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# Quantifying Cell Fractures in Si PV Modules

## Fracture Detection by Imaging

Electroluminescence (EL) is the most common imaging method for PV modules due to:

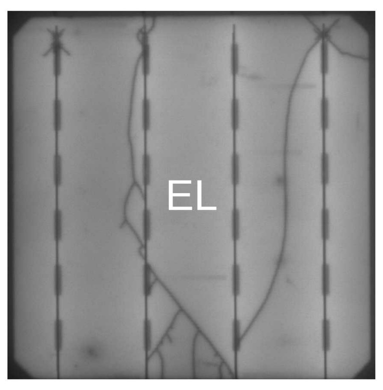
- Relatively low cost
- Ease of measurement
- Detects a variety of defects

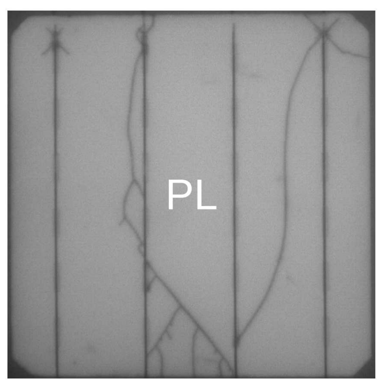
Photoluminescence (PL) provides an advantage for crack detection:

- Light-generated carriers enable radiative recombination where electrically isolated in EL

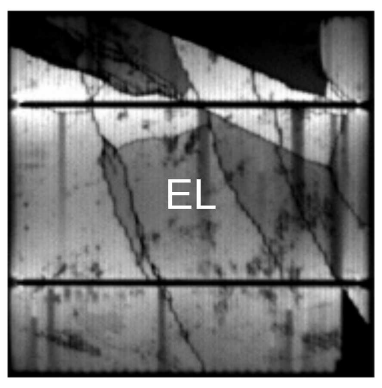
And resolves defect types when combined with EL

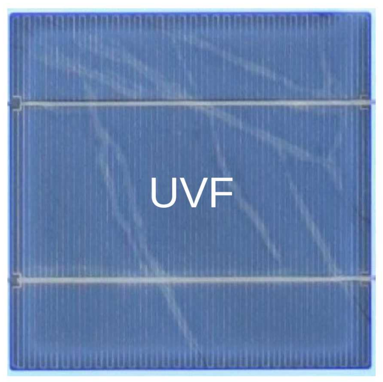
However is more difficult to perform




EL and PL images exhibit high contrast between cell fractures and pristine regions in silicon PV cells and modules, and therefore are ideal for detecting cell cracks via digital image processing.



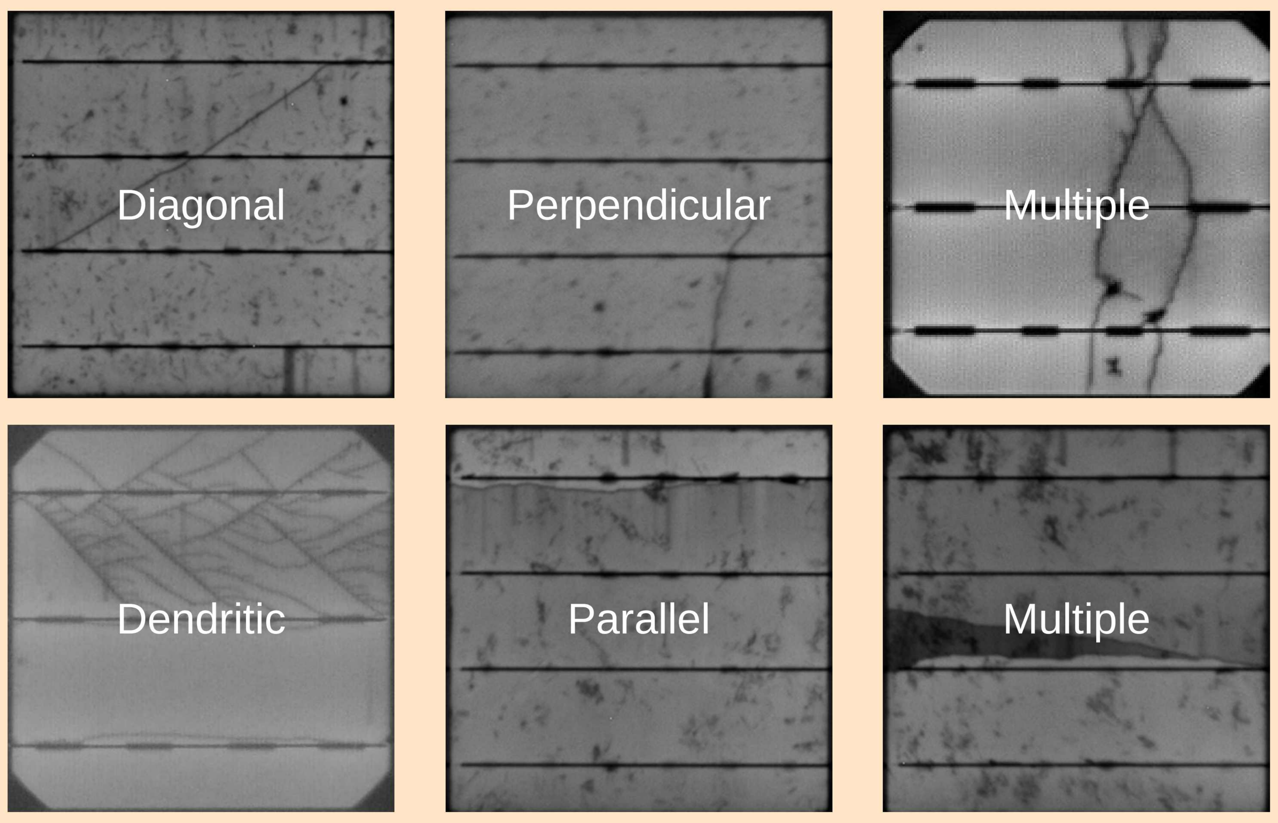




Fractures can also be detected in some cases by:

- Visible light photography ("snail trails")
- Ultraviolet fluorescence (encapsulant fluorophore formation)

But are material-specific

## Cell Fracture Geometries

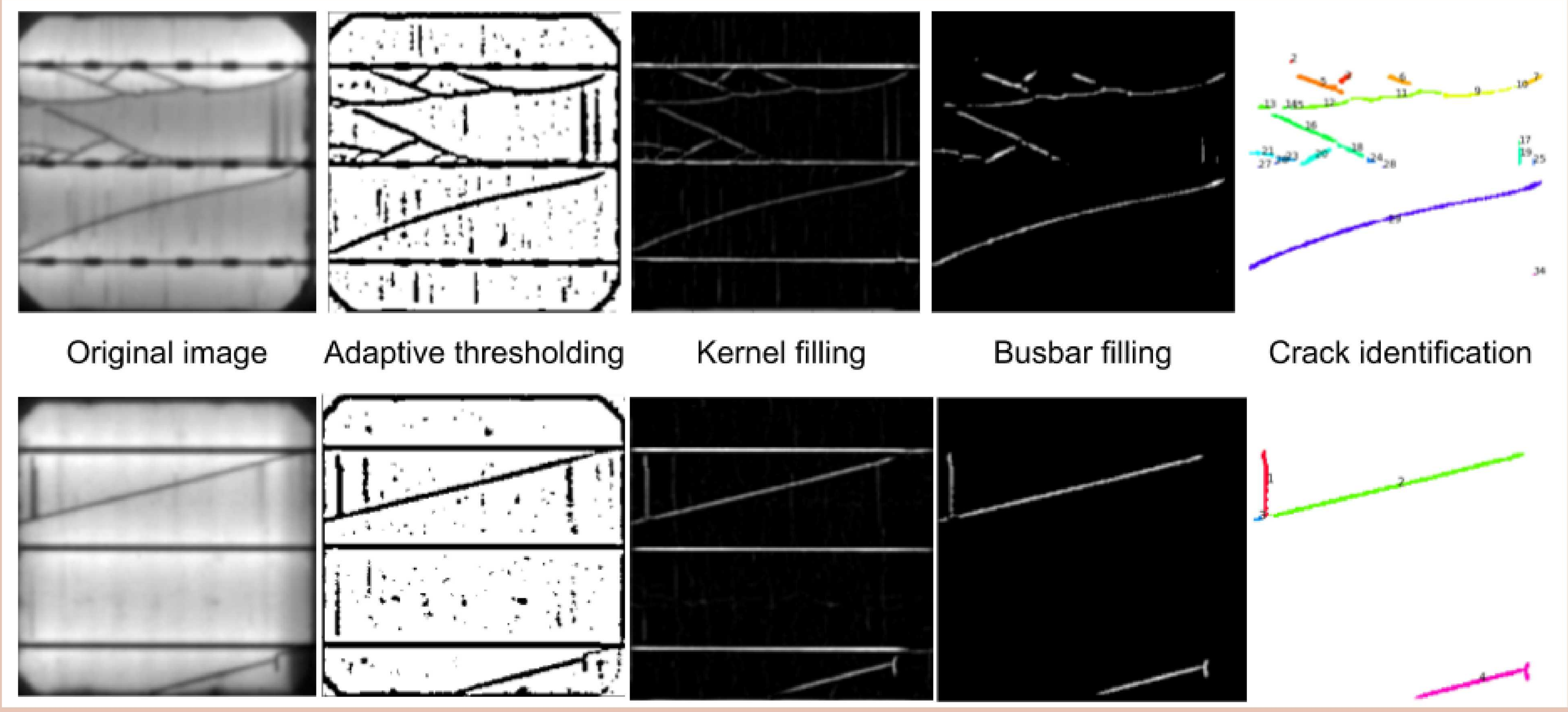



Different fracture geometries have different criticalities:[1]

- Cracks leading to electrical isolation have a larger influence on power output
- Electrical isolation depends on crack orientation, intercepts, and whether the crack affects the cell metalization[2]
- Cracking creates a defective silicon surface, increasing local recombination[3]
- Shunts can occur as a result of debris formation and collection inside cell cracks[4]

Quantifying cell fractures is a first step toward statistical understanding of the occurrence of these degradation modes.

## Crack Segmentation & Feature Quantification



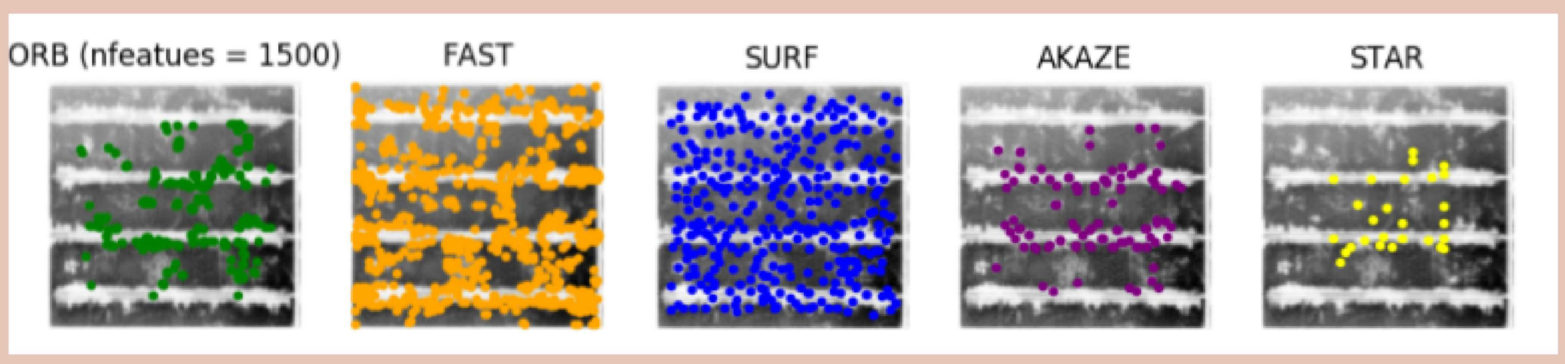

Thresholding and kernel operations enable image segmentation of cell fractures. Fourier transform image filtering is used to distinguish cracks from grain boundaries in multi-crystalline cells.[8] Linear fits of fracture segments yield features at right.

<u>Crack Features</u>
Type
Length
Angle
Location
Busbar Intercepts
Edge Intercepts
Crack Intercepts

<u>Cell/Module Features</u>
# Cracks
# Cracked Cells
Total Crack Length
% Dark/Isolated
Total Busbar Intercepts
Total Edge Intercepts
Total Crack Intercepts

### Image Segmentation by Local Feature Extraction

A number of automated local feature detection algorithms exist to locate occurrences of specific patterns in images. This approach is sometimes used with a bag of visual words approach for unsupervised clustering of images. Local feature detection can also be used to segment images by these features. Below are examples of local features detected by various algorithms. Combinations of local features related to cracks can be used for image segmentation, which is then analyzed with connected component types of analysis as above.




<u>Local Feature Detection Algorithms</u>
ORB (Oriented FAST Rotated BRIEF)
FAST (Features Accelerated Segment Test)
SURF (Speeded-Up Robust Features)
AKAZE (Accelerated KAZE)
STAR

## Applications of Fracture Quantification

<u>Correlation With Electrical Performance</u>

Statistical comparisons of fracture-related features with I-V and other electrical parameters will reveal criticalities of different crack geometries and combinations for module performance.

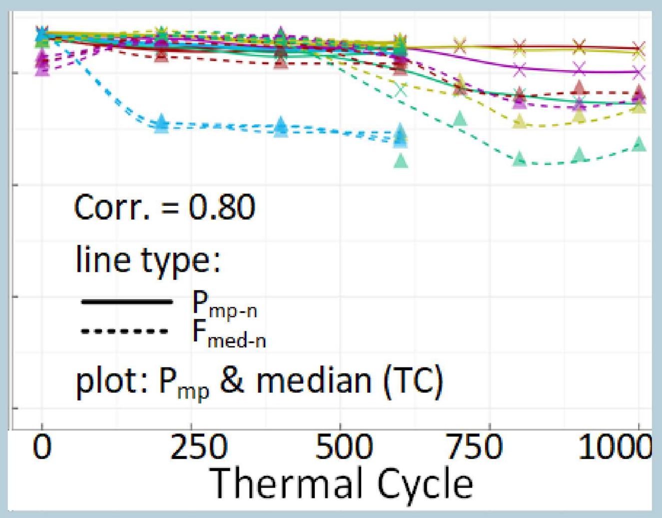
<u>Tracking Fractures Through Time</u>

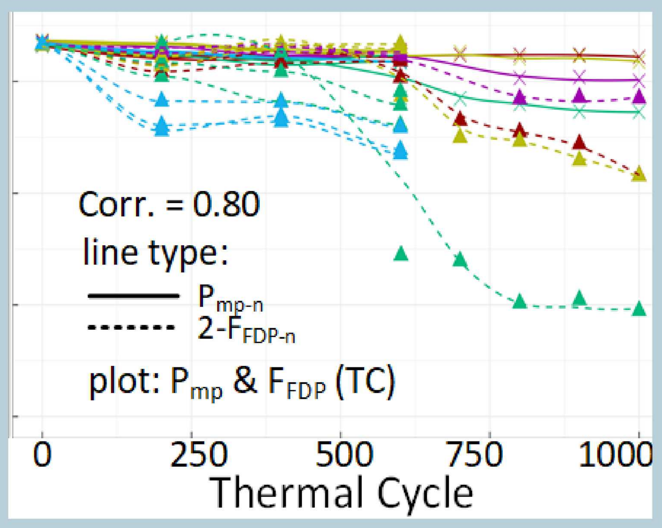
Features of individual cracks through accelerated exposure or time in the field will aid understanding of how cracks progress, and which types of cracks are likely to cause power loss. This will also reveal vulnerabilities of specific cell and module architectures and materials to fractures and related power loss.

<u>Fracture/Cell/Module Classification</u>

Machine learning classification[9] of fractures, cells, and modules by their measured features will build a framework for distinguishing critical and non-critical fractures. Together with time-series analysis, this will enable image detection of faulty and at-risk fielded modules.

Right: Intensity-based module-level image parameters, median intensity and fraction of dark pixels (FDP), with correlation to module maximum power and co-plotted through thermal cycling exposure.[10]



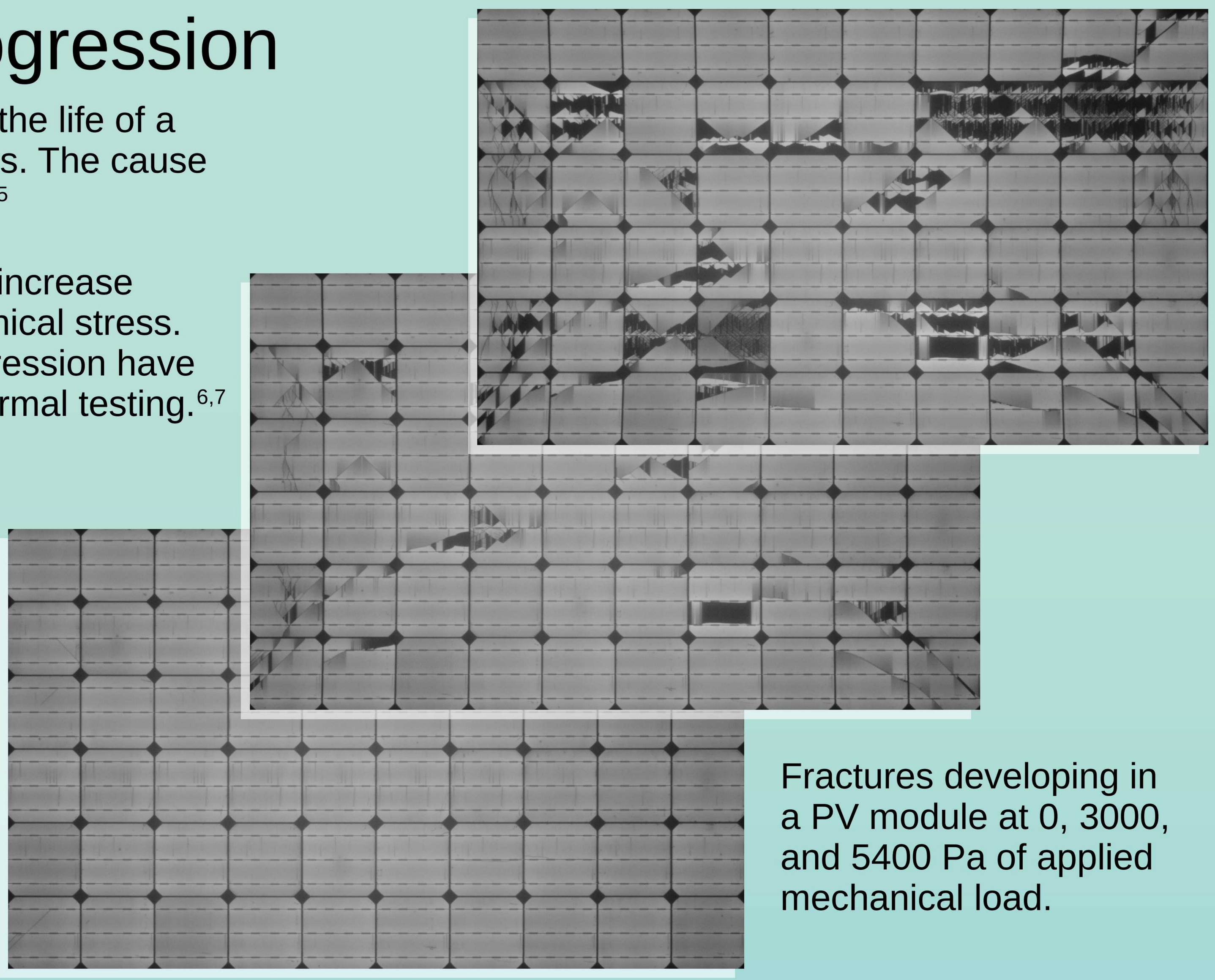

## Crack Formation and Progression

Cell fractures can be initiated at various points in the life of a PV module, by either thermal or mechanical stress. The cause of a fracture influences its geometry and severity.[5]

Fractures can also progress (lengthen, widen, or increase electrical impact) as a result of thermal or mechanical stress. In the laboratory, cell fracture formation and progression have been demonstrated with mechanical load and thermal testing.[6,7]

### Real-World Causes of Cell Fracture

| | Thermal | Mechanical |
|---|---|---|
| Initiation | Cell Firing<br>Soldering | Shipping<br>Installation<br>Extreme Weather |
| Progression | Extreme Temperatures<br>Temperature Cycling | Wind Loading<br>Snow Loading |



Fractures developing in a PV module at 0, 3000, and 5400 Pa of applied mechanical load.

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