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AI-Driven Defect Detection Using Multi-Spectral Imaging

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Motivation

- Multispectral imaging has diverse applications, including artwork analysis, weather forecasting, and more. The full potential of multispectral imaging in fault detection for photovoltaic (PV) modules using artificial intelligence (AI) remains underexplored. Previous efforts have only combined one imaging technique with AI for fault detection in PV modules.
- This study aims to develop a methodology for **automatic identification of failure modes in PV modules** using nine-channel multispectral images. The approach integrates **multiple imaging techniques—visual image (VI), electroluminescence (EL)**, and **ultraviolet fluorescence (UVf)**—to detect a broader range of failure modes. This method improves detection of issues in modules exposed to aging in real-world conditions or accelerated stress testing. The integrated approach promises faster and more accurate detection of potential problems compared to single-image analysis.
- The study also seeks to predict the **electrical performance of PV modules** using AI-driven analysis of multispectral images.

Multi-Spectral Image Capturing

Visual Image Setup:

- 2 flash units and Rectangular soft boxes positioned at a 45° angle for even light distribution
- Light in visual spectrum from the module

Electroluminescence Image Setup:

- A power supply connected to PV module
- IR emissions from the cells

Ultaviolet Fluorescence Image Setup:

- 4 UV lamps (emitting at 365 nm) positioned at a 45° angle
- A UV filter (high pass) to eliminate UV reflections
- When UV light (high energy) is absorbed by degradation by products of polymeric materials, which may have fluorescence effect, they emit photons in the visible range (lower energy)

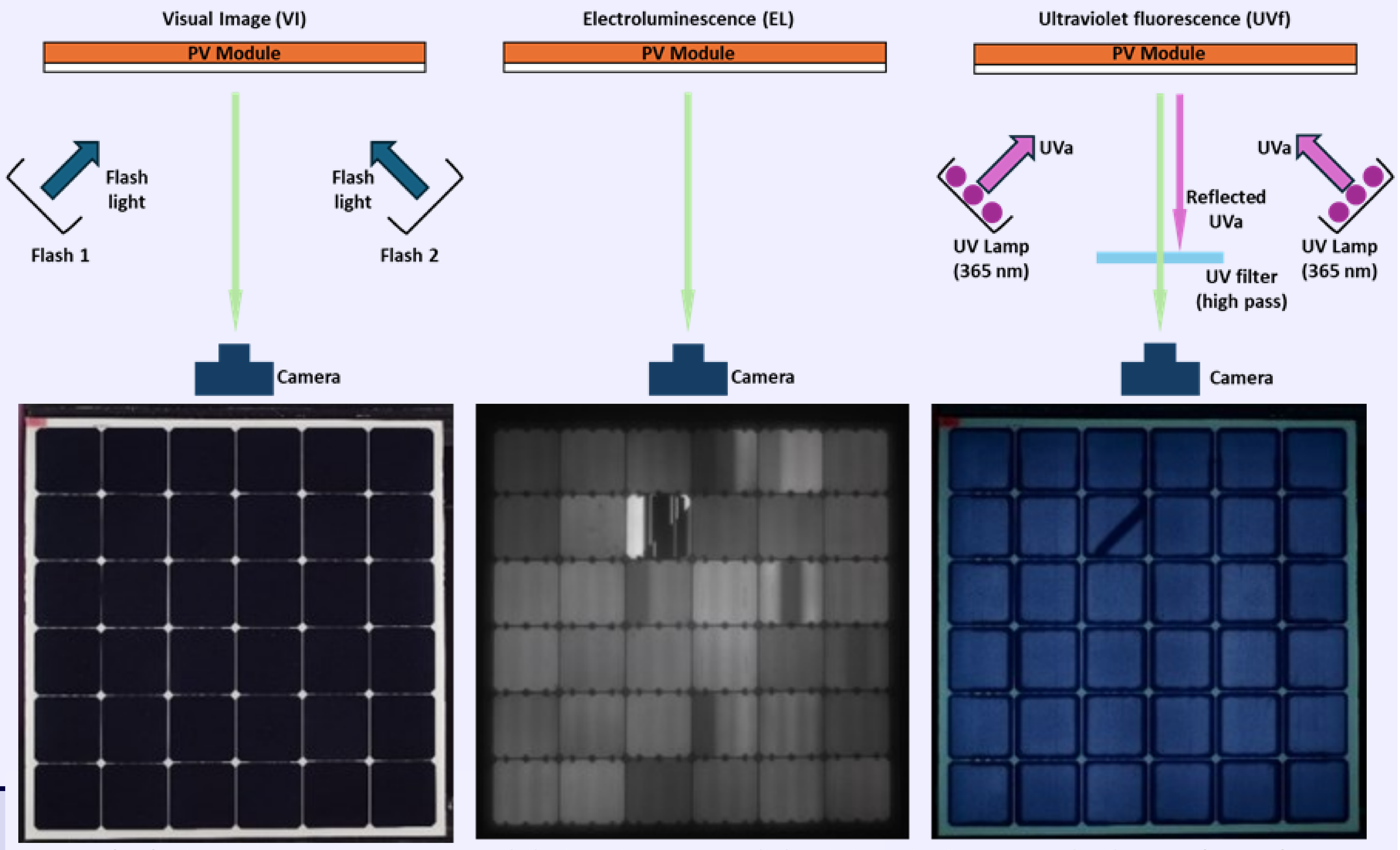
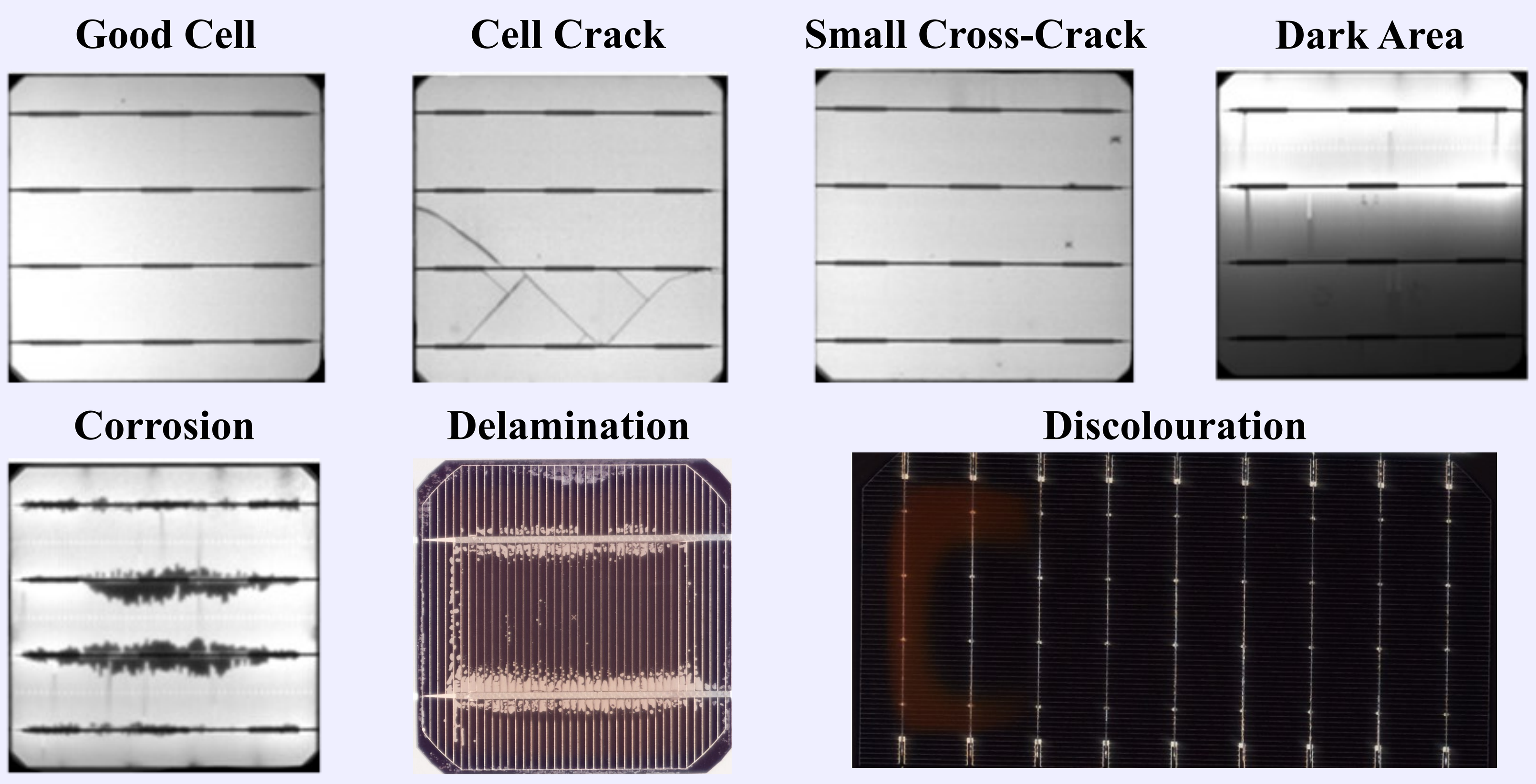


Figure 1. (top) Schematic view of visual inspection (VI), electroluminescence (EL) and ultraviolet fluorescence (UVf) setups. **(bottom)** VI, EL, and UVf images of an IBC module after a long-term outdoor exposure.

Example:

- A cell crack and damaged metallization (at the rear side of the cell) are visible in the EL image
- UVf image confirms there is only one cell crack (oxygen bleaching on the cell crack area)
- Using multispectral image like in this case gives possibility to separate damaged metallisation and cell crack without any hesitation.

Cell Classification



- Discoloration can be identified through both VI and UVf images, depending on specific conditions such as encapsulant type. In cases where discoloration is intense, it may also lead to oxidation of the front metallization, which can be observed in the EL image (red frames in figure below). In such instances, cells are labelled with multiple failure modes.

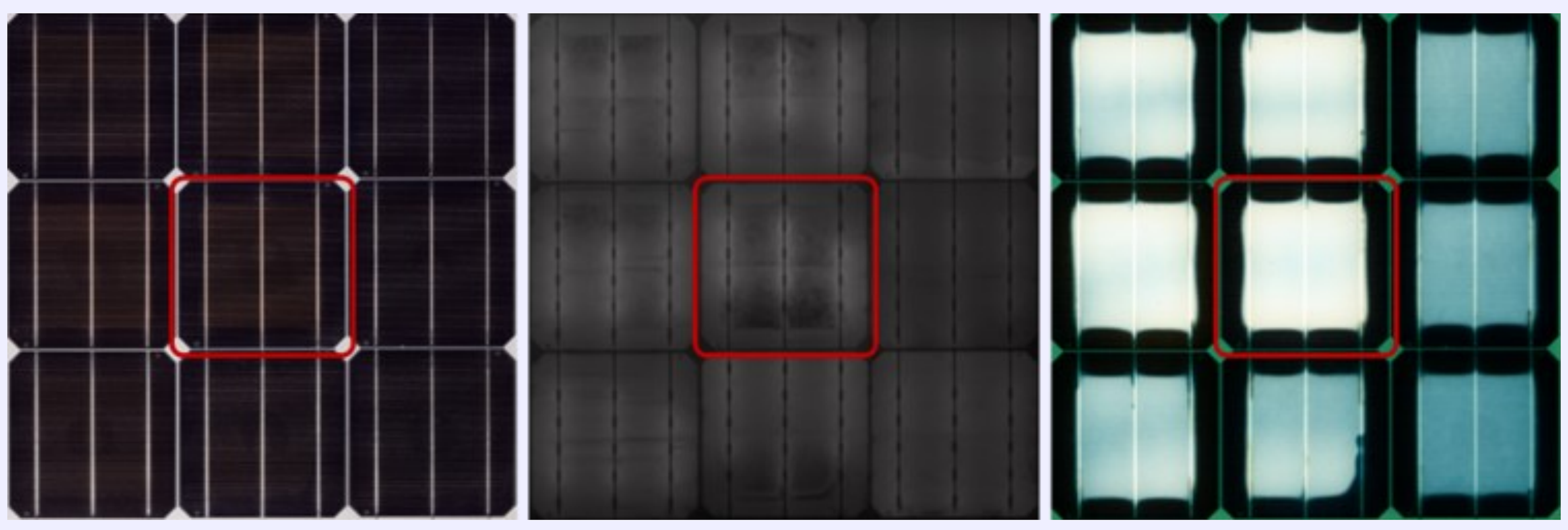
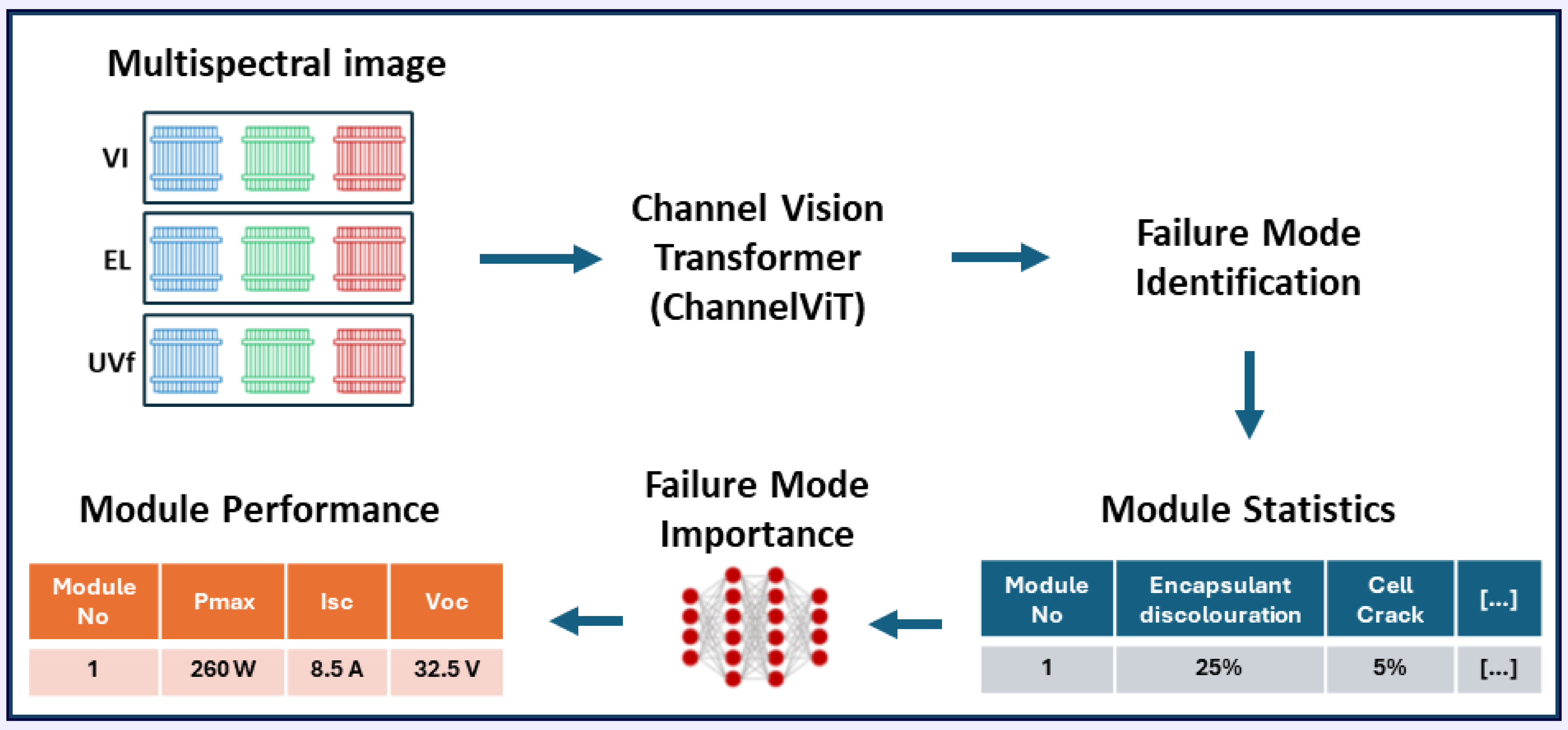


Figure 2. (left) VI, **(middle)** EL, and **(right)** UVf images of a section of a module after 10 years of operation under frequent shading. The cell within the red frame is labelled as **"discolouration"** and **"corrosion"**.

Methodology



Preliminary Results

- The classification model, **ChannelViT**, was trained on the Duramat dataset [1] and tested on the Infinity dataset [2]. This means the model was trained on different technologies than those used for classification prediction. Despite the model never having encountered images from the Infinity dataset during training, it achieved an impressive prediction accuracy of **94.4%**.

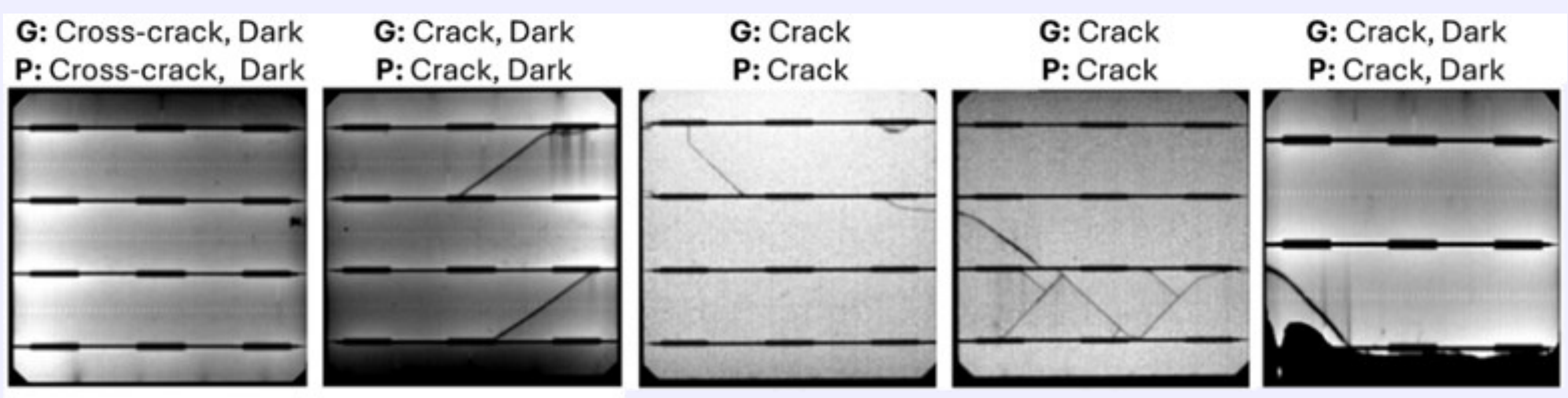


Figure 3. Examples of correct Vision Transformer predictions for the Infinity dataset, where the ground truth (G) is the same as the prediction (P).

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References: [1] X. Chen, "GitHub," PV-Vision, 2022. [2] K. Knoebl, G. Oreski, L. Neumaier e B. Brune, "Zenodo," Project repository: Advanced Degradation Modelling of Photovoltaic Modules and Materials, 2024. Available: https://zenodo.org/records/13354817.