2026 Helmholtz – OCPC – Program
for the involvement of postdocs in bilateral collaboration projects

Title of the project:

Suppressing energy loss in up-scaling perovskite photovoltaic modules

Helmholtz Centre and/or institute:

Karlsruhe Institute of Technology (KIT), Institute of Microstructure Technology (IMT)

Project leader:

Prof. Dr. Ulrich Paetzold and Dr. Renjun Guo

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Department: (at the Helmholtz centre or Institute)

Institute of Microstructure Technology (IMT)

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Description of the project (max. 1 page)**:**

Background and Motivation

Although perovskite solar cells (PSCs) have achieved rapid efficiency gains, a substantial performance gap remains between champion small-area cells and large-area perovskite solar modules (PSMs). Scalable fabrication methods (e.g., blade coating and slot-die coating) inevitably introduce additional energy-loss pathways during upscaling, including non-uniform crystallization arising from altered film-formation dynamics and poor interfacial contact induced by process-specific fluid flow. Therefore, systematically identifying the dominant sources of energy loss in large-area PSMs and developing compatible mitigation strategies to narrow the module–cell efficiency gap are critical to overcoming a key bottleneck in the commercialization of perovskite photovoltaics.

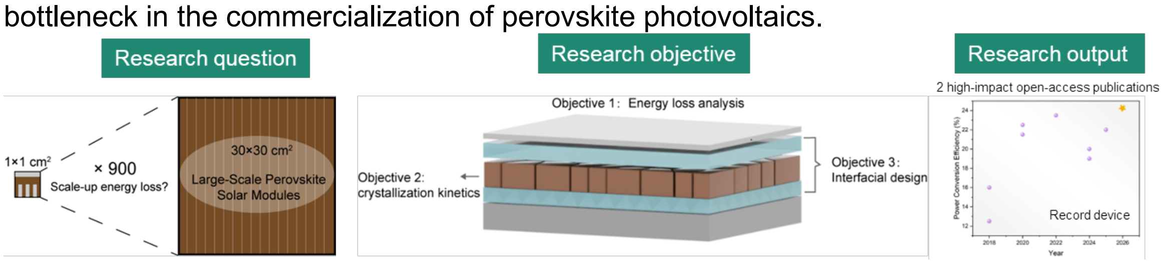

Figure 1. *Project overview illustrating the scale-up challenge from 1 × 1 cm^2 cells to 30 × 30 cm^2 perovskite modules and the corresponding research strategy. The project integrates energy-loss analysis, crystallization-kinetics control, and interfacial design to mitigate scale-dependent losses and enable record-level large-area device performance.*

Research Questions

Under the dynamic non-equilibrium conditions of large-area slot-die coating processes, achieving precise control over buried interface contact, bulk crystallization kinetics, and surface/interface defects through multi-interface synergistic interfacial modulation can fundamentally suppress non-radiative recombination and ion migration. This will enable the simultaneous enhancement of module performance and stability.

Research Objectives

Objective 1: Energy loss analysis for current start-of-art devices: employ techniques including photoluminescence quantum yield measurements and ultraviolet photoelectron spectroscopy to identify and quantify the sources of energy loss in large-area perovskite solar modules.

Objective 2: Understanding and controlling crystallization kinetics during large-area perovskite fabrication: utilize in-situ grazing-incidence wide-angle X-ray scattering to elucidate crystallization dynamics during large-area perovskite deposition. Develop solvent engineering and Lewis acid-base additive strategies to modulate nucleation and crystal growth, enabling more controllable crystallization processes, improving film uniformity in scaled-up fabrication, and reducing defect density.

Objective 3: Interfacial modulation strategies: engineer functional buried interfaces through the synergistic integration of organic self-assembled monolayers and inorganic nanoparticles to improve contact quality and passivate defects. And explore advanced passivation materials to achieve uniform surface coverage and effective passivation, minimizing interfacial energy losses.

Expected Outcomes & Impact

Scientific contributions: The project will establish a clear research framework and possesses solid foundations in scalable coating techniques, interface engineering, and advanced characterization methodologies, ensuring the successful execution of this project. With a clear target- slot-die coated perovskite modules to achieve: 1） Power conversion efficiency exceeding 24.0%, surpassing the current slot-die benchmark of 23.2%. 2) T80 operational stability exceeding 1500 hours under ISOS-L-2 protocols, representing a 50% improvement over current start-of-art benchmarks.

Publications and dissemination: Publish a minimum of 2 high-impact open-access journal articles systematically addressing the application of novel additives/solvent engineering and interface engineering in scaled-up devices, as well as validated strategies for suppressing scale-up losses.

Description of existing or sought Chinese collaboration partner institute (max. half page)**:**

The project will collaborate with Prof. Linjie Dai, **Peking university**, Department of Physics, State key Laboratory of Artificial Microstructure and Mesoscopic Physics. develops the research methods and builds the concepts to promote the artificial microstructure and mesoscopic physics in life sciences, energy, and various applied disciplines. Guided by the Outline of the National Medium-and Long-Term Science and Technology Development Plan, the laboratory builds a research basement with the Mesoscopic physical research features and the close integration of atomic, molecular, optical physics and condensed matter physics, and in-depth development of major basic scientific issues and application frontiers in mesoscopic physics. Combined with the frontier scientific issues of mesoscopic physics research and the major national plans and tasks undertaken, three major research directions have been formed in the laboratory, namely, “Mesoscopic optics and Femtophysics”, “Mesoscopic System Condensed Matter Physics and Devices” and “Mesoscopic physical intersection and major applications”.

Prof. Linjie Dai received his Ph.D. degree in Physics from the University of Cambridge in July 2021. From 2021 to 2023, he conducted postdoctoral research at the Cavendish Laboratory, University of Cambridge. From 2023 to 2025, he was a Marie Skłodowska-Curie Fellow at the Massachusetts Institute of Technology. His research focuses on ultrafast optics, strong-field physics, and quantum optics in low-dimensional materials, with an emphasis on their applications in semiconductor devices, clean energy, and quantum technologies. He has published over 40 papers in high-impact journals, including *Nature* and *Nature Photonics*.

Required qualification of the postdoc:

- PhD in Physics (Condensed Matter Physics)
- Experience with Extensive experience in perovskite photovoltaic, including high-efficiency up-scaling inverted (p–i–n) perovskite solar cells. Proven record of device performance optimization and stability studies.
- Additional skills in advanced materials and device characterization techniques, including GIWAXS, SEM, EDS, PL, TRPL, UV–Vis spectroscopy, AFM, KPFM, AFM-IR, XPS, and UPS. Solid background in solid-state physics and semiconductor physics.
- Language requirement: English (professional working proficiency)