

HIGH-RESOLUTION MULTISPECTRAL IMAGING OF PV MODULES

Background and Why the Test Matters

The **High-Resolution Multispectral Imaging** setup at SUPSI PVLab enables detailed investigation of photovoltaic (PV) modules by combining **visual inspection (VI)**, **electroluminescence (EL)**, and **ultraviolet fluorescence (UVF)** imaging as developed in the **EAGLE project** [1]. Each technique reveals distinct characteristics of the module, and their combination provides complementary information about defects and degradation mechanisms that may not be identifiable with a single imaging technique.

A key feature of the setup is the use of a single **150-megapixel multispectral camera** for all three imaging modes. The high resolution allows entire PV modules to be captured in a single image while retaining enough detail to investigate individual cells and local defects. Using the same camera also facilitates accurate comparison among VI, EL, and UVF images and avoids uncertainties associated with aligning images acquired with different cameras. The different imaging modes provide complementary diagnostic information:

- **Visual inspection (VI)** records features visible at the module surface, such as manufacturing quality (i.e., contaminations, cell or contact alignment), discolouration, delamination and changes in module materials.
- **Electroluminescence (EL)** reveals electrically inactive or degraded regions and is particularly effective for detecting cell cracks, disconnected areas, metallization-related defects and other electrical irregularities.
- **Ultraviolet fluorescence (UVF)** provides information on the degradation of polymeric materials and can reveal degradation patterns associated with effects such as historical thermal stress, oxygen ingress and moisture-related processes.

Imaging Procedure

At SUPSI PVLab, the module is measured in a dedicated darkroom using a 150 MP Phase One iXM-MV150 multispectral camera. The imaging geometry and camera settings are controlled to obtain high-resolution, repeatable measurements. Three complementary images are acquired (Figure 1):

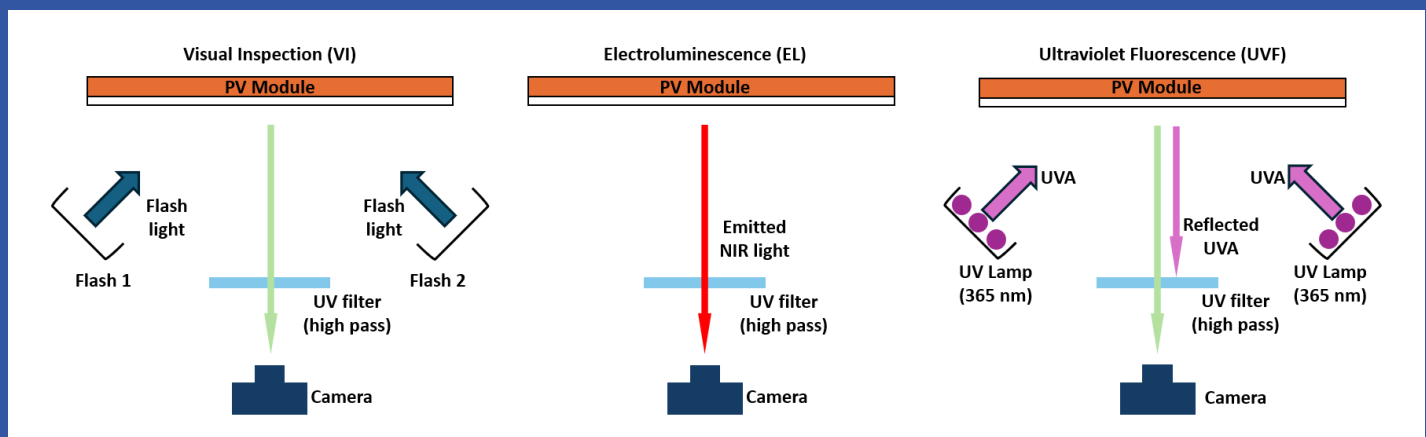


Figure 1: Schematic view of visual inspection (VI), electroluminescence (EL), and UV-fluorescence (UVF) setups.

1. Visual inspection (VI)

The module is illuminated using two flash units equipped with soft boxes. The illumination is positioned at approximately 45° to the module surface to minimise reflections from the front glass. A colour reference is included to enable traceable comparison of colour changes, which is particularly useful when investigating material discolouration, delamination or oxidation.

2. Electroluminescence (EL)

The PV module is electrically forward-biased in darkness (at both 100% and 10% of the module's short-circuit current), causing the solar cells to emit near-infrared radiation. The resulting image allows very small cracks, electrically inactive areas, metallization defects, shunts, high recombination and other electrical non-uniformities to be detected at cell level.

3. Ultraviolet fluorescence (UVF)

The module is illuminated by four 365-nm UV sources. A dedicated optical filter in front of the camera suppresses reflected UV radiation, allowing fluorescence emitted in the visible spectrum by module materials to be recorded more clearly. Depending on the module materials and degradation mechanisms, the resulting fluorescence patterns can provide information about module materials, polymer ageing, historical hot spots, oxygen ingress, moisture-related degradation, and cell cracks.

Example:

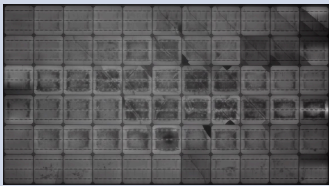
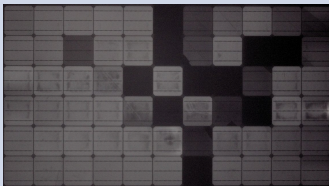
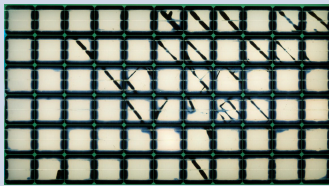
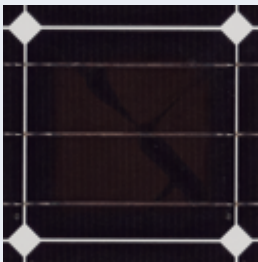
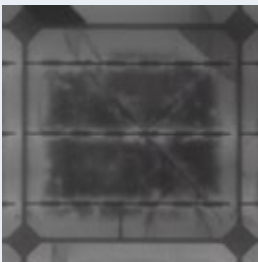
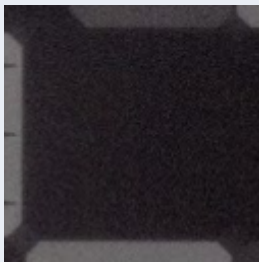
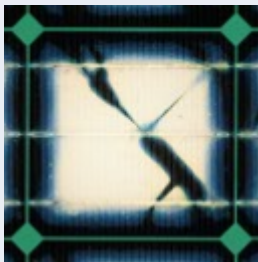
Visual Inspection (VI)	Electroluminescence (EL) at 100% I_{sc}	Electroluminescence (EL) at 10% I_{sc}	Ultraviolet Fluorescence (UVF)
			
			
Encapsulant and glass discolouration Cell cracks (indirectly visible due to oxygen bleaching on encapsulant discolouration)	Front metallisation corrosion Cell cracks and breakages Solder bond damages Interconnect ribbon damages	Corrosion Cell cracks Dark and darker cells	Cell cracks (indirectly visible due to oxygen bleaching)

Table 1: A PV module after more than 5 years operation in BIPV-insulated roof mounting configuration (no rear side ventilation) [2].

Key Takeaways

- High-resolution imaging enables both full-module documentation and detailed cell-level investigation from the same image.
- VI, EL and UVF provide complementary information: defects that are difficult or impossible to identify with one technique may become visible with another.
- Using one multispectral camera for all imaging modes improves image comparability and reduces uncertainties associated with multiple-camera configurations.
- Multispectral imaging can support the investigation of defects including cracks, electrically inactive areas, corrosion, discolouration and delamination, as well as providing information on their underlying degradation mechanisms.
- High-resolution VI, EL and UVF imaging provides a traceable way to document how PV modules change before, during and after accelerated ageing or natural ageing, making it valuable for both reliability research and detailed failure analysis.

References

- [1] SUPSI and FFHS, ["EAGLE – A deep learning approach to photovoltaics reliability."](#) Final Report, Swiss Federal Office of Energy (SFOE), Project SI/502555, 2026. [Accessed: Oct. 1, 2026].
- [2] E. Özkalay, A. Virtuani, G. Eder, Y. Voronko, P. Bonomo, M. Caccivio, C. Ballif, and G. Friesen, ["Correlating long-term performance and aging behaviour of building integrated PV modules."](#) Energy and Buildings, vol. 316, Art. no. 114252, 2024.