

Temperature Effects in Solar Photovoltaics

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Poster Presentations

Highly-efficient and rapidly-fabricated dye-sensitized solar cells through molecular design of the Cu-complex hole-transport material

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Dye-sensitized solar cells (DSSCs) are highly promising for indoor Internet-of-Things (IoT) applications due to their excellent performance under low-intensity illumination. Copper(I/II) diimine complexes are among the most effective redox systems for solid-state DSSCs (ssDSSCs), yet their broader implementation is fundamentally limited by oxidation-induced structural reorganisation, which promotes intermolecular interactions, crystallisation, and poor control over solid-state morphology during device fabrication.

Here, we demonstrate that this limitation can be overcome through ligand-level steric engineering that decouples redox energetics from solid-state packing. By extending the 6,6'-substituents from methyl to butyl, the complex $[\text{Cu}(\text{C1C4})_2]^{2+}/^{+}$ suppresses coordination-sphere flattening upon oxidation while preserving the electronic structure of the Cu–N core. This enables the formation of amorphous, uniformly infiltrated films under rapid processing conditions, in contrast to the pronounced crystallisation observed in conventional systems.

We combine crystallographic analysis, density functional theory, and thin-film characterisation to establish a direct link between reduced geometric reorganisation, suppressed crystallisation, and improved charge transport in the solid state. These features translate into reproducible device performance, with efficiencies exceeding 10% under 1 sun and above 36% under indoor illumination, achieved using a rapid fabrication protocol (5–10 min).

More broadly, this work identifies coordination-sphere control as a key design parameter for regulating solid-state organisation in redox-active metal complexes, providing a generalizable strategy for the development of next-generation hole-transport materials. Notably, this represents one of the simplest and most rapidly assembled solid-state DSSCs reported to date with efficiencies exceeding 10%.

Outdoor Stability of Carbon-Based Perovskite Solar Modules over 12-Months

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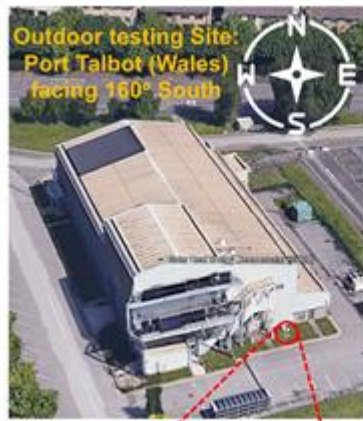
Printed mesoscopic carbon-based perovskite solar cells (C-PSCs) offer a pathway to scalable, low-cost photovoltaics, with champion cells recently exceeding 22% PCE (1). C-PSCs represent one of the most intrinsically stable perovskite device architectures, demonstrating over 10,000 hours stability in controlled standard conditions for a 50 cm² device (2). This has been further supported by the addition of encapsulation materials, to prevent these devices decomposing in the presence of moisture (3). These accelerated testing methods provide useful insight into device stability, but do not fully represent the reality of real-world environmental exposure.

Here, we present 12-months of outdoor weathering data for 518 cm² active area MAPbI₃ C-PSC modules, fabricated using low-cost manufacturing techniques. Following outdoor continuous intermittent power point tracking for over 12 months, an encapsulated module retained 68% of initial PCE. Performance remained stable during cooler months, despite significant fluctuations in humidity, only falling when temperatures rose during summer months. Similar temperature dependant trends were observed in repeated outdoor trials and in indoor tests conducted under controlled conditions.

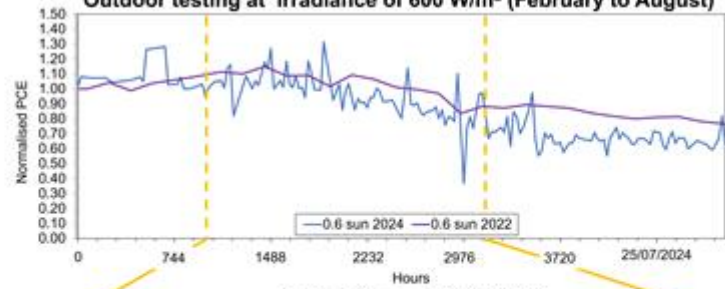
Overall, the weathering trials identified key degradation pathways linked to fabrication, namely non-uniform heating during perovskite annealing, encapsulation, and infiltration-related failures. Controlling heat exposure and conformity during module manufacture and operation is therefore critical to extending lifetime. These results highlight the importance of real-condition assessments in optimising the scale-up of novel perovskite technologies, providing key insights into the steps required to achieve commercially viable lifetimes.

References

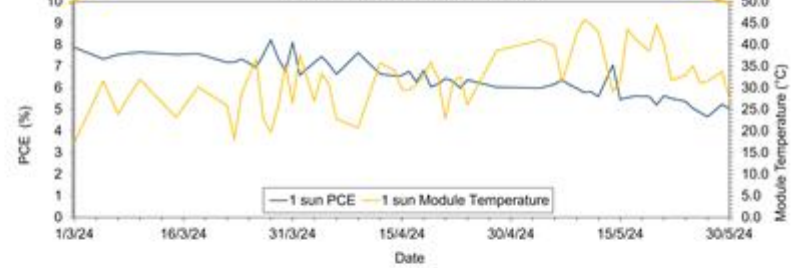
1. Liu, J. et al. Electron injection and defect passivation for high-efficiency mesoporous perovskite solar cells. *Science* 383, 1198–1204 (2024).
2. Grancini, G. et al. One-Year stable perovskite solar cells by 2D/3D interface engineering. *Nat. Commun.* 8, 1–8 (2017).
3. Cheacharoen, R. et al. Encapsulating perovskite solar cells to withstand damp heat and thermal cycling. *Sustain. Energy Fuels* 2, 2398–2406 (2018).



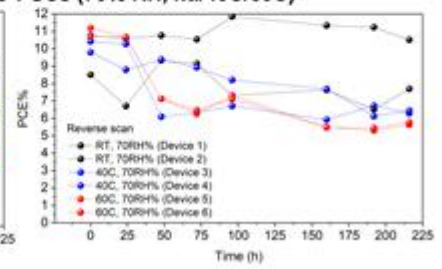
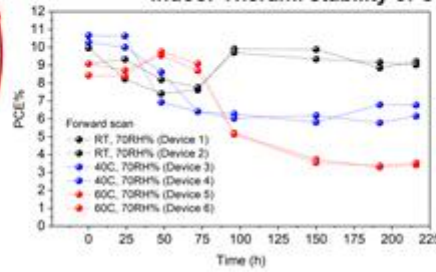
Outdoor testing at irradiance of 600 W/m² (February to August)



At irradiance of 1000 W/m²



Indoor Thermal stability of C-PSCs (70% RH, r.t./40C/60C)



Quantifying Temperature Effects in Floating Bifacial Photovoltaics: Separating Thermal, Optical and Structural Contributions

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Photovoltaic module temperature directly affects conversion efficiency and energy yield, making thermal behaviour a key consideration in floating photovoltaic (FPV) systems. FPV is often assumed to outperform land-based PV because of water-induced cooling; however, the extent to which this thermal advantage contributes to annual energy yield remains unclear because temperature effects are frequently assessed alongside changes in tilt, irradiance and bifacial rear-side illumination.

This study introduces AQUAPV, a coupled hydro-thermal-optical modelling framework that separates thermal, structural and optical contributions to FPV performance. Three configurations are evaluated for a 1 MWp bifacial PV installation in London, United Kingdom: optimally tilted land-based PV, standard floating bifacial PV over natural water, and an enhanced floating configuration incorporating a high-reflectance surface beneath the array. Simulations use synthetic meteorological data and are validated against an analytical PV performance framework.

Results show that although floating deployment modifies module operating temperature, thermal effects account for only a small proportion of the annual performance difference between floating and land-mounted PV. The dominant loss mechanism is the reduced tilt required by floating-platform stability. Floating modules operate close to the 25 °C standard test condition reference temperature on an annual-average basis, reducing sensitivity of annual yield to module temperature coefficient.

Increasing surface reflectance beneath the floating array from 0.07 to 0.70 recovers 80.5% of the performance penalty associated with restricted tilt, reducing the yield gap relative to optimally tilted land PV to 0.6%. If higher tilt angles become structurally feasible, the enhanced floating configuration outperforms equivalent land-mounted PV by 6.3%.

These findings show that, at temperate latitudes, FPV performance is governed more strongly by structural geometry and irradiance than by thermal effects alone. AQUAPV provides a framework for determining when water-induced cooling produces meaningful photovoltaic energy gains.

Temperature Effects on Silicon Heterojunction and FAPbI₃ Perovskite Solar Cells for Space Applications

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Space photovoltaics must endure harsh conditions beyond radiation, including thermal shock and extreme temperatures, which are factors that are less frequently studied. This work presents thermal performance results for two potential space solar cell technologies: silicon heterojunction (HJT) and FAPbI₃ perovskite solar cells.

Silicon HJT cells offer a high manufacturing throughput and a low cost per watt, making them an attractive option for space applications. However, they typically suffer from severe low-temperature performance loss due to a declining fill factor, as seen in recent work, which is unlike homojunction devices, which remain stable. In this study, we demonstrate a HJT device, manufactured by LONGi, that instead shows a linear efficiency increase down to -120 °C with no collapse in performance. This is believed to be due to the use of nanocrystalline silicon for the doped layers, rather than the standard amorphous silicon. Thermal shock tests on P and N-type HJT cells (100 °C to -80 °C, 100 cycles at 16 °C/min and 50 cycles at 30 °C/min) were also conducted and the cells showed no changes in performance immediately after testing.

FAPbI₃ perovskite solar cells offer promising efficiencies and radiation tolerances but are vulnerable to thermal shock due to their thin-film structure and FAPbI₃'s room-temperature instability. Doping FAPbI₃ with varying levels of MAPbBr₃ (1%, 3%, 5%, 7%) revealed that 5% MAPbBr₃ most effectively suppressed the formation of the non-photoactive δ -phase after thermal shock (± 80 °C, 16 °C/min, 100 cycles), while also minimising degradation in the hysteresis index and power conversion efficiency. This finding was validated with a 35 km high-altitude balloon test, conducted with the University of Pisa.

Together, these results indicate that both LONGi's HJT design and MAPbBr₃-doped FAPbI₃ perovskites show promising thermal robustness for space photovoltaic applications, addressing a critical but underexplored aspect of space solar cells.

Molecular Interfaces for Thermo-Adaptive Organic Photovoltaics

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The operating temperature of a photovoltaic device is generally considered a source of performance loss, with strategies consequently focused on improving thermal stability or dissipating excess heat. An alternative approach is to introduce molecular materials whose interfacial properties respond dynamically to the thermal environment. In my work I have explored metal-organic framework (MOF) confinement of a molecular switch as a strategy for developing thermally adaptive interfaces for organic photovoltaics (OPVs).

Spiropyran offers a well-defined molecular switching system through interconversion between its closed spiropyran (SP) and zwitterionic merocyanine (MC) forms. While this transformation is conventionally exploited through photochemical switching, confinement within a chemically defined porous environment provides an opportunity to modify the relative thermodynamic and kinetic accessibility of the two states. I am interested in exploring whether MOF confinement can regulate the competition between photoinduced switching and thermally driven relaxation, enabling temperature-dependent control of the molecular state under continuous illumination.

The MOF-confined molecular layer is incorporated at the hole-selective interface of an OPV, where changes in molecular state are expected to modify the local polarity, interfacial dipole and electronic environment experienced by the adjacent organic semiconductor. Temperature-dependent absorption spectroscopy is combined with photovoltaic measurements to follow the SP/MC population and device characteristics under controlled illumination and thermal cycling. In particular, we examine whether changes in temperature produce reversible changes in molecular population under otherwise constant illumination, and whether these changes correlate with variations in V_{oc} , fill factor and charge extraction.

By coupling molecular confinement, stimulus-responsive chemistry and photovoltaic interfaces, this work explores a shift from thermally stable materials towards thermally adaptive molecular interfaces. The study provides a chemical framework for investigating whether operating temperature can be exploited as a stimulus to dynamically regulate interfacial electronic properties in emerging photovoltaic materials.

Muon spin spectroscopy probes carrier lifetime inside completed silicon solar cells across temperature

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Understanding how carrier recombination evolves with temperature is essential for predicting photovoltaic performance in real-world and extreme environments, from cryogenic to elevated operating conditions. We present temperature-dependent carrier lifetime measurements using photoexcited muon spin spectroscopy (photo- μ SR) [1], a bulk, contactless probe that penetrates fully metallised devices, a regime largely inaccessible to conventional methods such as photoconductance decay (PCD). At the HIFI spectrometer, ISIS Neutron and Muon Source, sample environments span 20–600 K, well beyond the window of most established lifetime characterisation tools.

In photo- μ SR, implanted spin-polarised muons capture an electron to form muonium, a hydrogen-like centre whose spin depolarisation rate tracks the excess carrier density created by a synchronised laser pulse. Muon spin polarisation is read out from the positrons emitted on decay, and scanning the pump–probe delay reconstructs the full carrier lifetime spectrum at a controlled implantation depth.

We measured a completed silicon heterojunction (SHJ) solar cell, its stripped substrate (metallisation removed) and a reference passivated wafer from 77–290 K. The completed cell showed consistently shorter lifetimes, consistent with additional recombination at metallised and interface layers. Lifetime increased with temperature in all samples, closely tracking benchmark PCD data for the stripped cell. One caveat is muon beam damage [2], which creates recombination-active bulk defects and shortens measured lifetimes, especially in long-lifetime wafers. Despite this, photo- μ SR proves a versatile probe of temperature-dependent recombination in fully processed cells across a uniquely broad temperature range.

[1] A. Yadav et al., IEEE J. Photovolt., to be published.

[2] J. D. Murphy et al., J. Appl. Phys. 132, 065704 (2022).

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