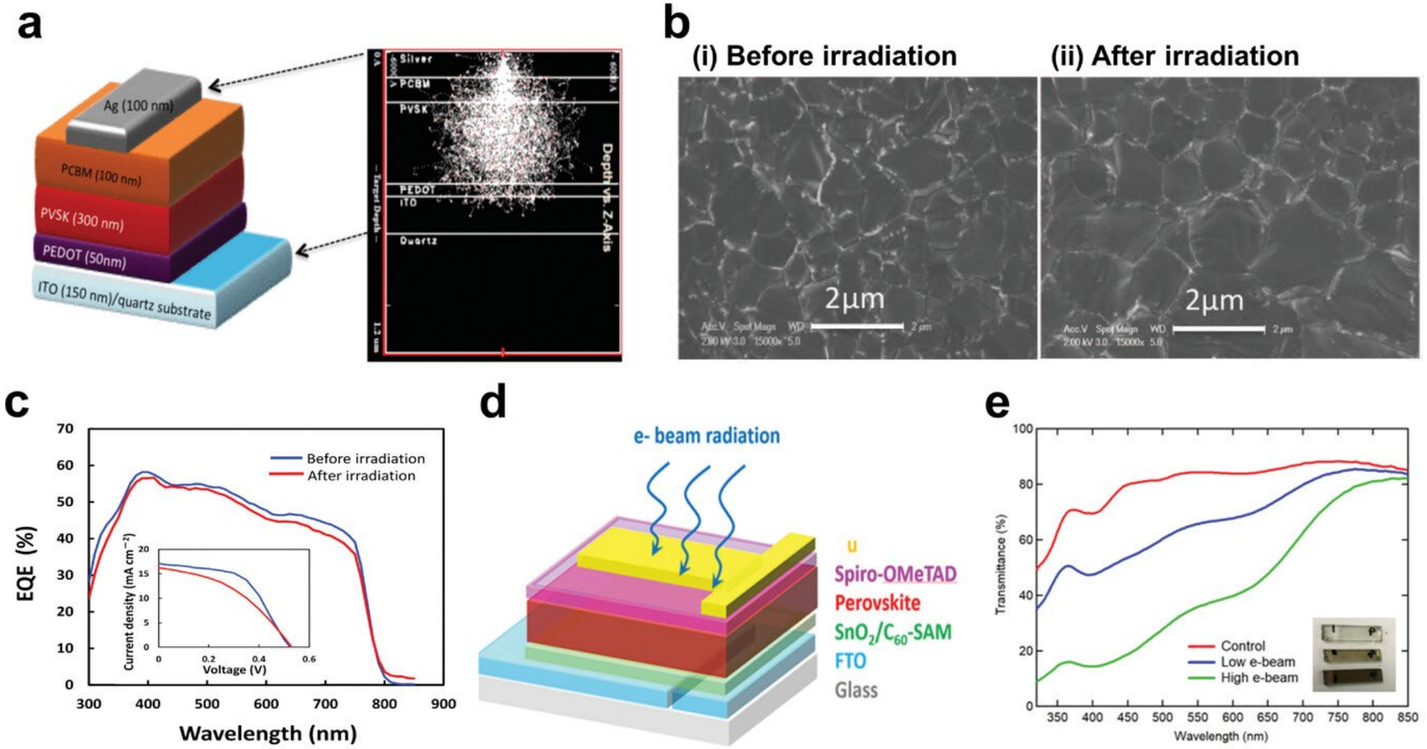


Tu et al., *Advanced Materials* (2021)

Very high efficiencies: **26.1%** (2023)

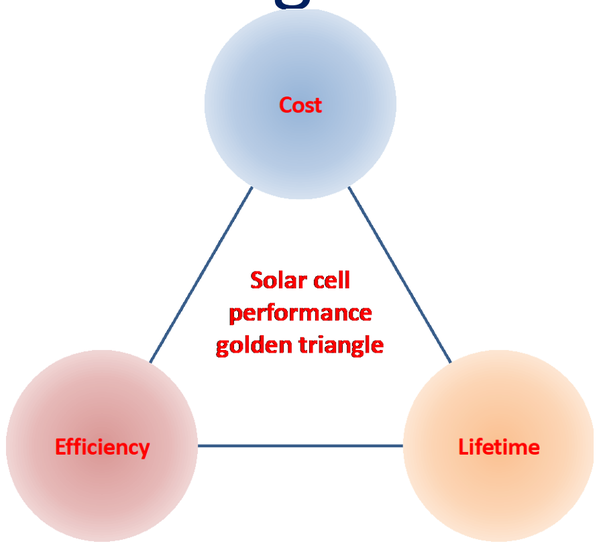
Low-temp solution processing, **lightweight** and **flexible**

Excellent radiation resistance



10% reduction for 10^{16} p cm^{-2} e- radiation vs. 40% GaAs, 20% for hardened InP

Challenges of **metal-halide** perovskite solar cells



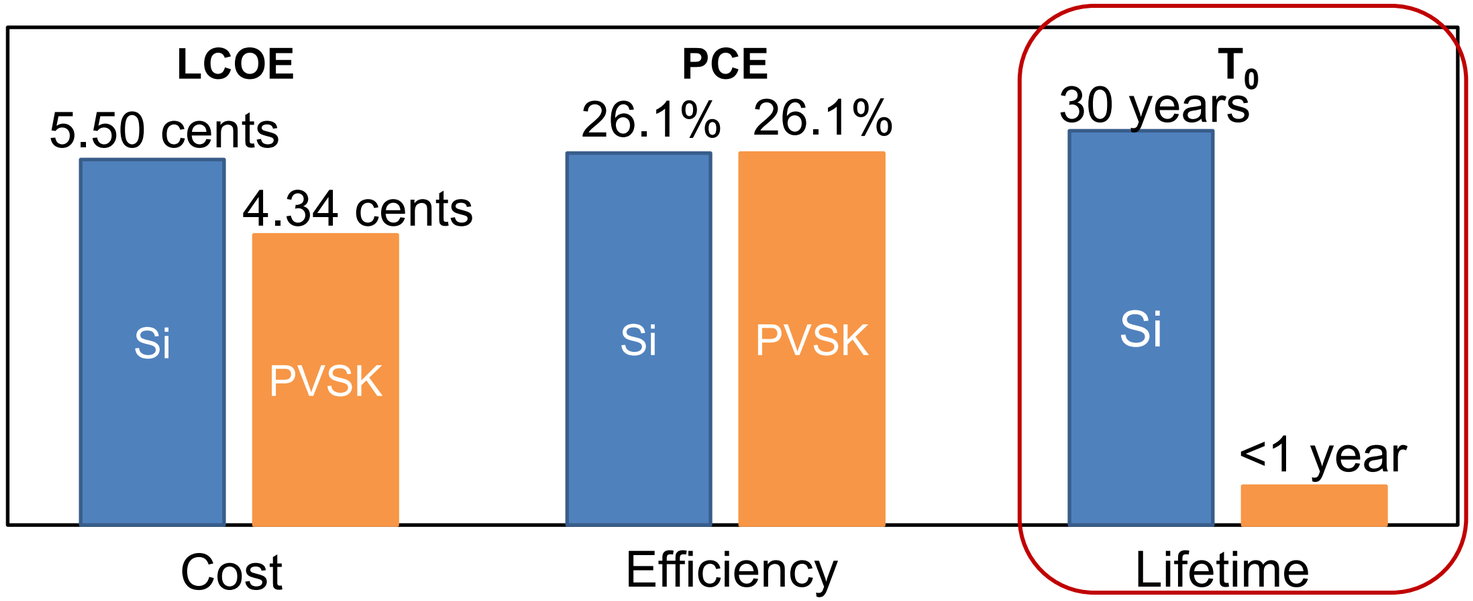
LCOE: levelized cost of electricity

PCE: power conversion efficiency

T_0: time span when the solar cell is failed

Major issue of perovskite solar cells

Comparison between single-junction devices



Lifetime and durability

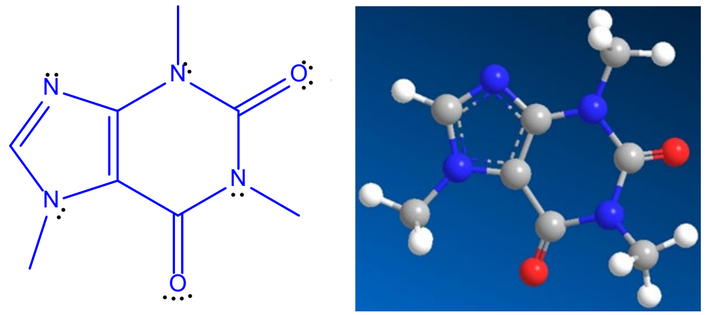
Thermal cycling/ Max temp. limitations

Can we tackle this directly?

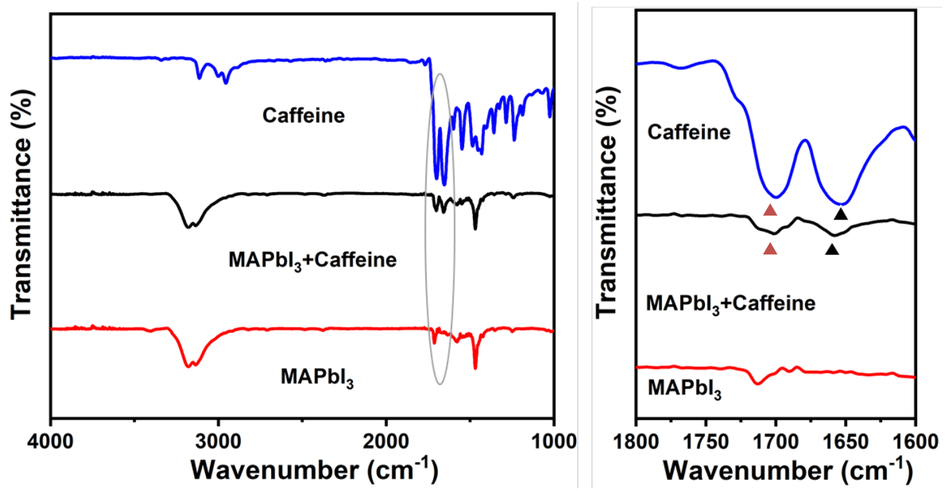
[1] Y. Yang et al., Nature communications, 2018, 9(1): 1-4.
[2] Q. Chen et al., Joule, 2018, 2(8): 1559-1572.

Strategy 1: Caffeine, formation of adduct

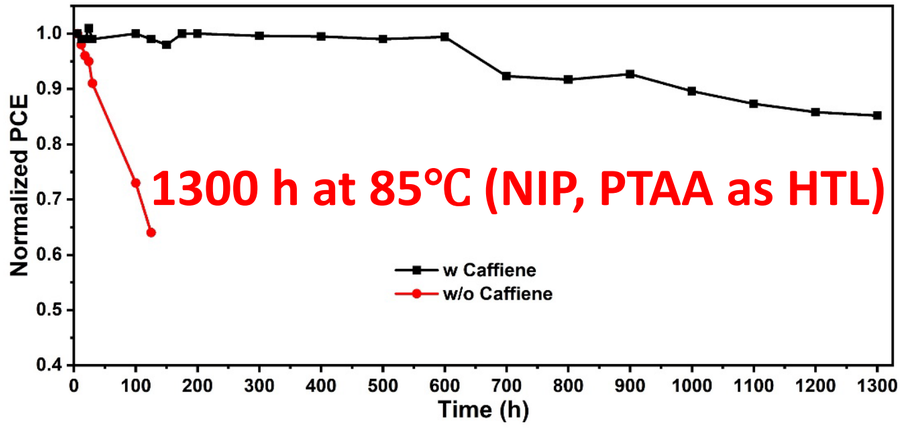
Molecular structure of caffeine

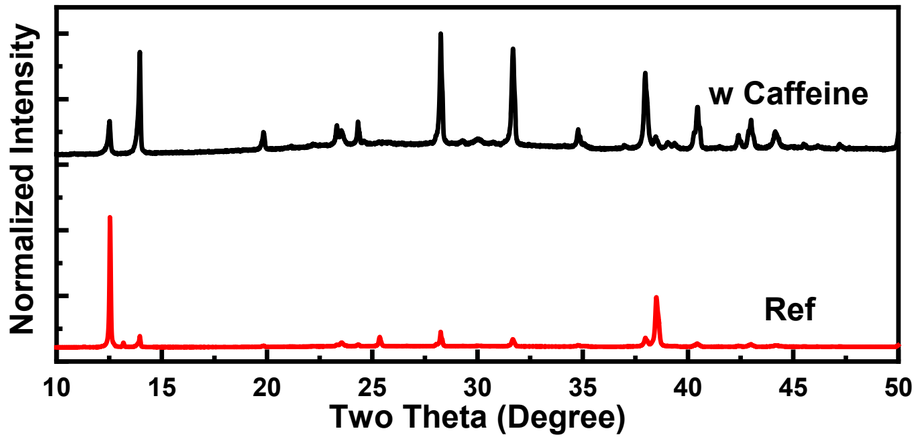


Interaction between C=O in caffeine and perovskite



Caffeine improves the performance and thermal stability of perovskite solar cells

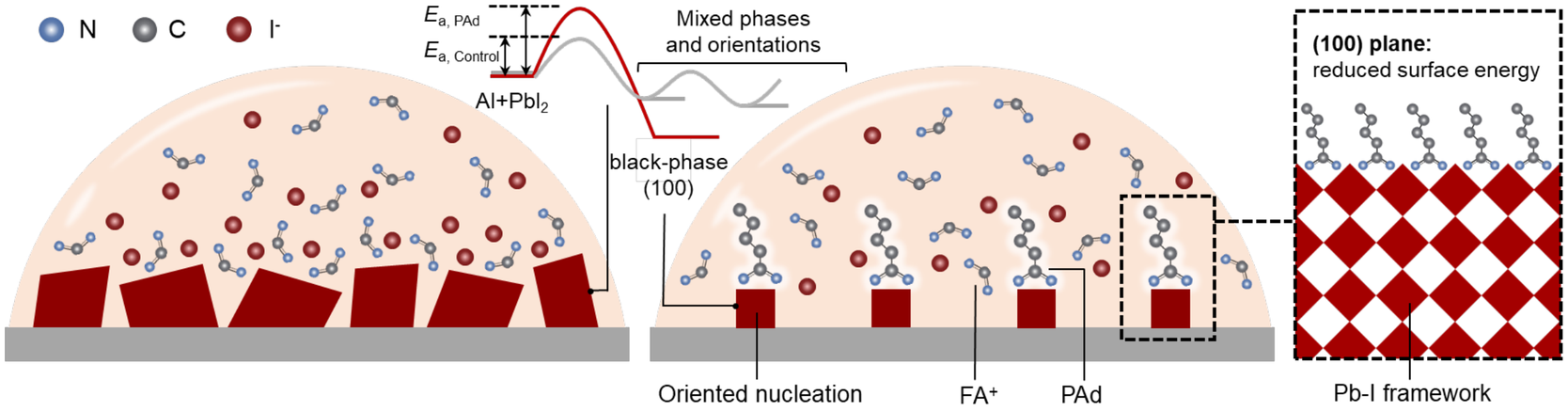


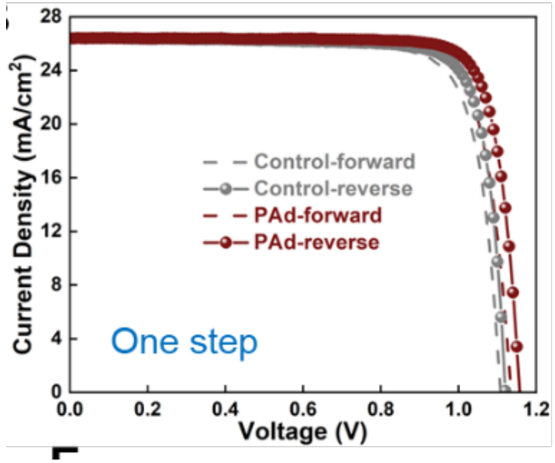


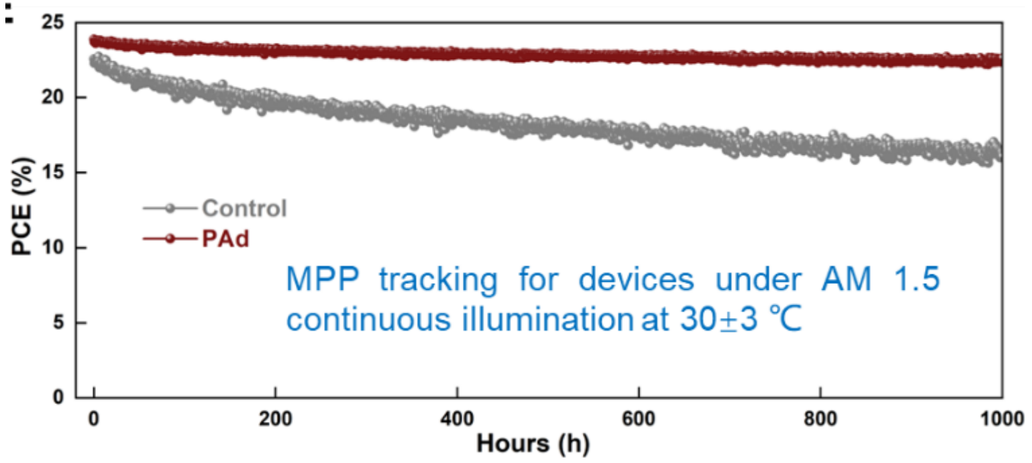
Rui Wang, Y. Yang et al. Joule, 2019, 3, 1464-1477

Strategy 2: Perovskite orientation control

An oriented nucleation mechanism that can help to avoid the presence of undesirable phases and improve the performance of photovoltaic devices in different film-processing scenarios.



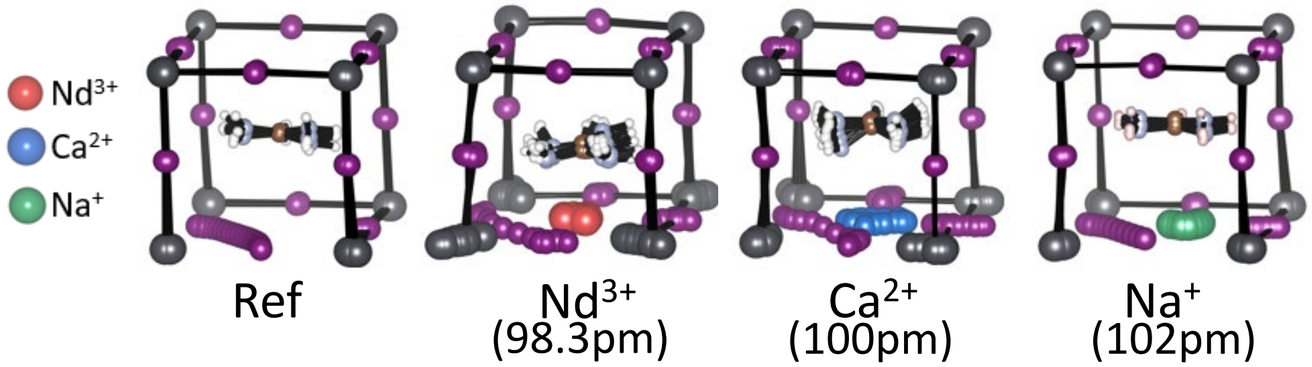




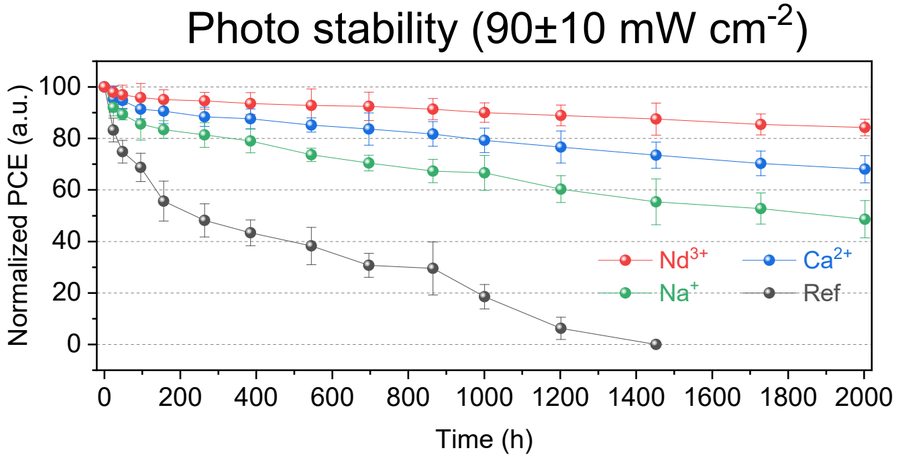
Prof. JJ Xue and Prof. Rui. Wang, Nature, 2023, 620, 323-327

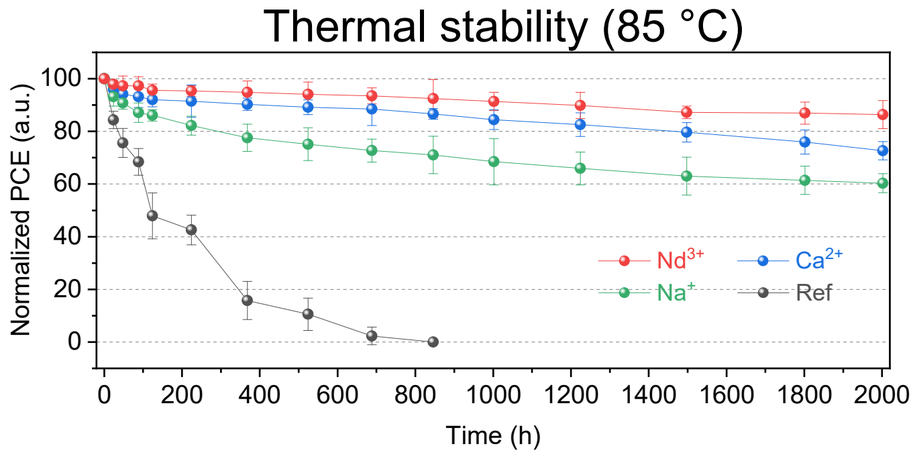
Strategy 3: Interstitial doping ions

Start from a well-utilized cation Na^+, we compare the interstitial doping ions with similar sizes:



Nd^{3+} ion significantly improve the stability of the devices

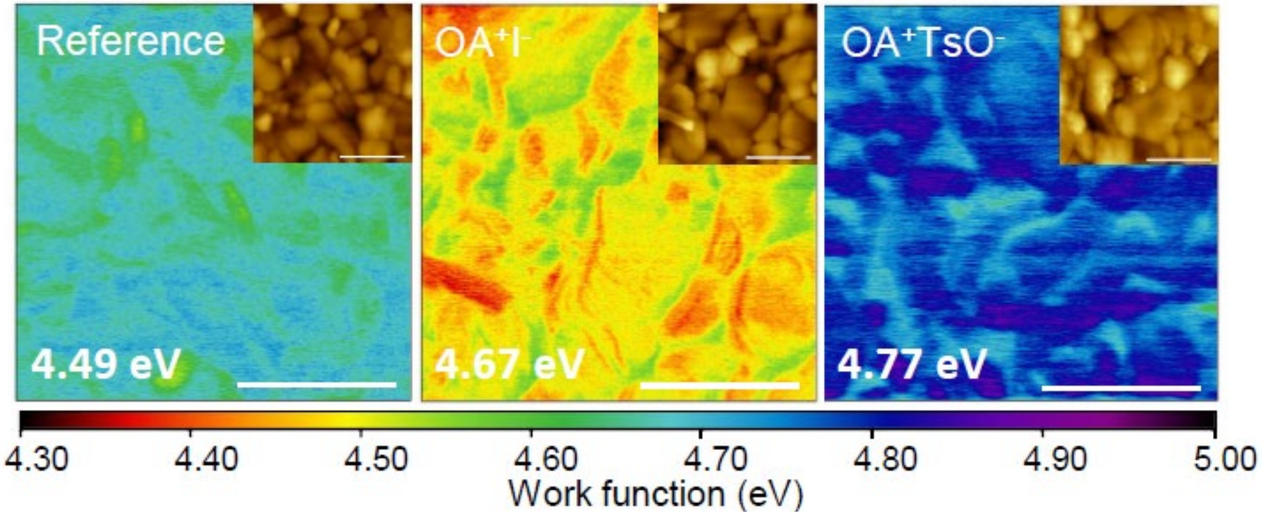


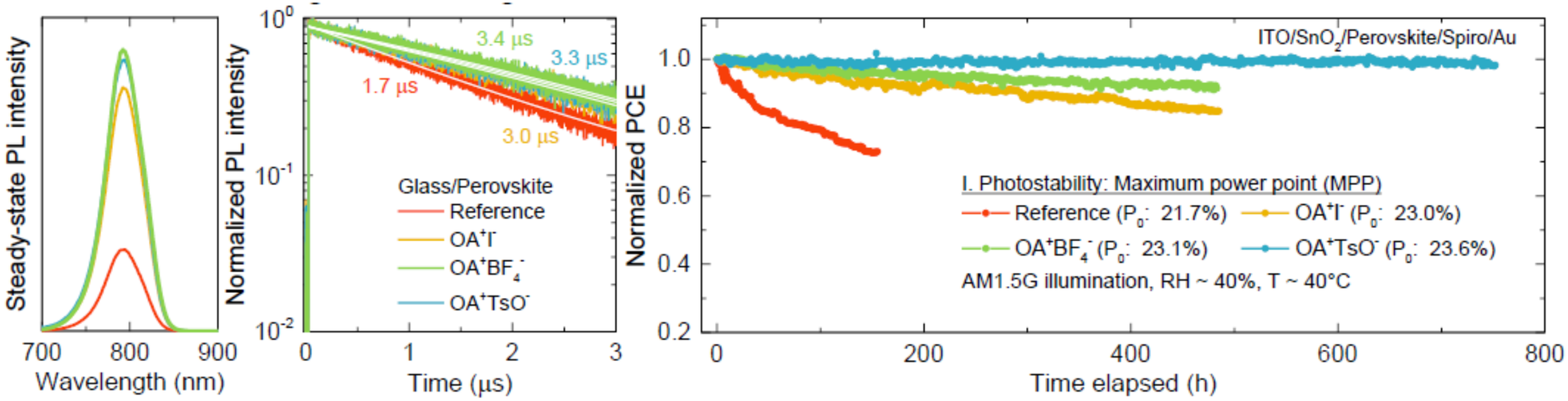


Y. Zhao, Y. Yang et al., Nat. Mater., 2022, 21, 1396-1402

Strategy 4: Stability-limiting heterointerfaces

n-type surface generally created by surface treatments with organic ammonium halide salts, we found that simple anion substitution can modulate surface energetics and improve the device stability.

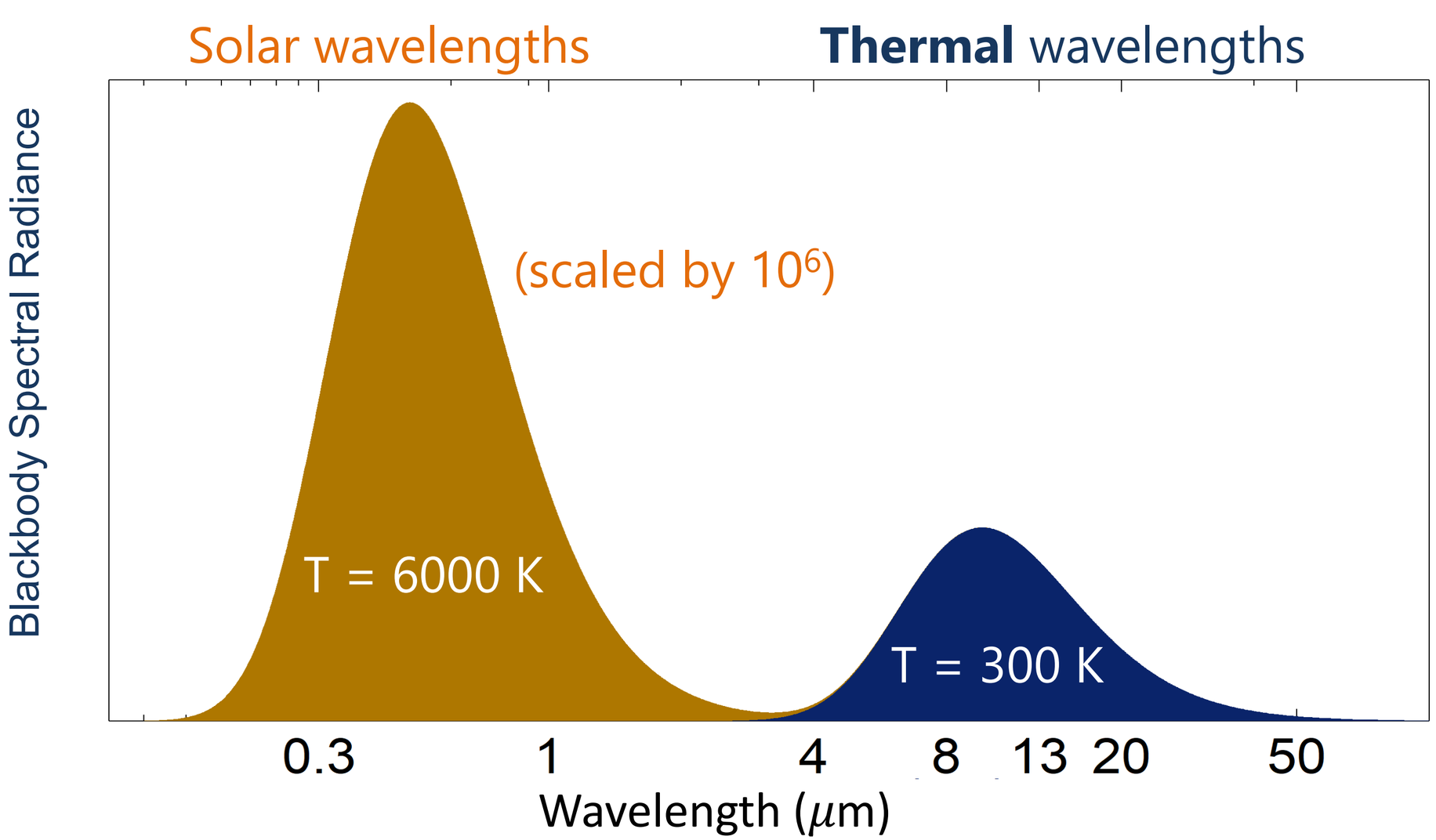


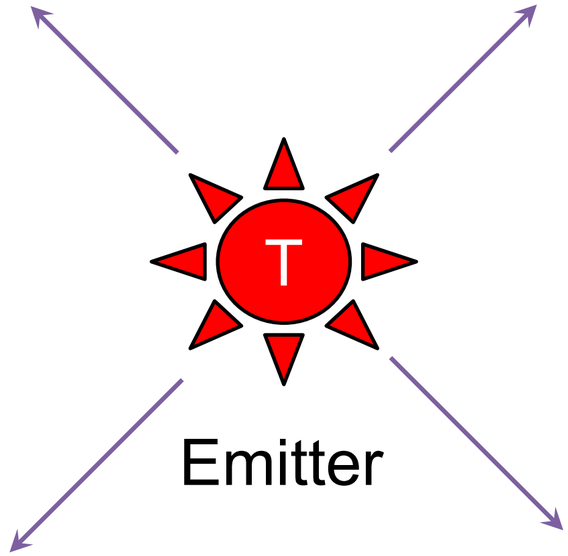


S. Tan, J.-W. Lee, Y. Yang et al., Nature, 2022, 605, 268-273

Thermal radiation: Essential for PV thermal management

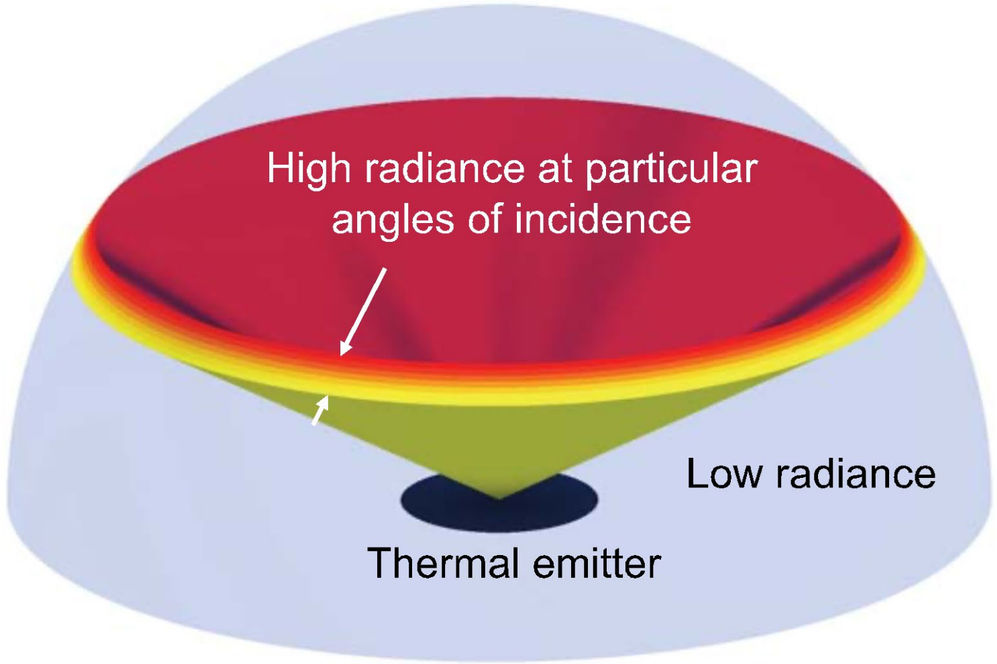
But: **broad spectrum**, lacks directionality, static

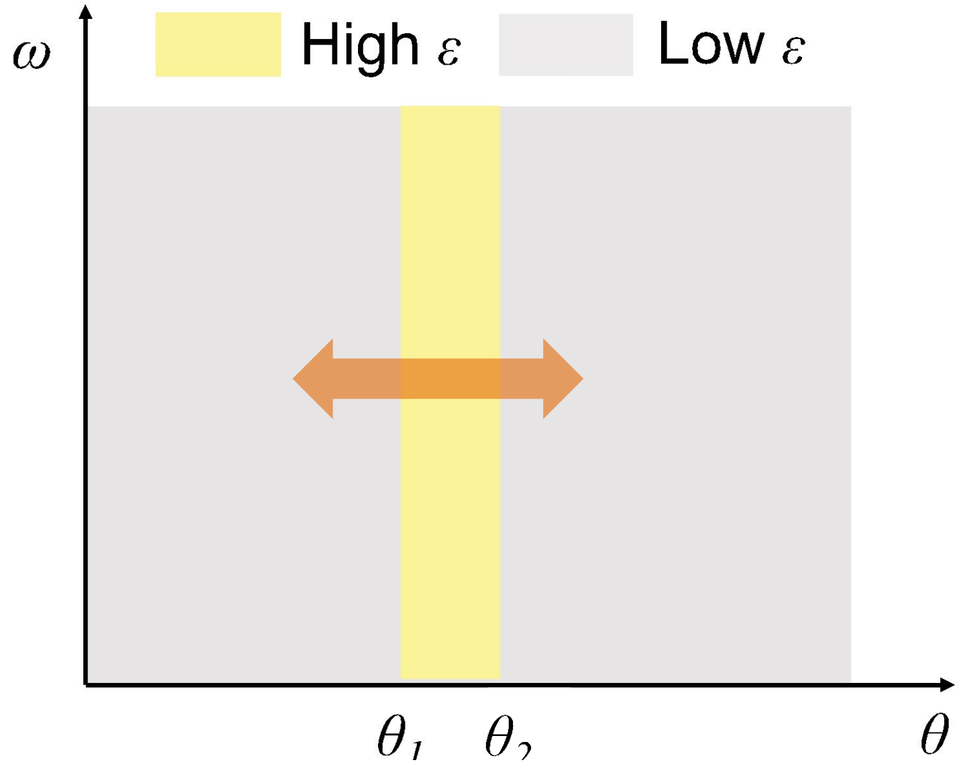




Broadband directional thermal emitters: a new capability

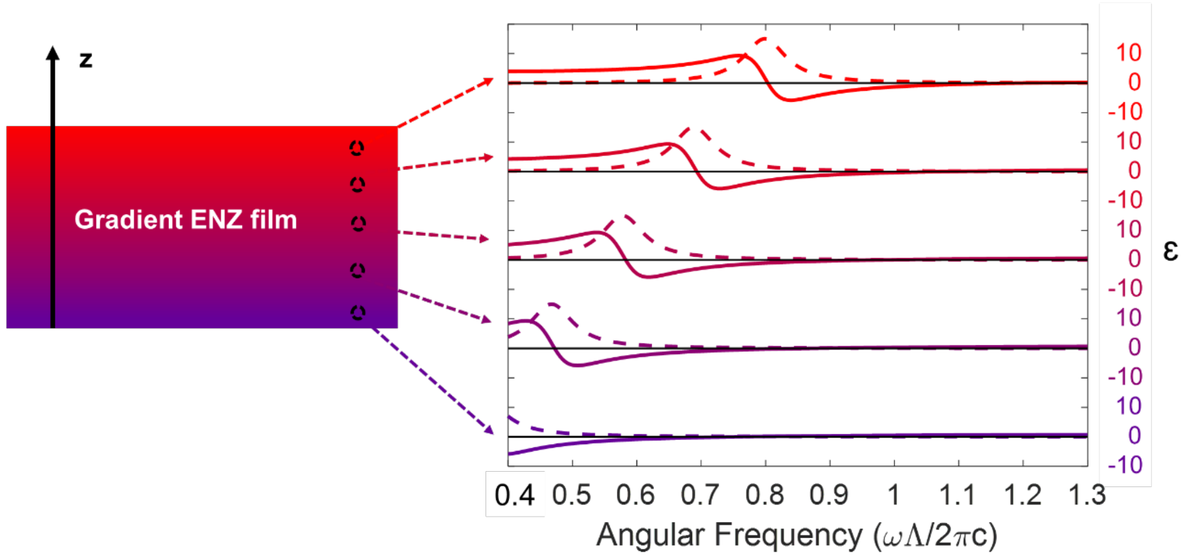
A **true, broadband ‘thermal antenna’:** could direct meaningful amounts of heat to specific directions

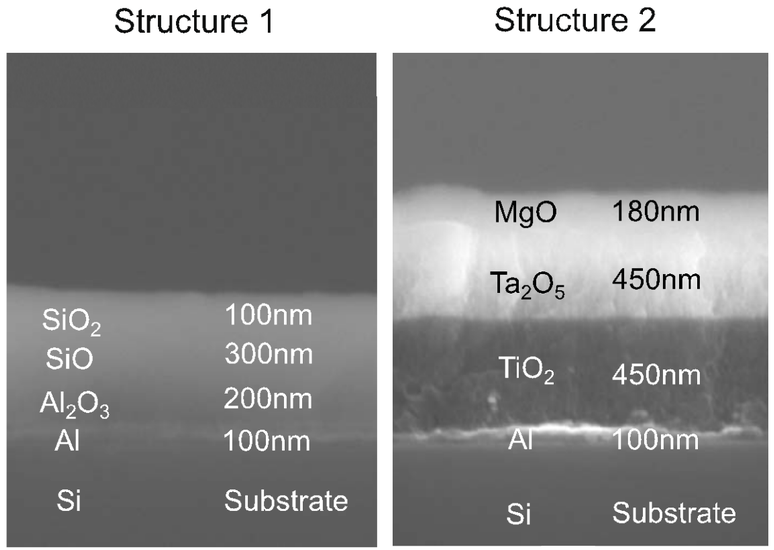




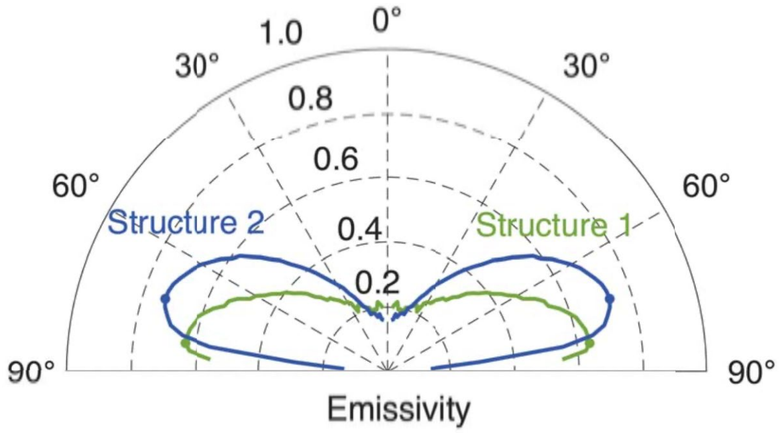
Gradient ENZ materials: strong light-matter confinement over a broad spectrum and broadband directionality

We proposed ***gradient*** ENZ photonic materials:

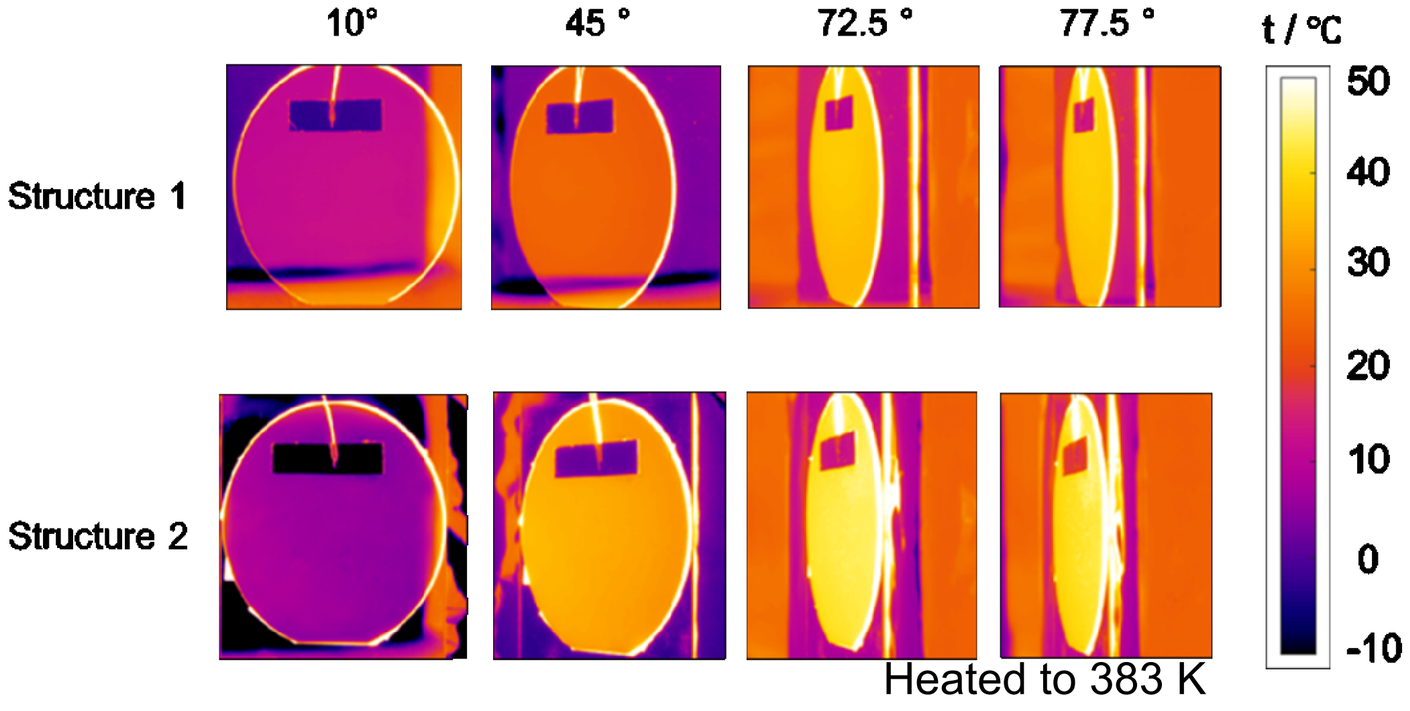


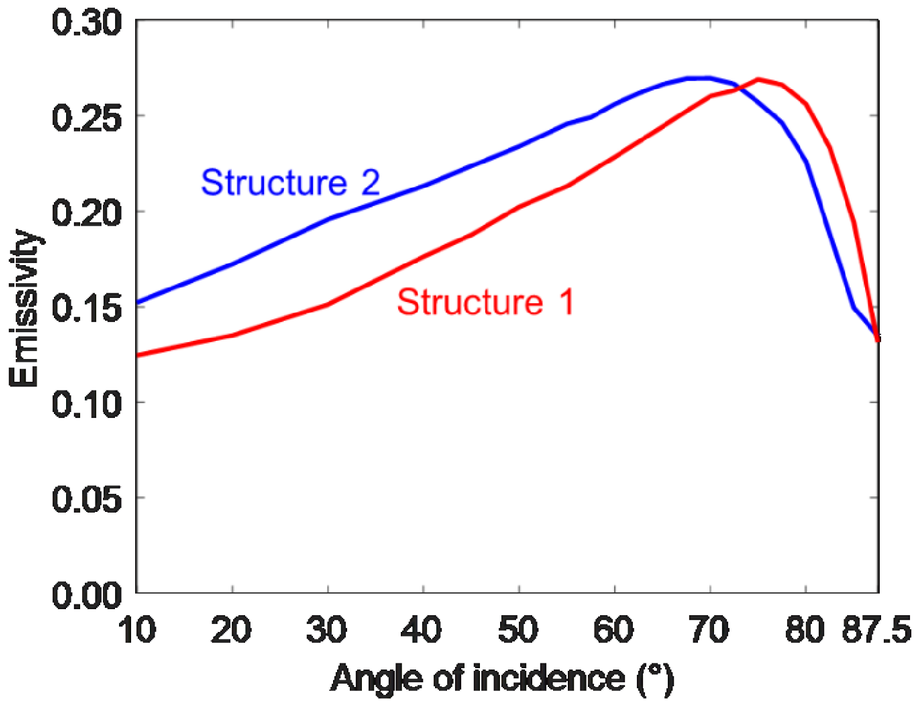


Jin Xu, Jyotirmoy Mandal and Aaswath P. Raman, *Science* 372 (6540) 393-397 (2021)



Thermal imaging reveals heat transfer impact



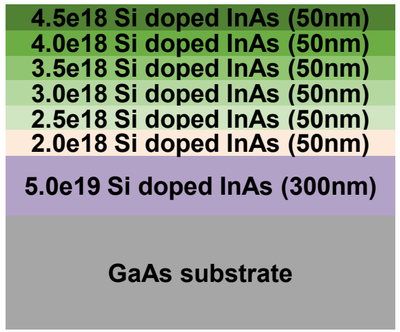


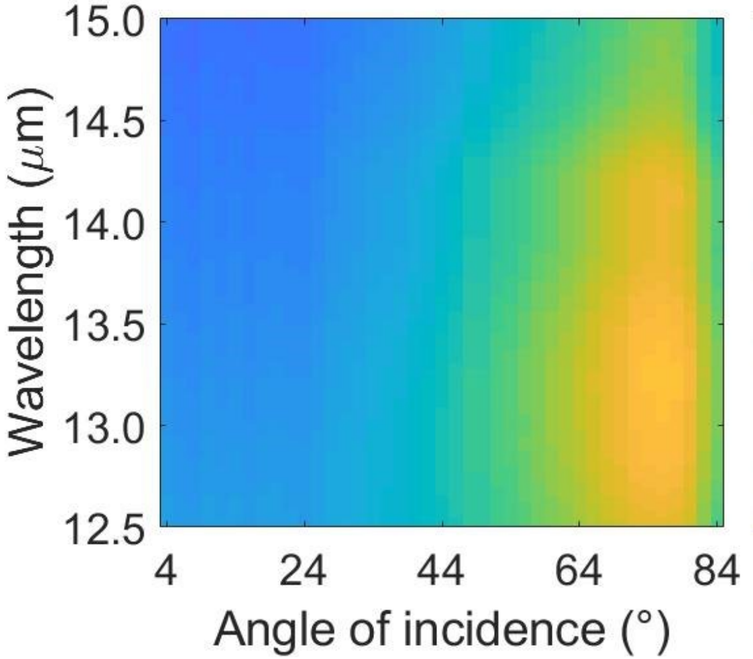
The broadband angular selectivity enables high radiance contrast between normal and oblique angles of incidence

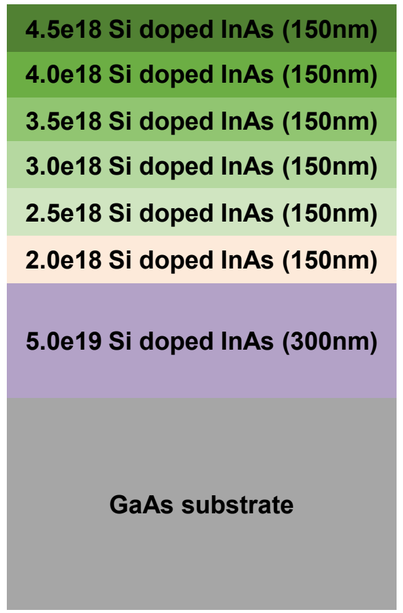
Jin Xu, Jyotirmoy Mandal and Aaswath P. Raman, *Science* **372** (6540) 393-397 (2021)

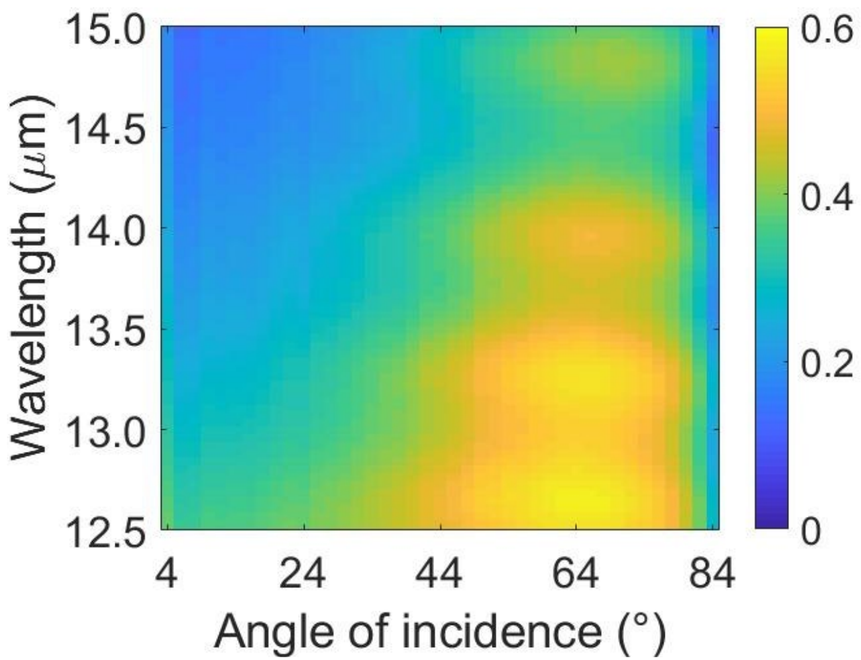
Graded doped InAs as a gradient ENZ emitter

A III-V driven approach enables more tailored control of spectral and directional characteristics as shown in the below measurements:



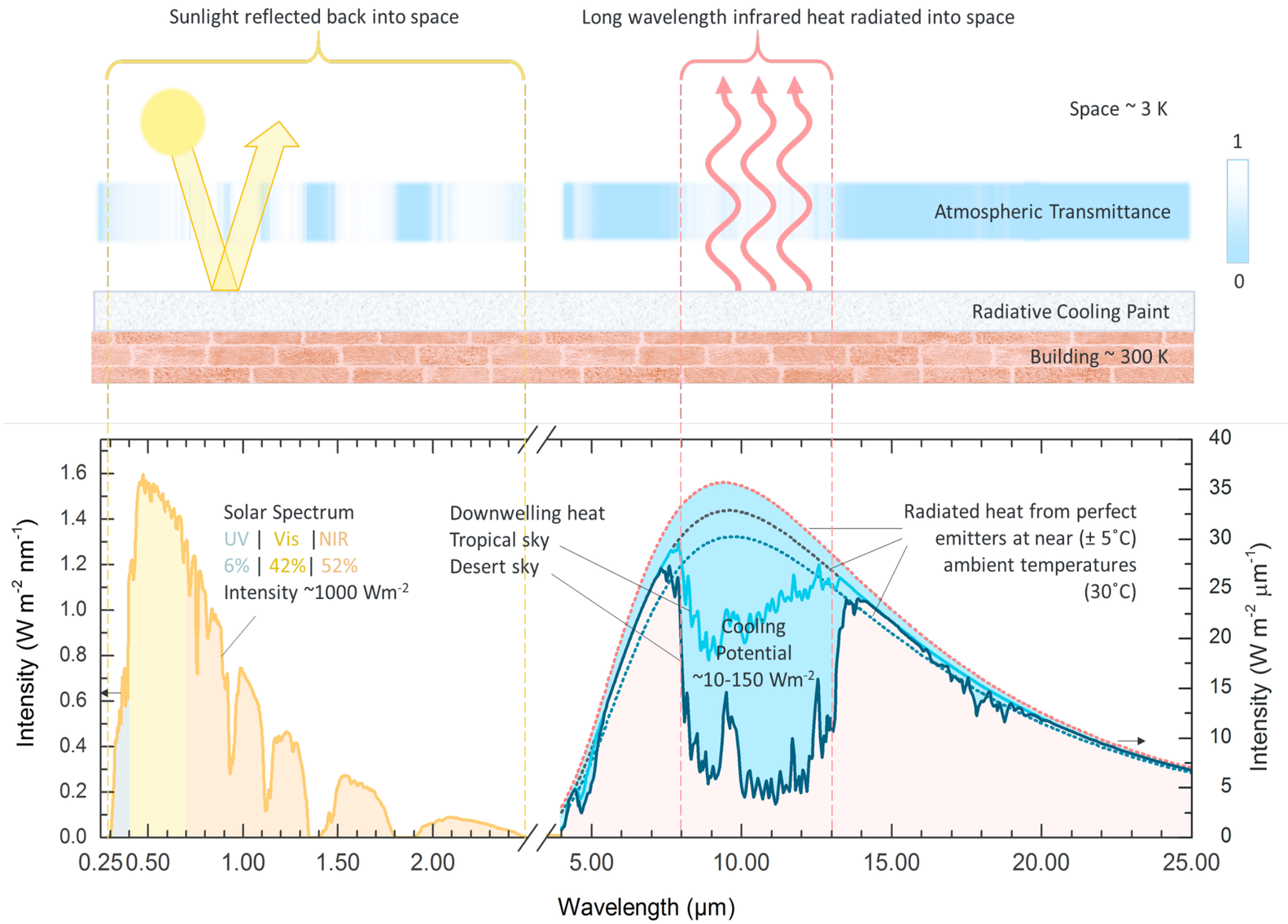




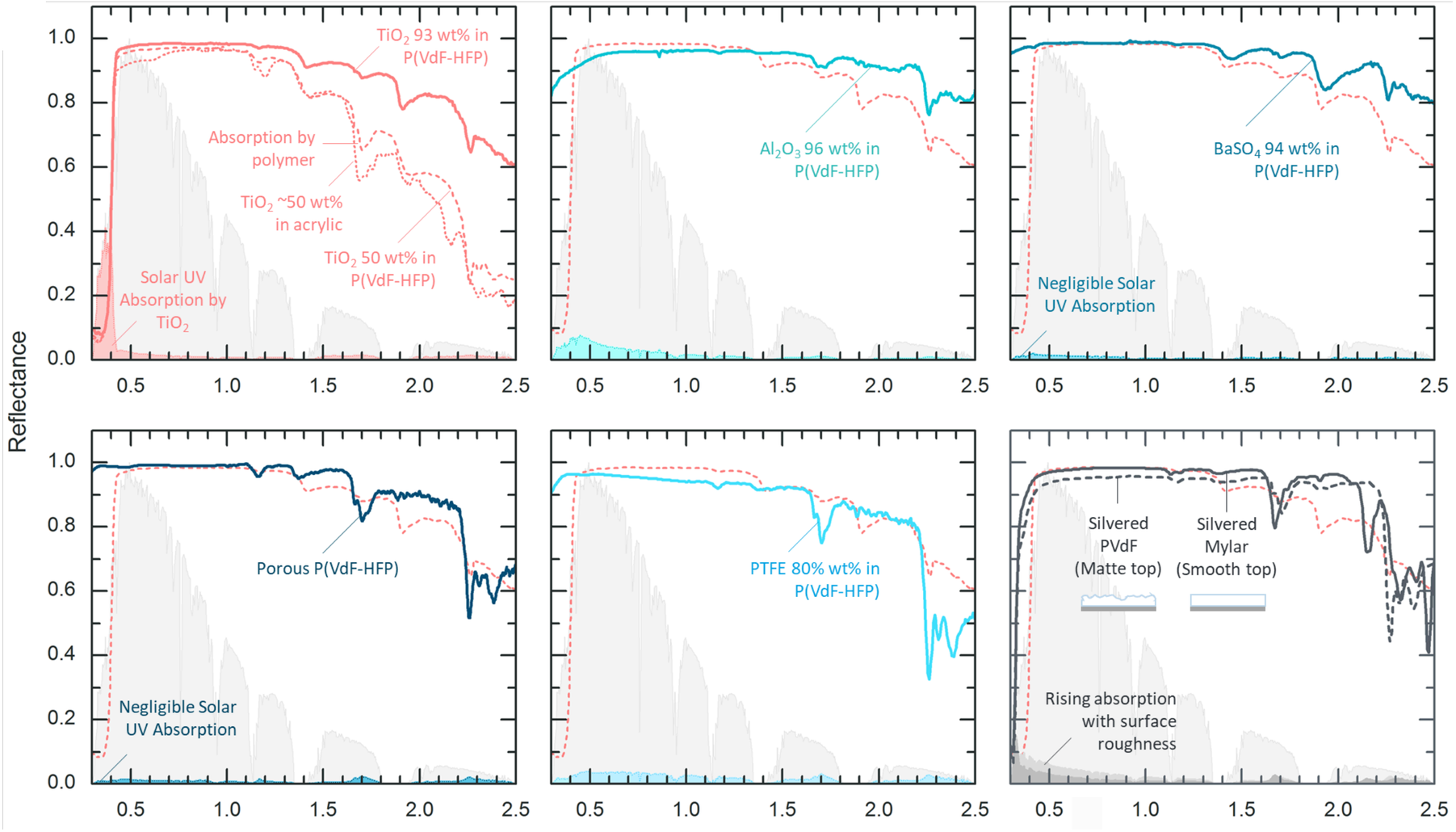


Jae S. Hwang, Jin Xu and Aaswath P. Raman, *Advanced Materials* (2023)

Radiative cooling: Thermal emission to space

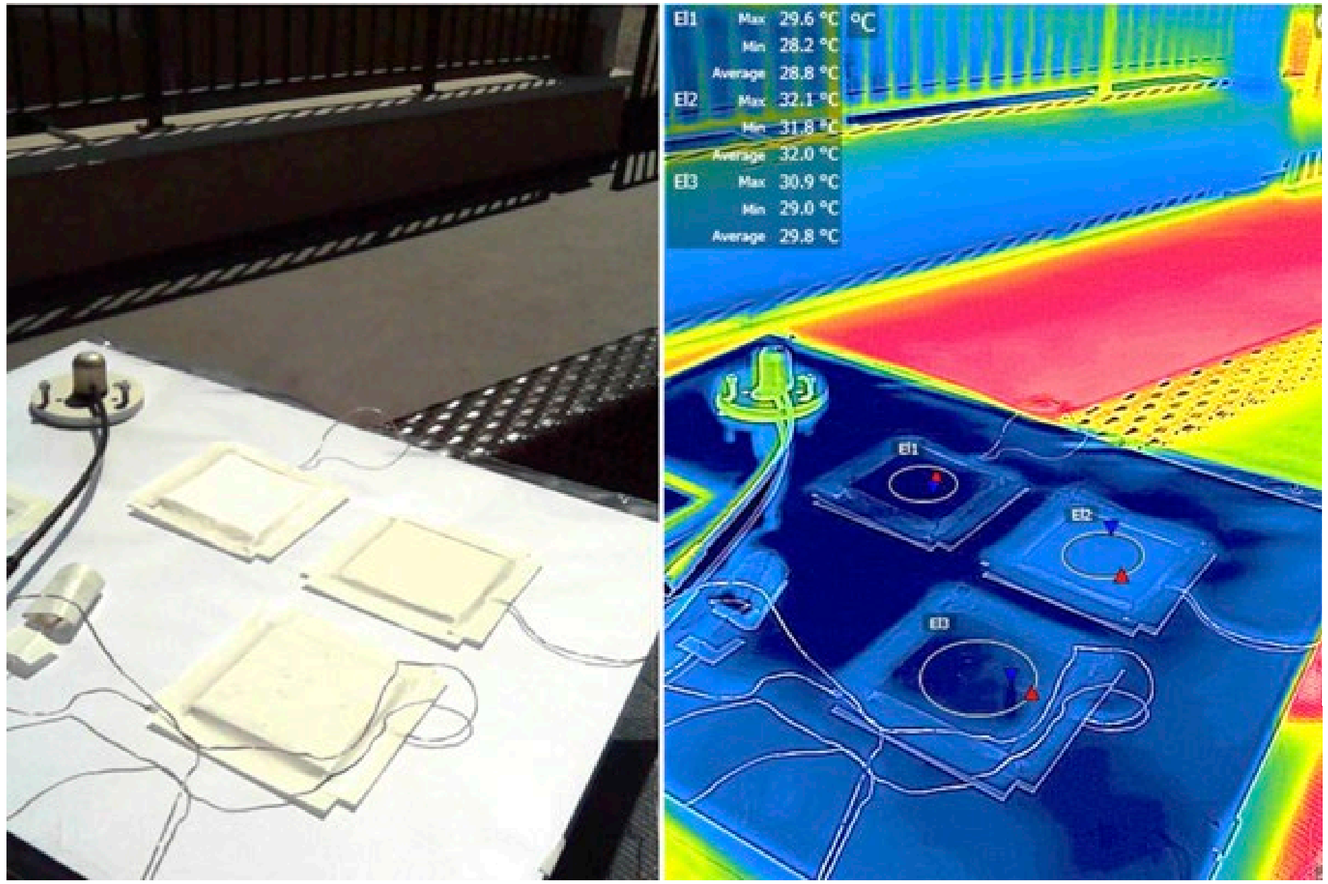


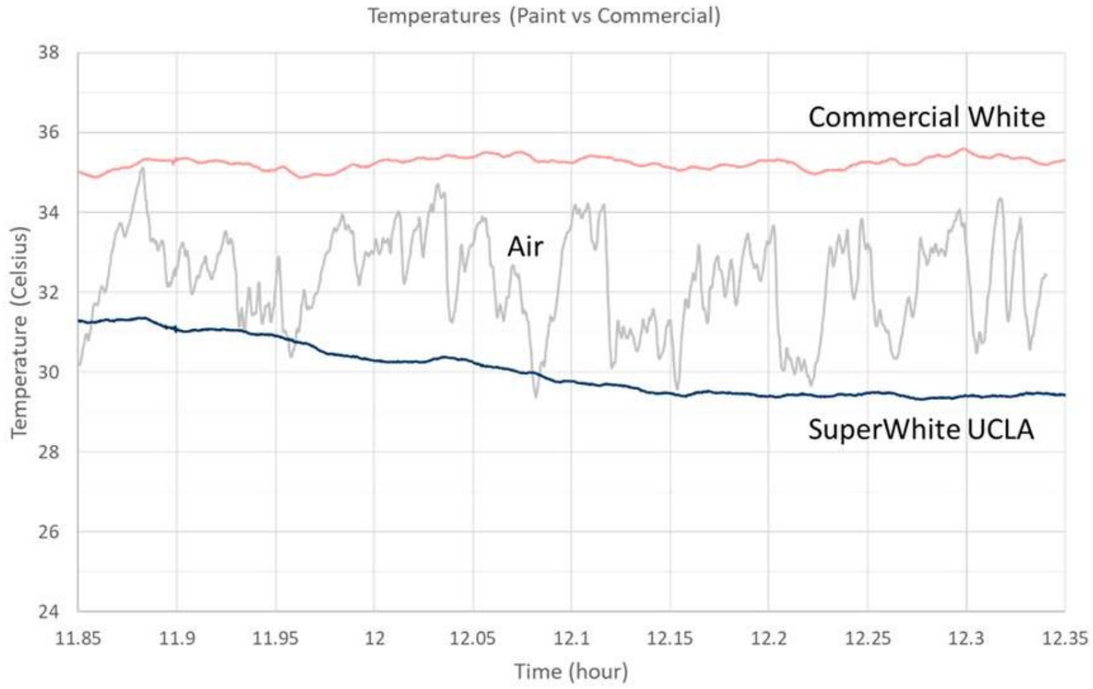
A range of paint-based strategies can be super-reflective



J. Mandal, Y. Yang, N. Yu and A. Raman, *Joule,* 4 (7), 1350-1356 (2020)

Super-white paint performance

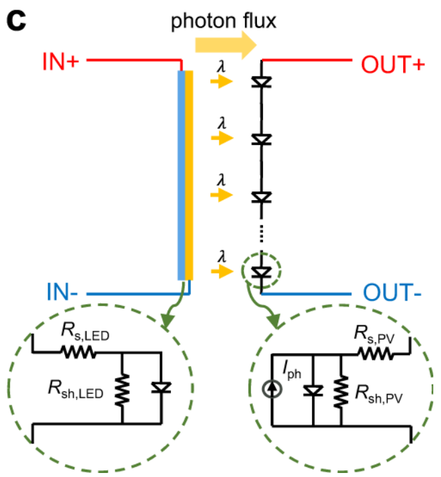


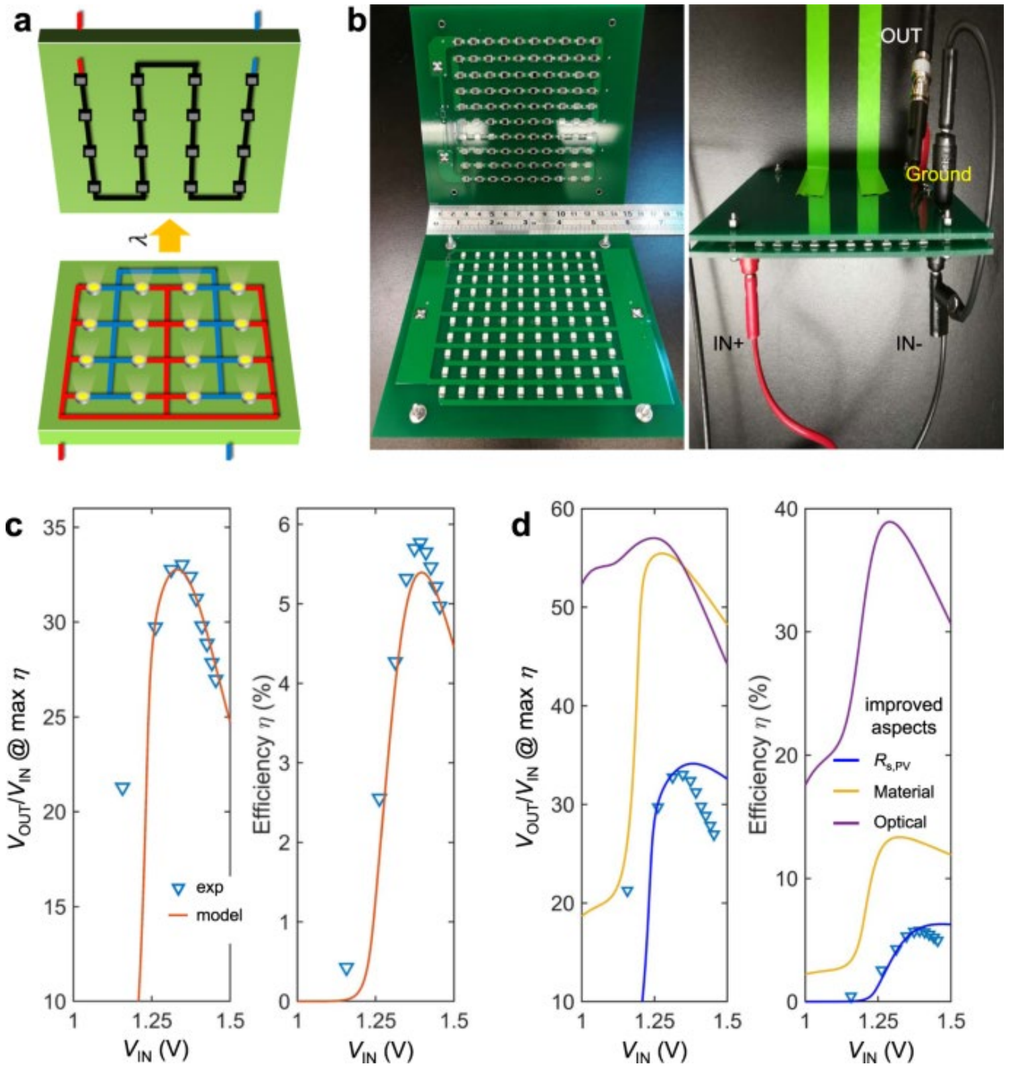


Photonic DC-DC Voltage Conversion

Potential for ultra-lightweight, high efficiency power electronics using a photonic approach

Emerging monolithic approaches could enable integrated voltage boosting and other capabilities





Zhao et al., *Nature Communications* (2021)

High specific power, durable PV systems: **Opportunities for different components**

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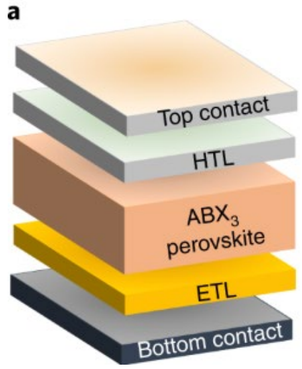

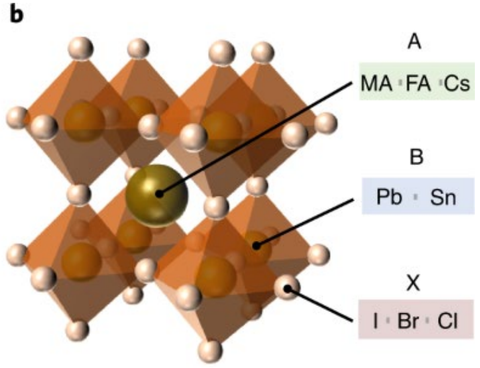

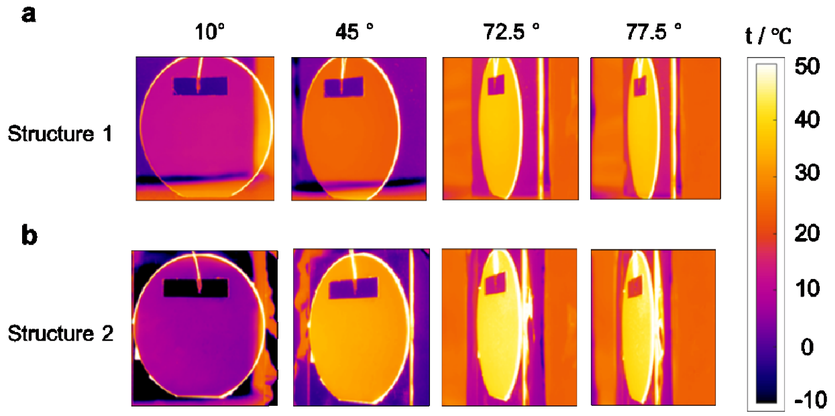

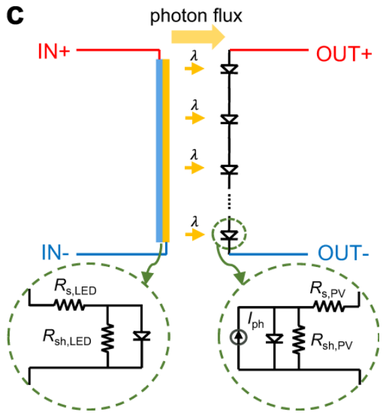

PV material:
Perovskites exhibit potentially superior radiation durability in lightweight form factor

Module level:
Advances in photonics allow us to control thermal radiation and enable dramatically improved thermal management

Power electronics:
Lightweight photonic approaches for voltage conversion

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