Automated Photonic-Pulses Processing for Thin Solar Energy Devices (Δ3P): Leveraging Machine Learning and Data Analysis for Enhanced Efficiency and Stability

Ornella Vaccarelli[1], Christophe Gisler[1], Tiziano Caldara[2], Sandy Sánchez-Alonso[3], and Jean Hennebert[1]
[1]iCoSys, HEIA, Fribourg; [2]LPI-Lab, EPFL, Lausanne; [3]LIMNO-lab, EPFL, Lausanne

Perovskite solar cells (PSCs) represent a breakthrough in next-generation photovoltaics, offering exceptional efficiency, flexibility, and cost-effective manufacturing. Their ability to transform solar energy systems positions them as a cornerstone of sustainable energy technologies. Despite these advantages, challenges remain in optimizing PSC performance and stability, particularly in tandem configurations combining perovskite and silicon layers to maximize energy conversion across the solar spectrum [1-2]. Achieving consistent film quality and precise control over crystallization processes is crucial to enhancing their efficiency and long-term reliability.

To address these challenges, we introduce an automated platform that integrates machine learning (ML) workflows for real-time process refinement and performance enhancement, as illustrated in Figure 1. Our research leverages computational analysis and advanced data processing techniques to study the efficiency and stability of PSCs. High-resolution microscopic images obtained during the fabrication process are processed using state-of-the-art segmentation techniques, including the Segment Anything Model (SAM) [3] and Detectron2 [4], to isolate and identify key morphological features such as crystal structures and nuclei. A ResNet152 convolutional neural network (CNN) further classifies segmented regions, enabling detailed morphological characterization. The resulted masks are studied within quantitative metrics, such as crystal size distribution, aspect ratios, spatial density, Shannon entropy, and Computable Information Density (CID) [5]. These properites are extracted to evaluate film homogeneity and structural properties, which would permit real-time adjustments to synthesis parameters, optimizing crystallization processes and improving device performance.

The resulting automated platform integrates image analysis, machine learning workflows, and data-driven process control, aiming to deliver tandem devices with efficiencies exceeding 30%. By combining cutting-edge AI techniques with real-time optimization, our approach addresses PSC key scalability challenges, paving the way for ultra-efficient, sustainable photovoltaic technologies.

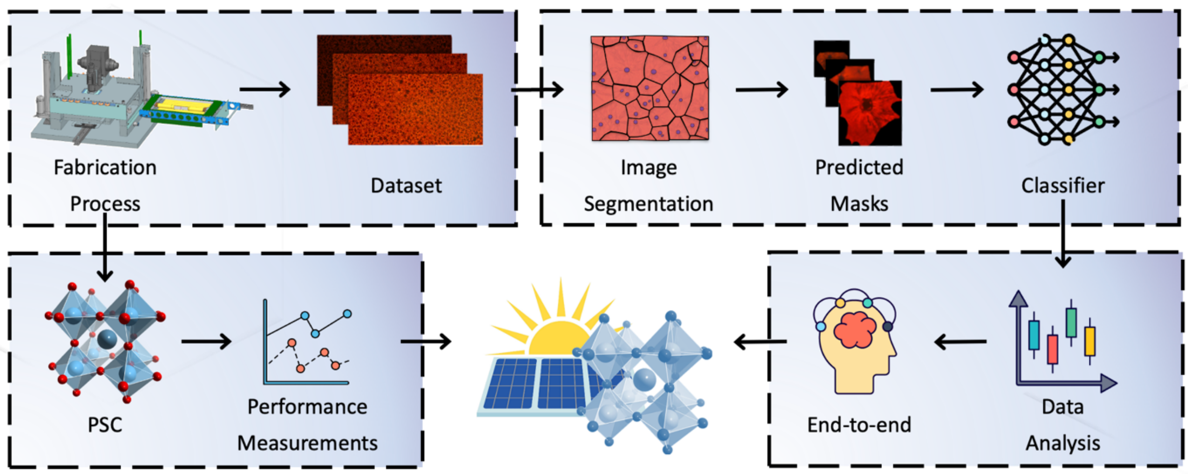

Figure 1: Schematic representation of the Δ3P project workflow.

References

[1] Sahli, F., Werner, J., Kamino, B.A. et al. Nature Mater 17, 820–826 (2018).
[2] S. Sanchez, N. Christoph, B. Grobety, N. Phung, U. Steiner, M. Saliba, A. Abate, Adv. Energy Mater. 8, 1802060 (2018).
[3] META AI - Y. Wu, et al. , Detectron2, https://github.com/facebookresearch/detectron2, (2019).
[4] META AI - A. Kirillov, et al. , Segment Anything, arXiv:2304.02643, (2023).
[5] M. Grasa Lainez, Shannon entropy, order and image compression (2022).