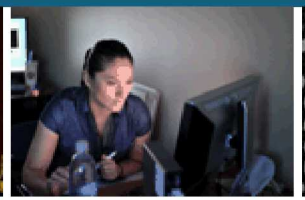
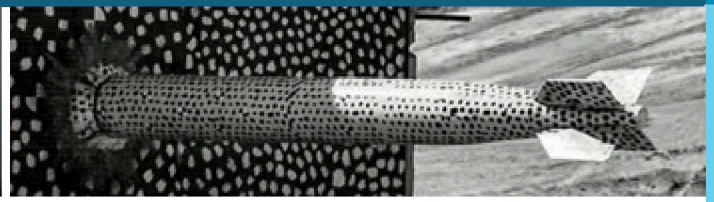
SAND2020-3339PE

Digital Image Correlation for PV

Optical Measurements of Displacement





Joshua Stein and Jennifer Braid

DuraMAT Meeting, March 16, 2020

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Digital Image Correlation (DIC) Projects

Sandia has three current projects using DIC on PV modules

1. DuraMAT SPARK: Highly instrumented modules for environmental characterization and simulation model validation
2. DuraMAT SPARK: Measurement of PV cell crack characteristics in PV modules using digital image correlation
3. DOE Project: Towards Commercialization of Low-Cost, Crack-Tolerant, Screen-Printable Metallization by Full-Size Module Testing and Field Characterization
    - Led by Osazda Energy

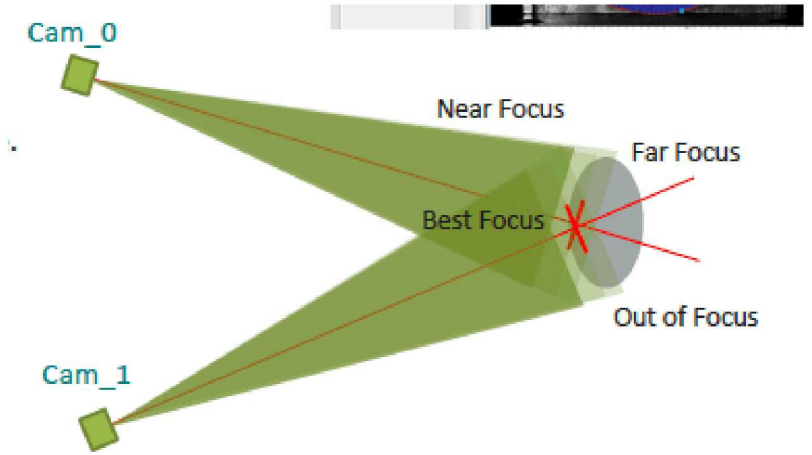
Digital Image Correlation Method and Application

DIC is a full-field image-based shape, deformation, and strain measurement technique.

- 2D (using sets of images from a single camera)
- 3D (Stereo DIC, using two cameras)

We are using DIC to measure:

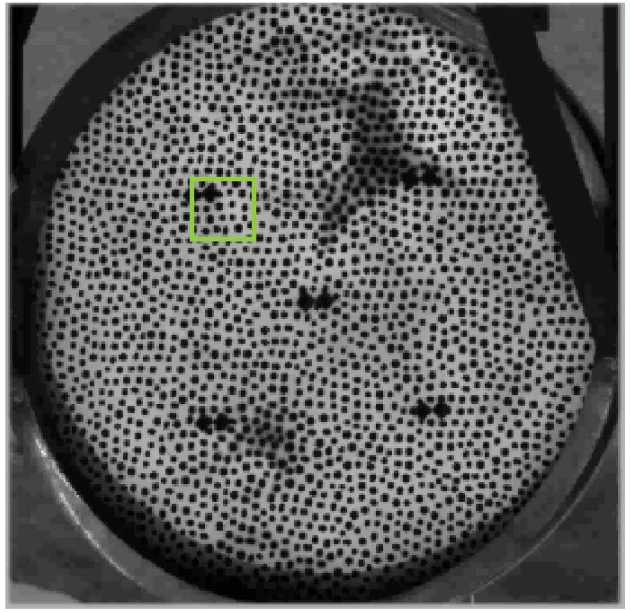
1. Module displacement/distortion under load
   - We will share some preliminary results of this application
2. PV cell crack widths inside the laminate



Steps of 2D DIC

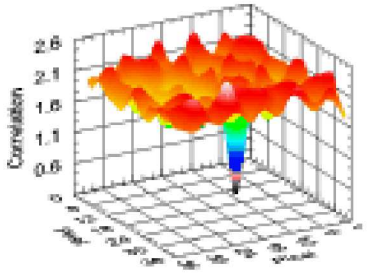
Subpixel accuracy makes DIC very powerful

- Area of interest in divided into subset areas
- Each subset has 3+ features



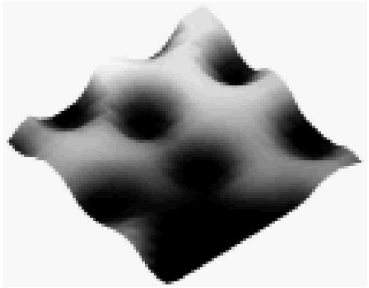
3 Hidden components of DIC‡

Matching



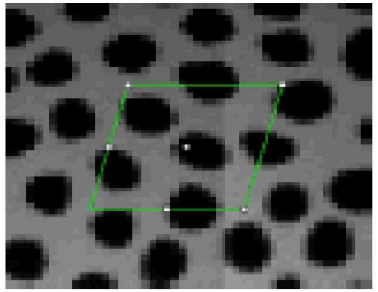
Matches subsets between images (e.g., Zero-normalized SSD)

Interpolation

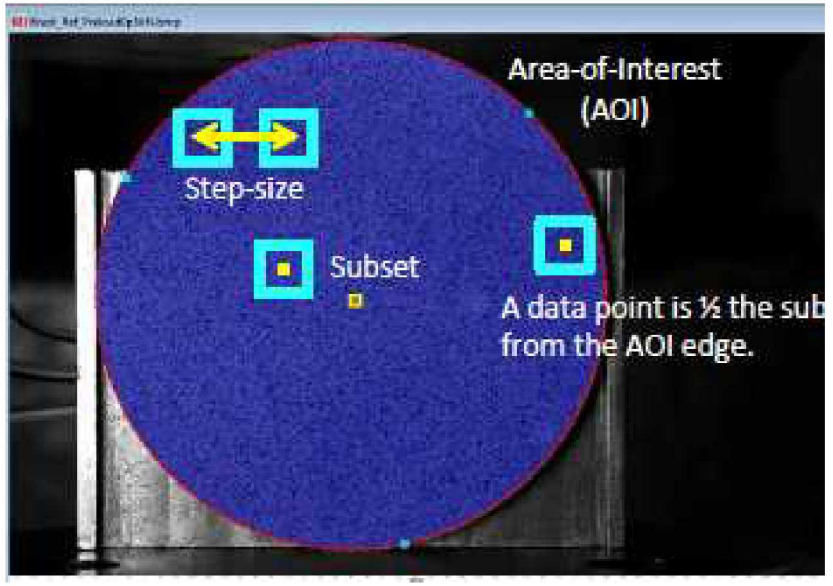


Interpolation allows subpixel matches (10x increase in resolution) (e.g., Optimized 8-tap)

Shape Function



Shape functions match subset displacement (e.g. quadratic)

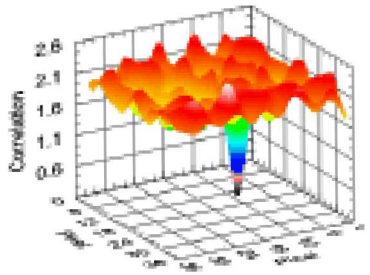


‡Phillip Reu – Experimental Techniques "Art and Application of DIC"

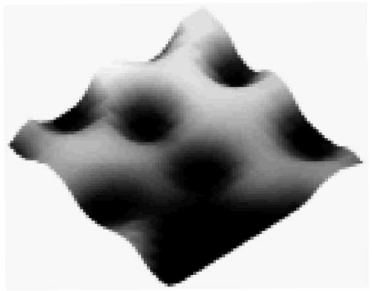
Steps of Stereo-DIC

3 Hidden components of DIC‡

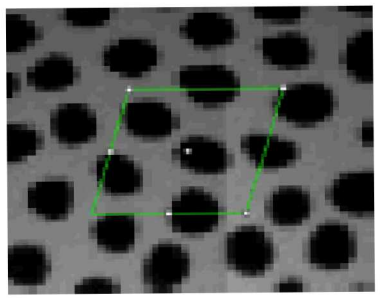
Matching



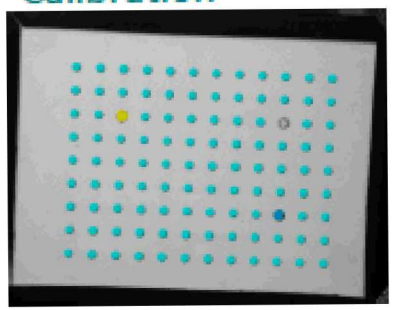
Interpolation



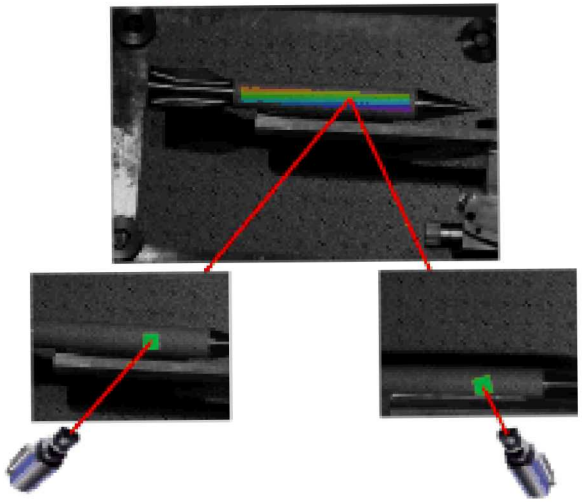
Shape Function



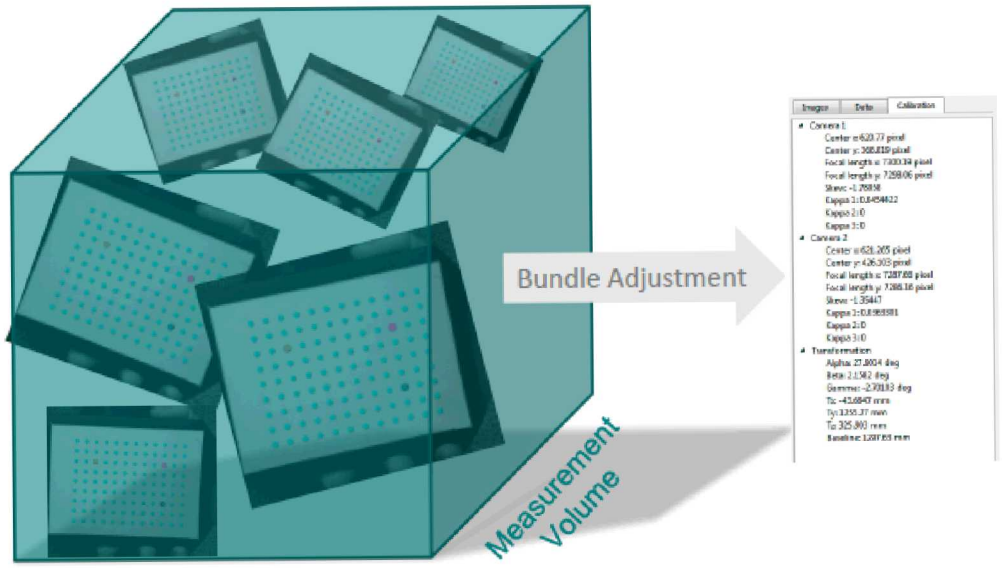
Calibration



Triangulation



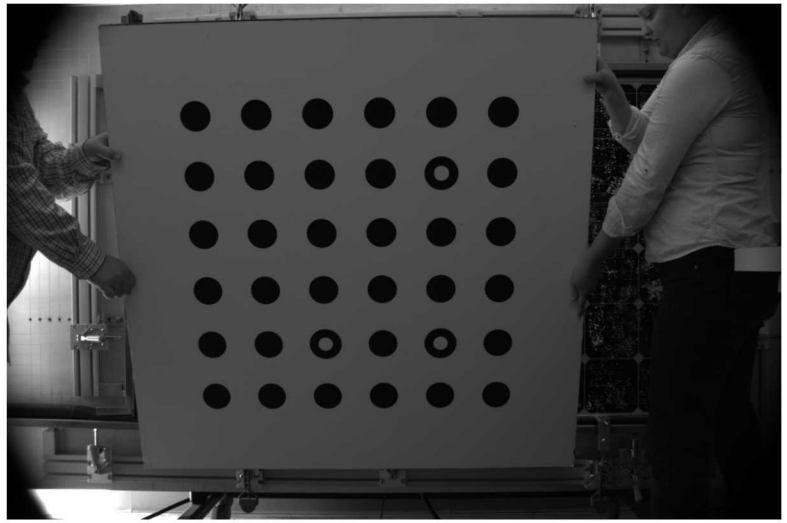
- Position
- Shape
- Displacement
- Strain
- Velocity

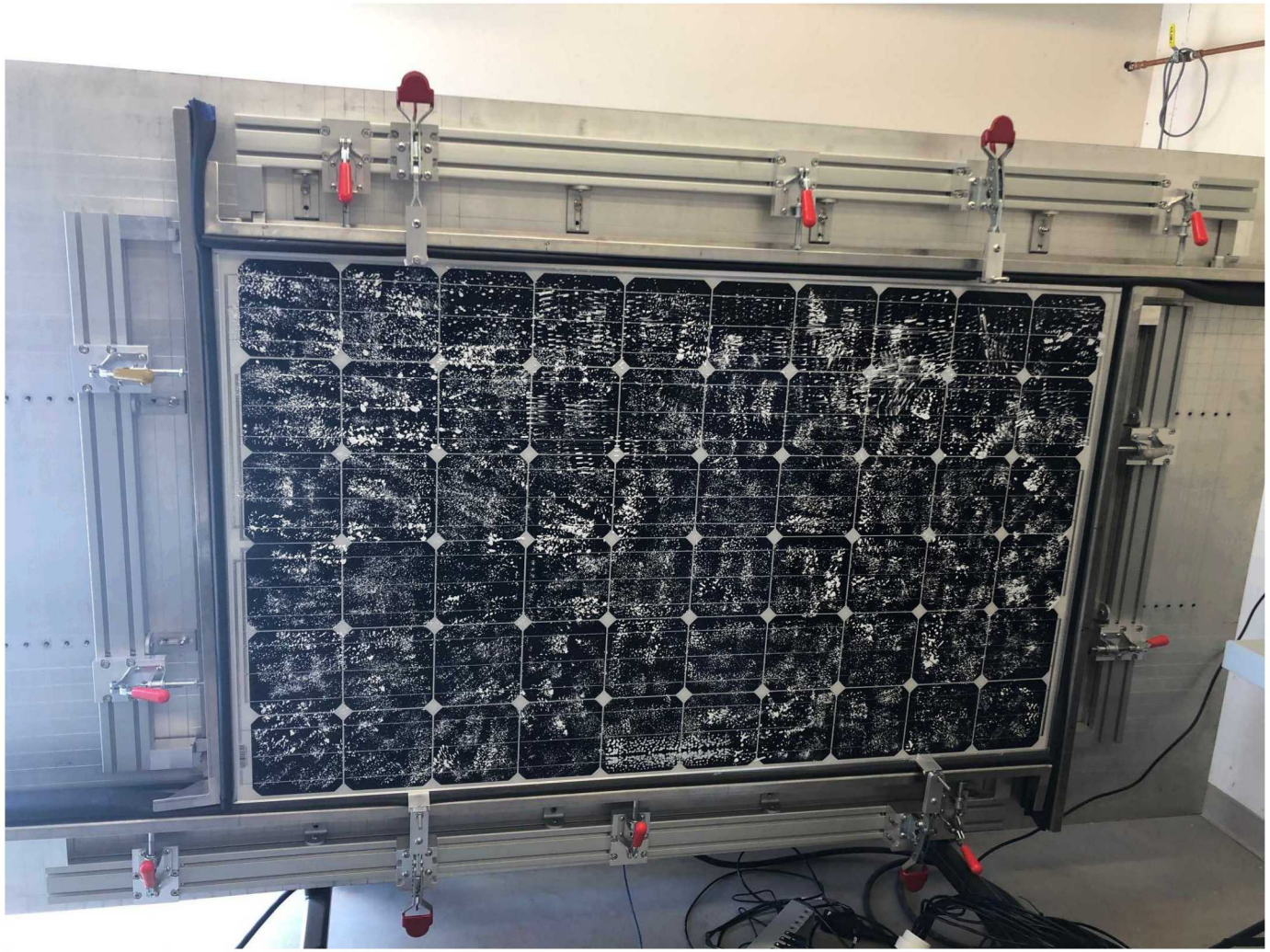


‡Phillip Reu – Experimental Techniques "Art and Application of DIC"

Full Field Deformation of PV Module Under Loading

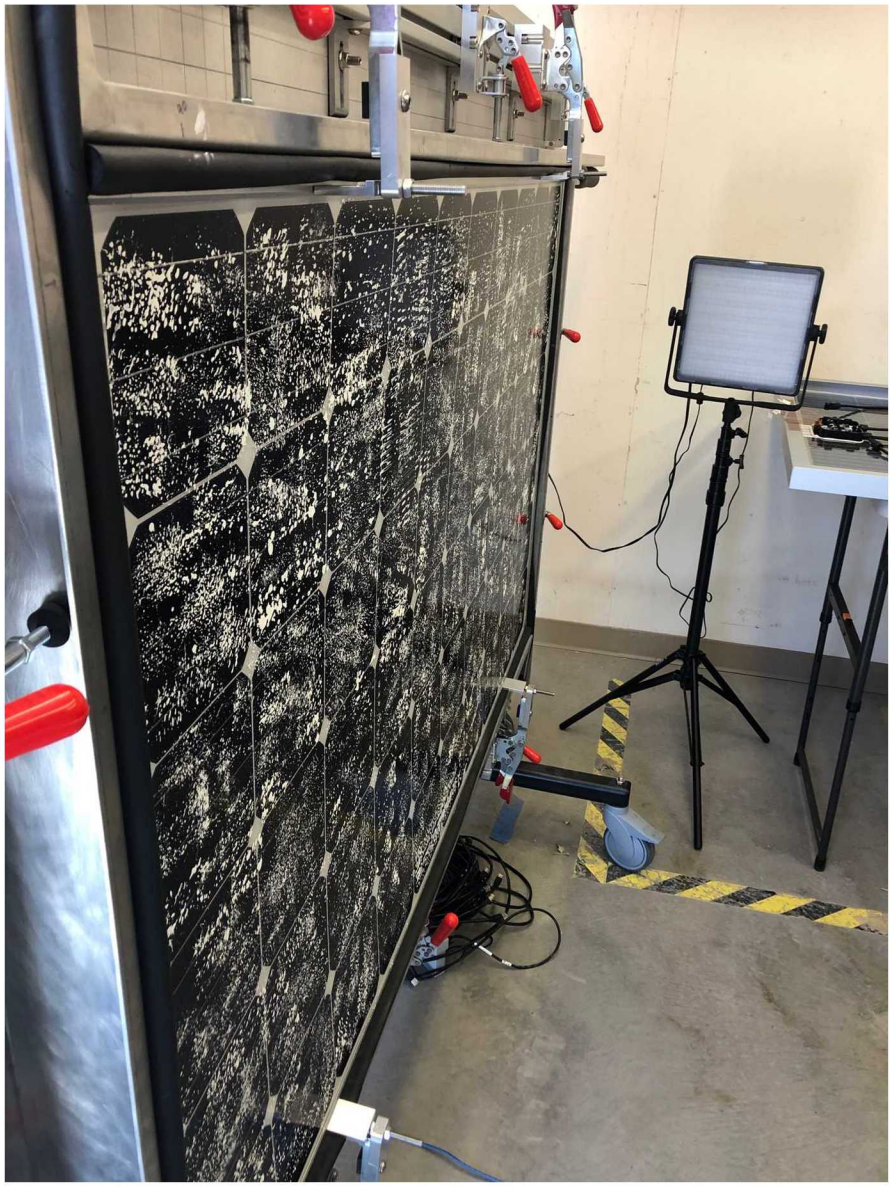
- Used a spare Suniva module for initial testing.
- Applied speckle pattern using white paint.
- Calibrated the stereo DIC using a 6in calibration board (*a bit too large for our camera resolution*).



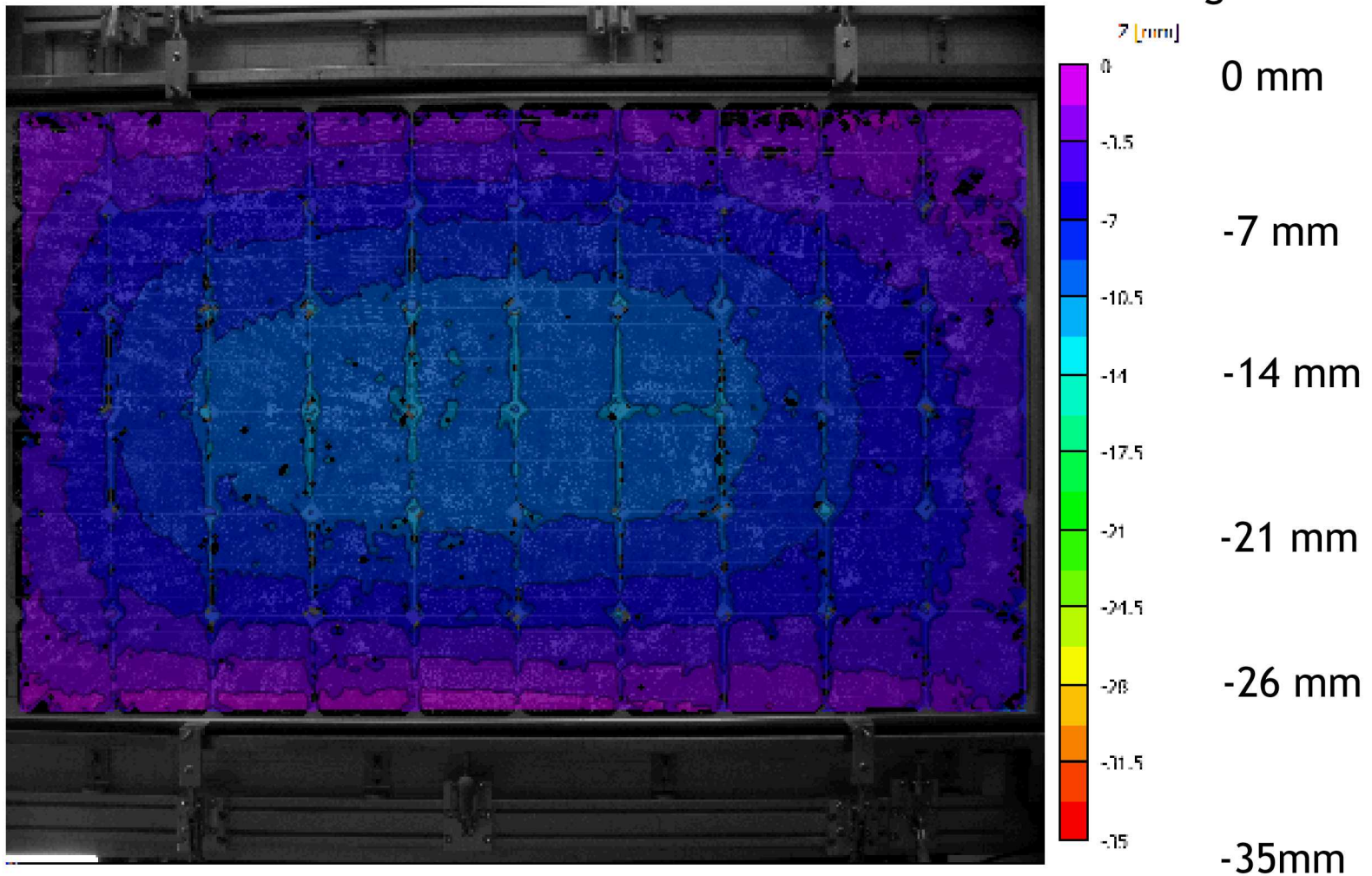


Applying the Load using the LoadSpot

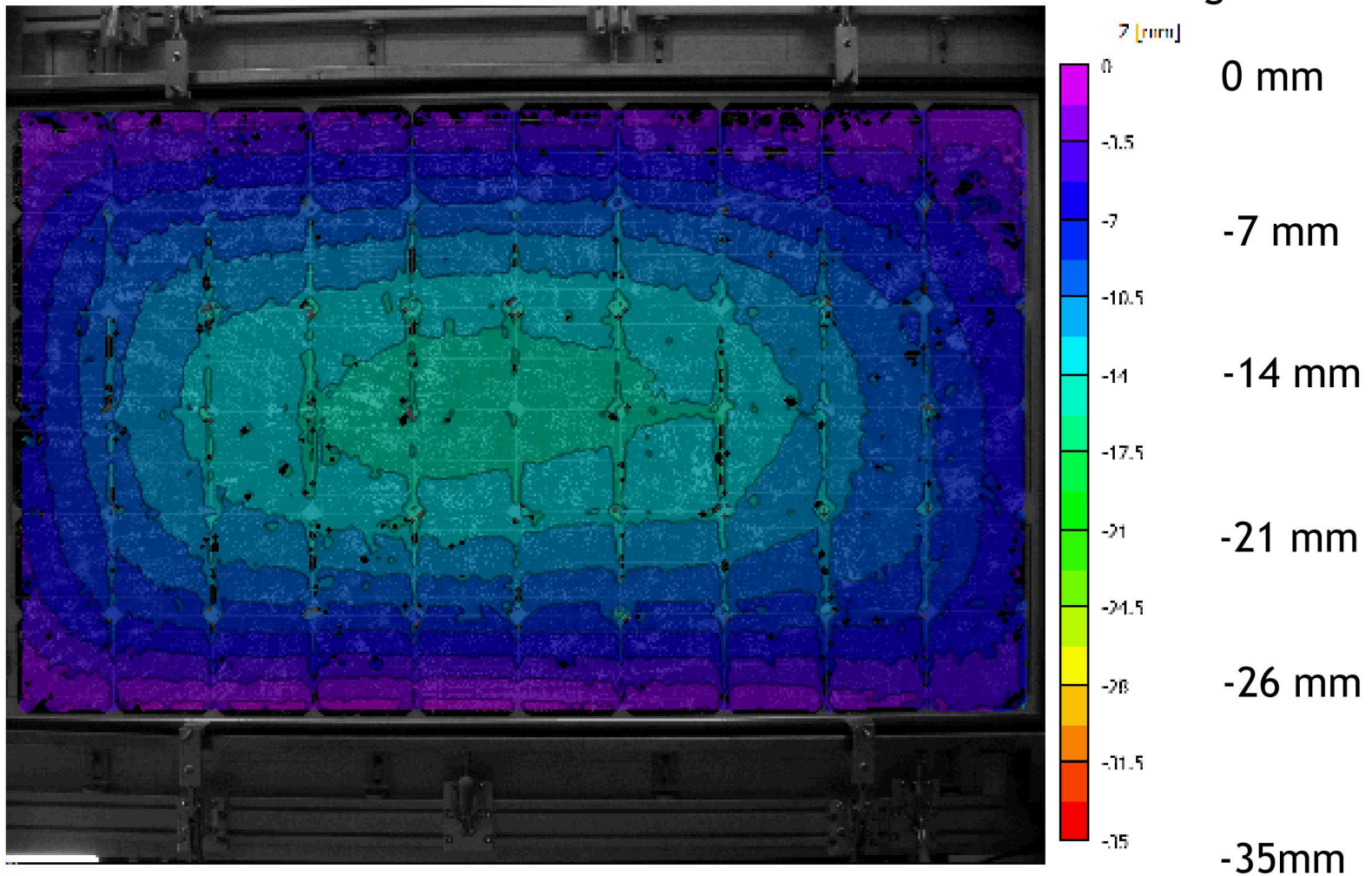
- Test applied 0 Pa to -4000 Pa to back of module in approximately -500 Pa increments.
- LoadSpot has optical displacement sensors but we did not hook them up for this initial test.
- We averaged 10 images at each pressure increment.
- We processed the images using Vic3D software to calculate displacement in Z (into and out of the plane of the module.
- The next slides show the results of the test.
- We believe this may be the first example of using DIC to measure full module displacement under loading.



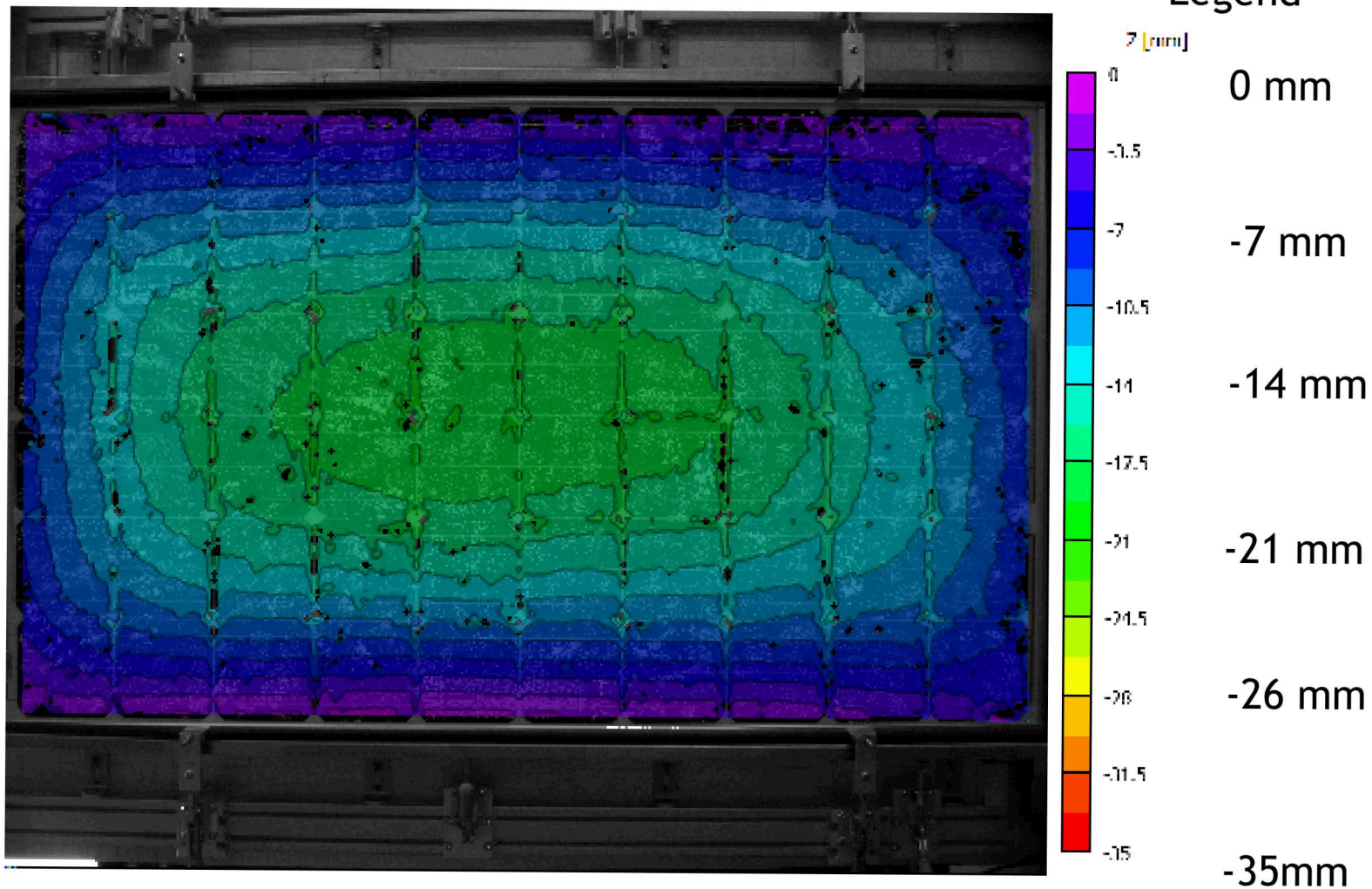
-600 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

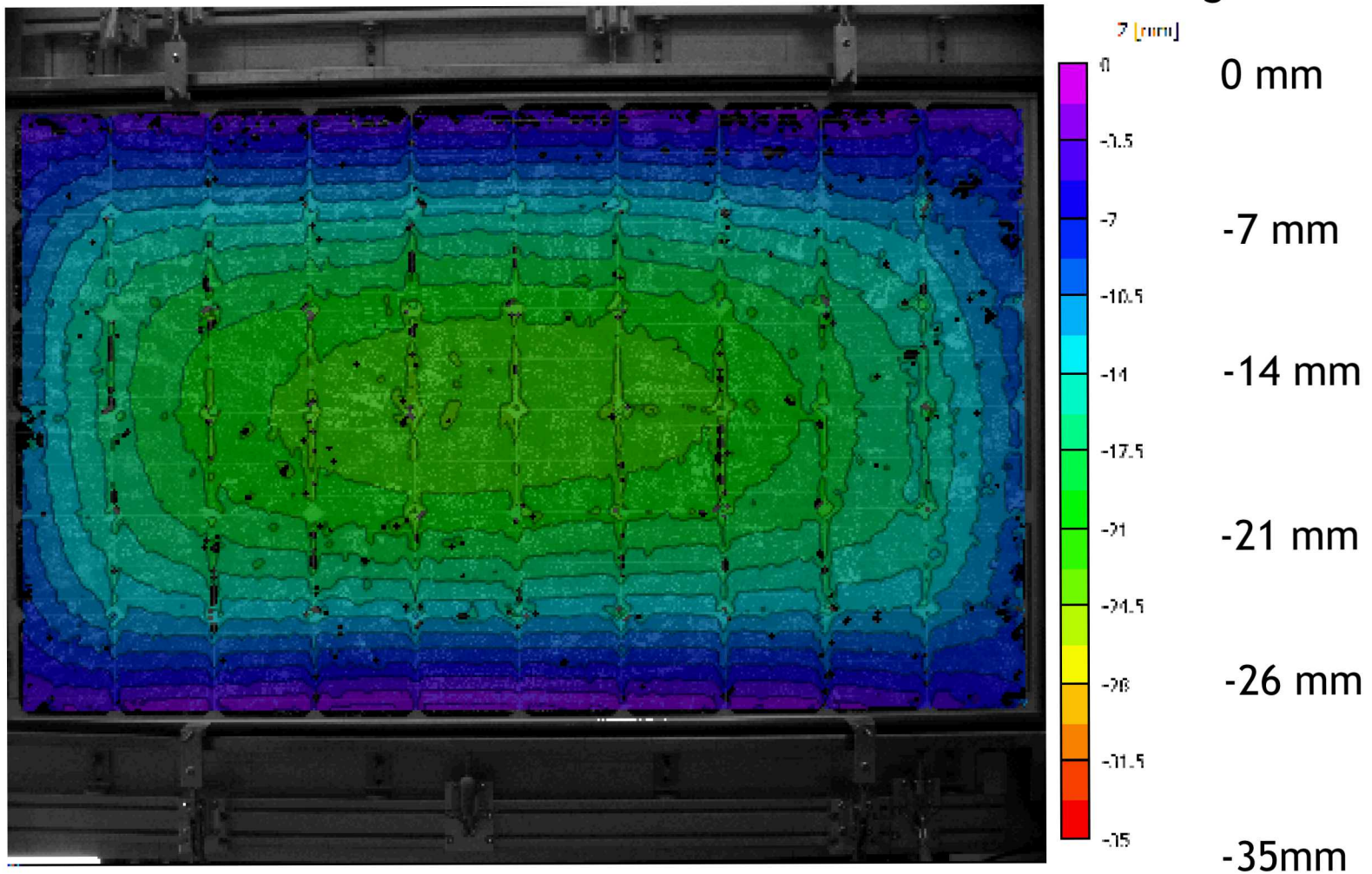
-1000 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

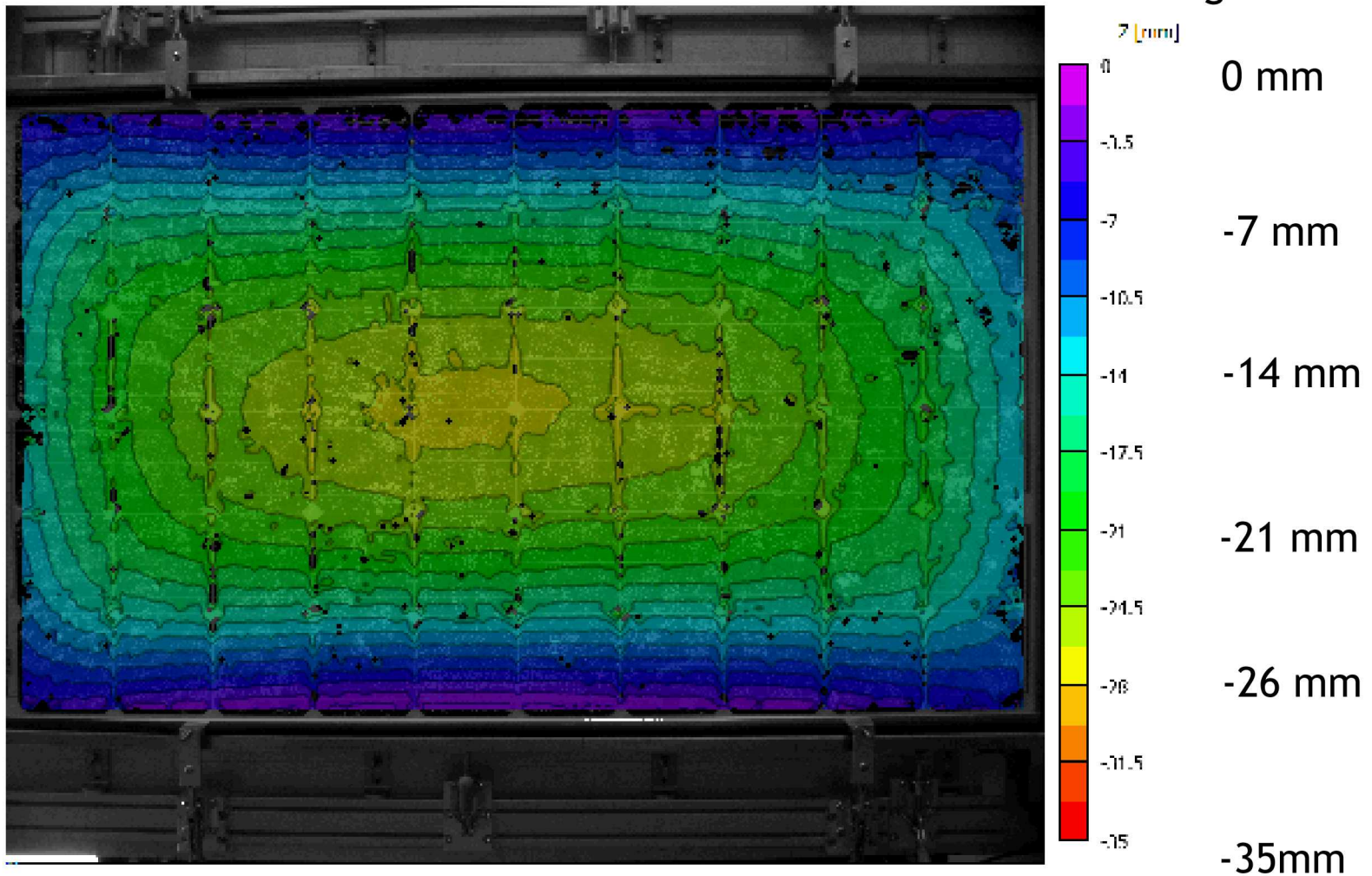
-1500 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

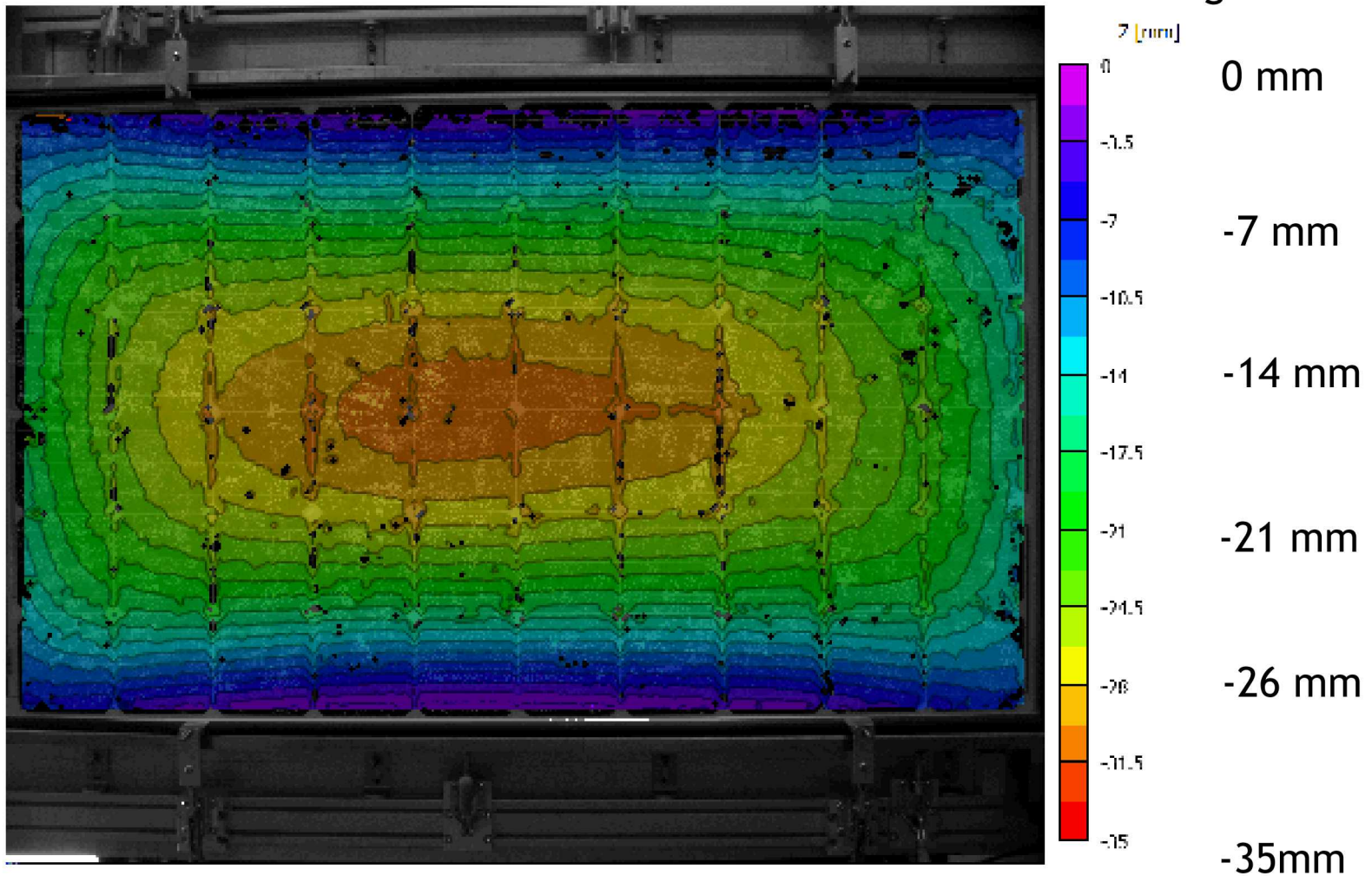
-2000 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

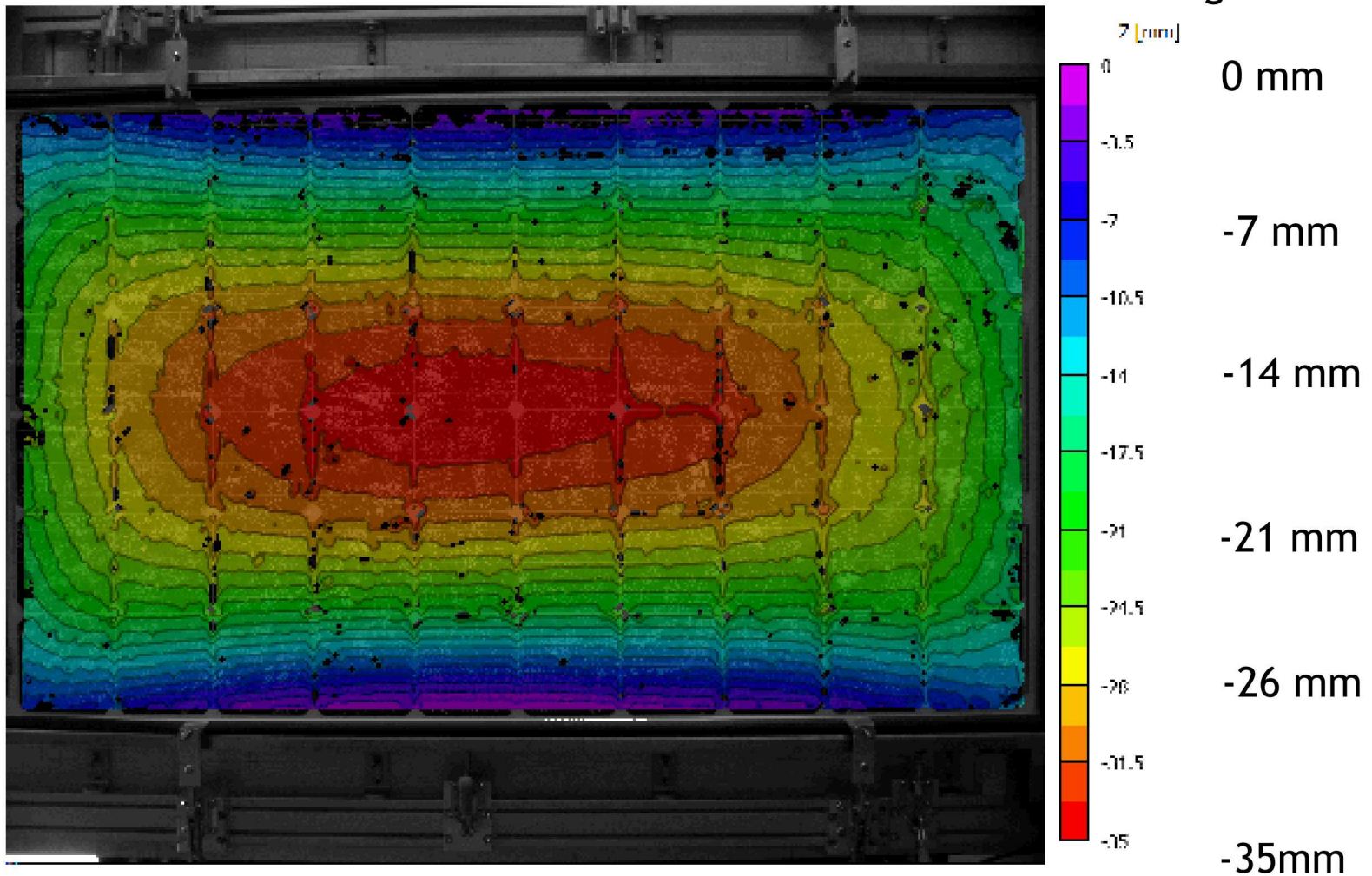
-2500 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

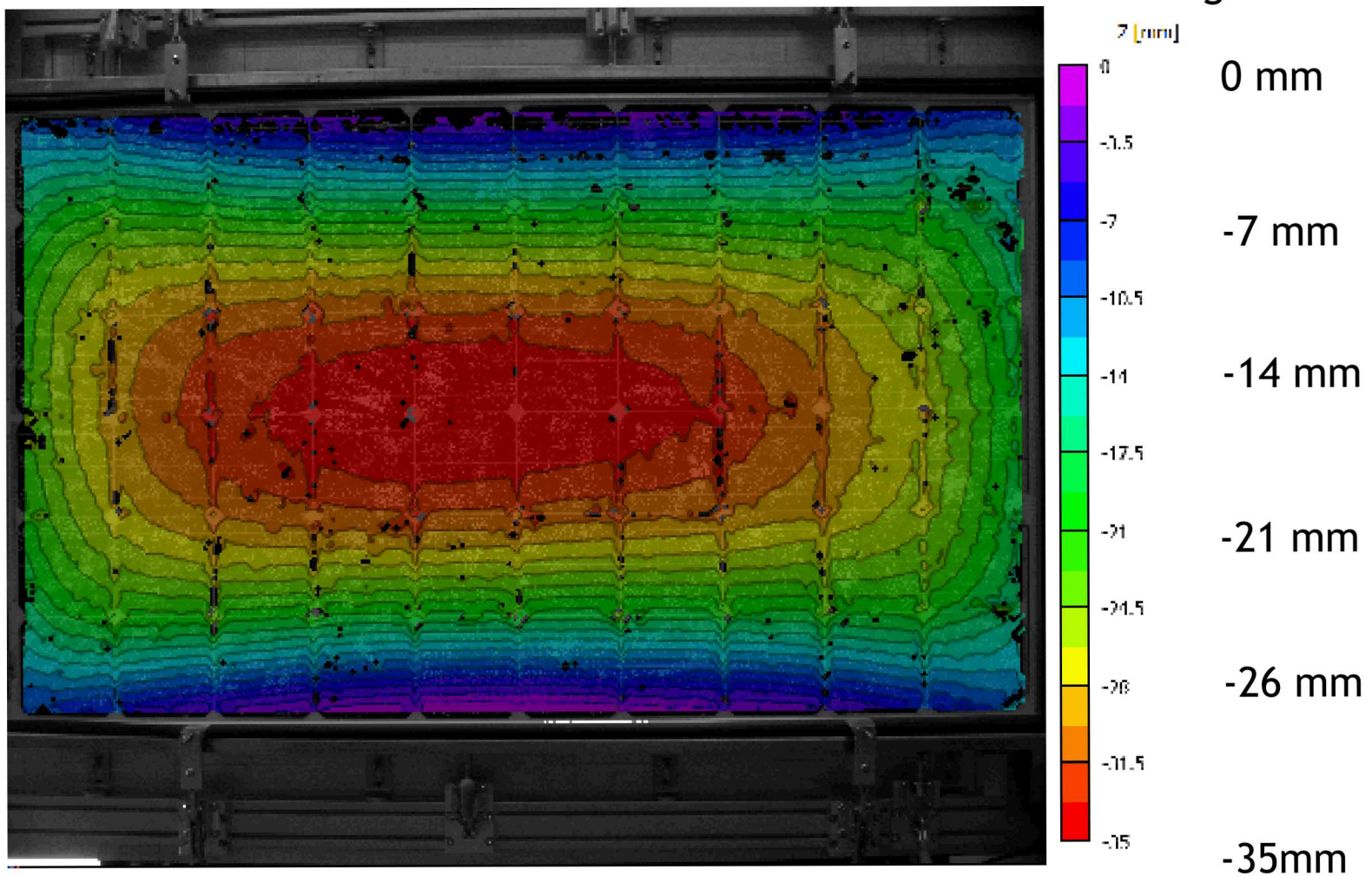
-3000 Pa


Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

-3500 Pa

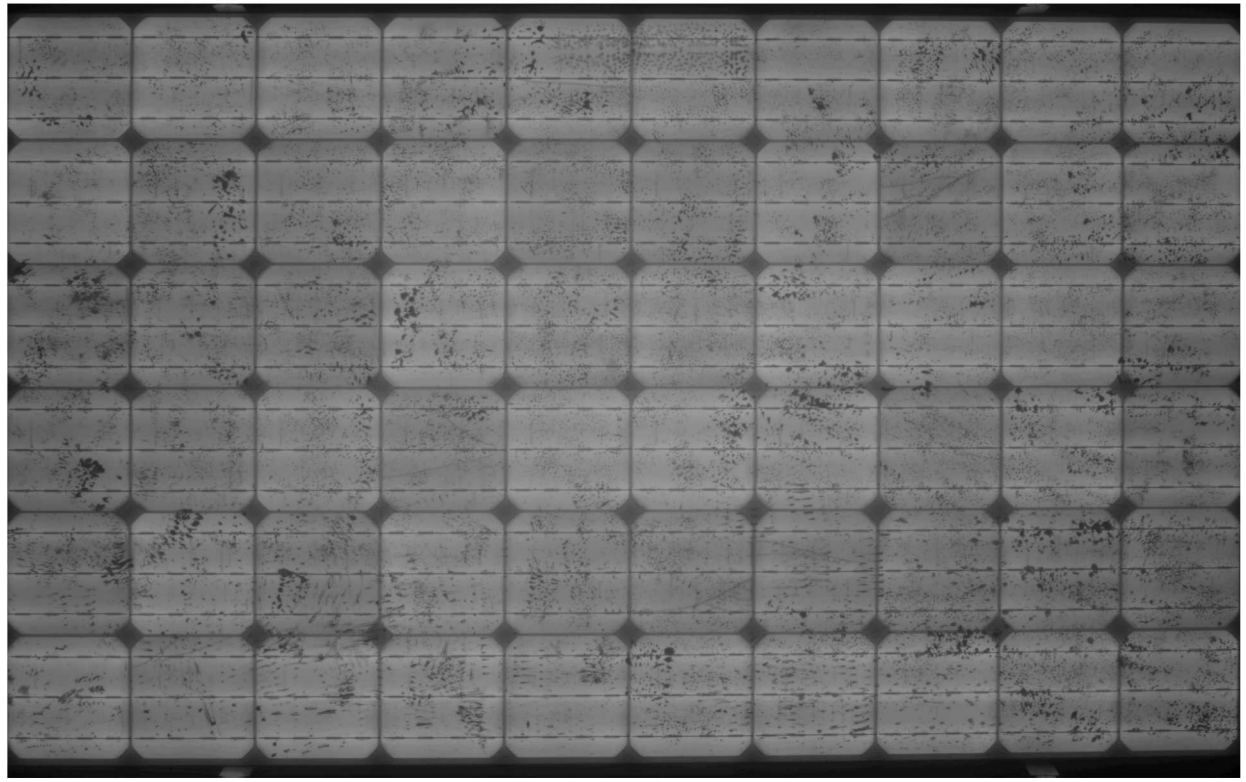

Legend
Z [mm]
0
-3.5
-7
-10.5
-14
-17.5
-21
-24.5
-28
-31.5
-35
0 mm
-7 mm
-14 mm
-21 mm
-26 mm
-35mm

-4000 Pa

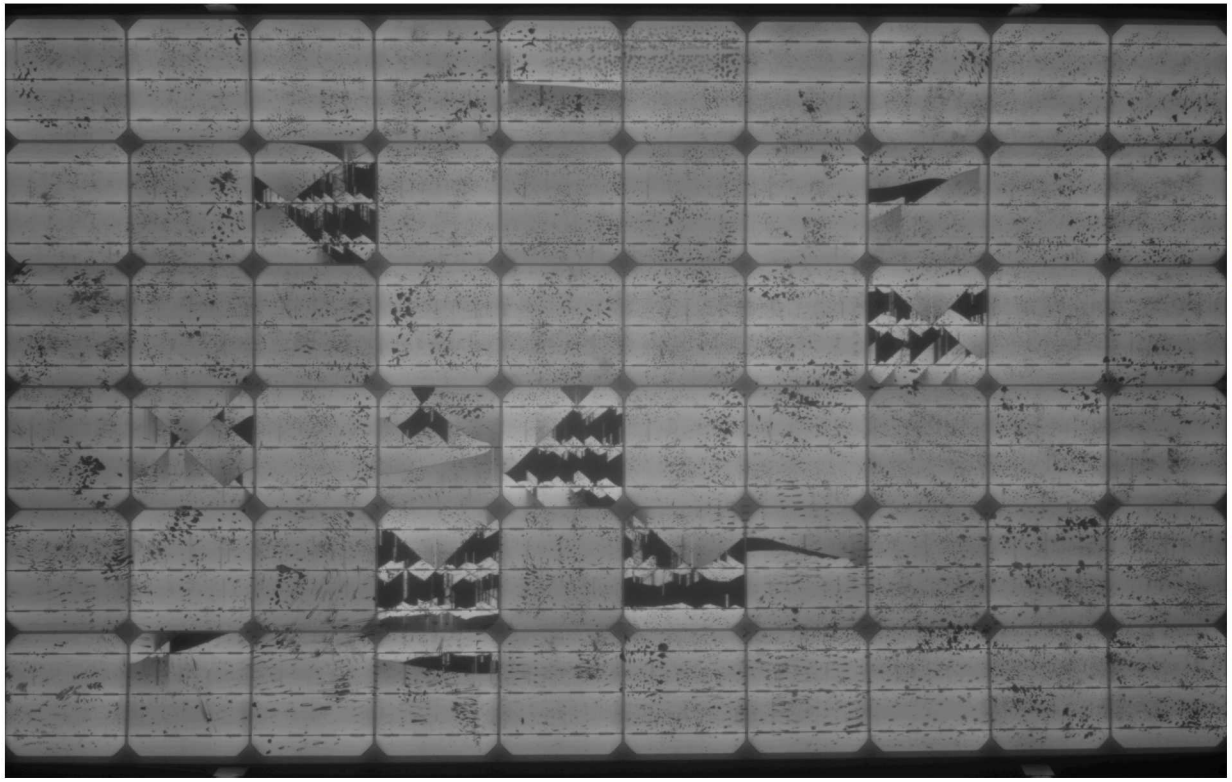


EL performed after initial loading DIC shows cell cracking

No cracks visible



-5400 Pa load



Speckle patter is visible in EL images but does not interfere with crack detection

Phase 2: Measuring PV Cell Crack Widths using DIC

- We plan to screen print the speckle patterns directly onto the PV cells
- Use those cells to build encapsulated test modules
- Run test modules on LoadSpot to induce cell cracks and measure X and Y displacements using Stereo DIC.
- Expected resolution in X and Y directions with 5 megapixel cameras:
  - 2-6 μm for full module area
  - <1-2 μm for single cell areas with optimized speckle pattern
  - Ultimate resolution may be affected by distortions caused by looking through glass.