

X-ray Diffraction Imaging for Crystalline PV Modules

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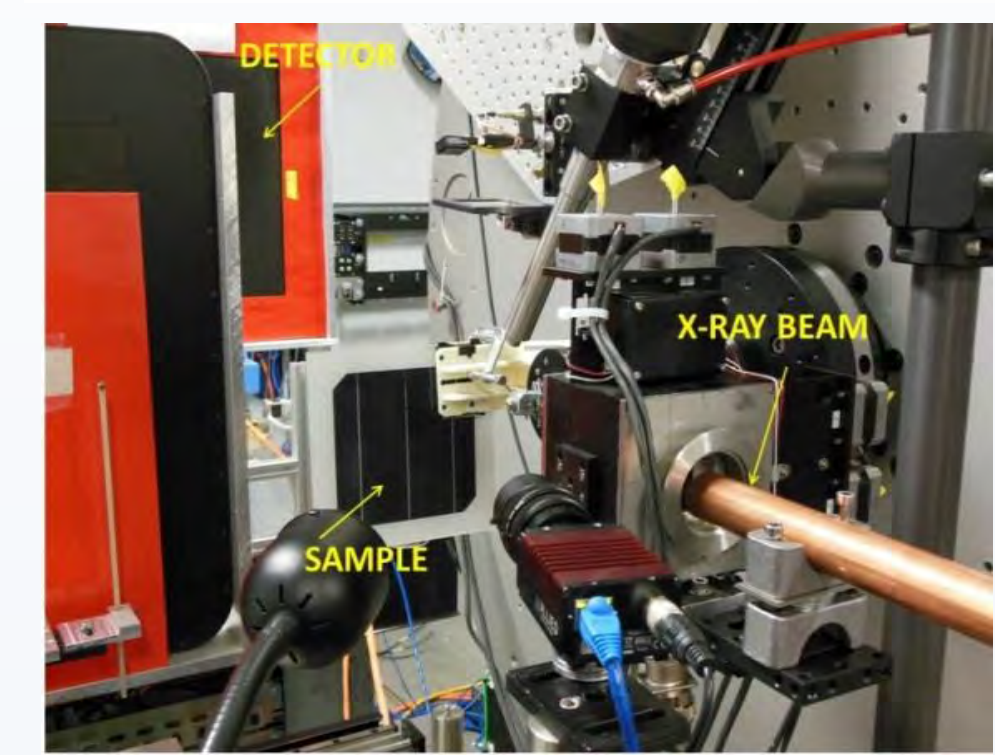
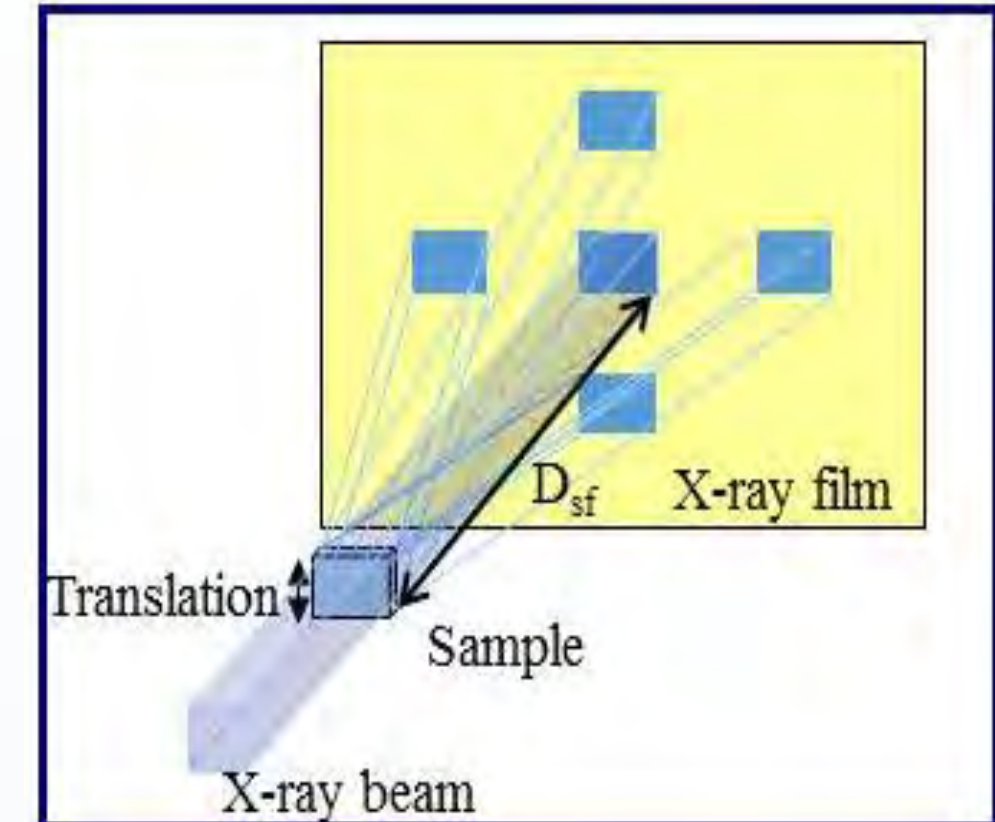
X-ray diffraction imaging or topography provides a fast non-destructive method to measure strain/stress inside a module and visualize material imperfections, cracks and micro-cracks. X-ray topography is a low background method which allows very fast data acquisition and detects very small angle deviations of the lattice planes up to the 1-5 mrad range.

There are two main options to perform X-ray diffraction imaging:

White light (or pink beam) X-ray diffraction imaging: It uses a wide bandwidth source of X-rays, where X-rays of all wavelengths are diffracted by the crystal at the same time and the crystal reflection is selecting the "right" wavelength automatically. Experimentally, it is a very simple technique.

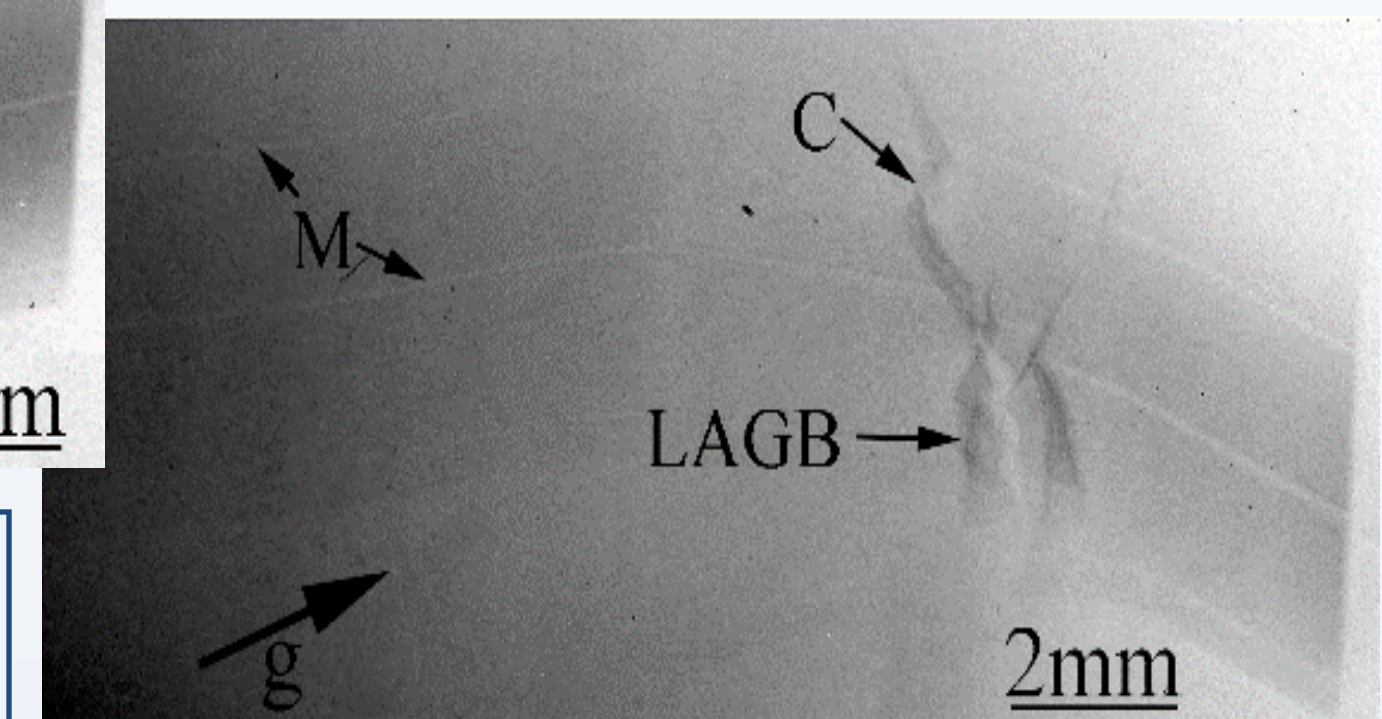
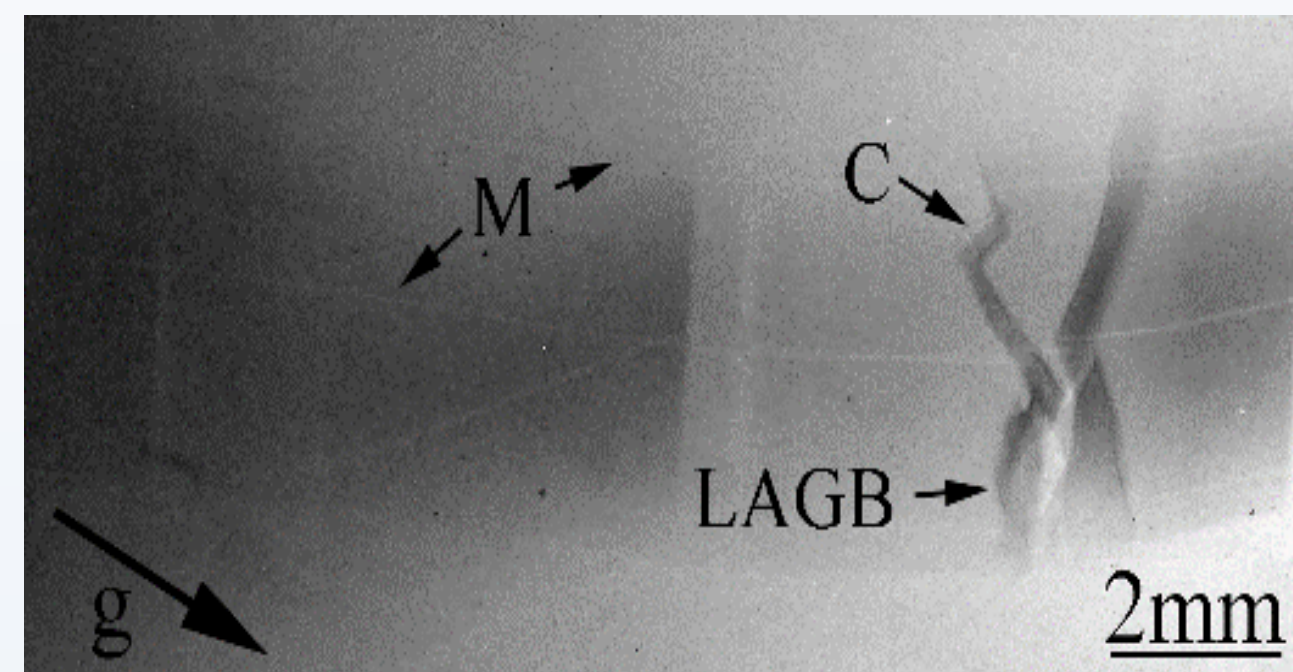
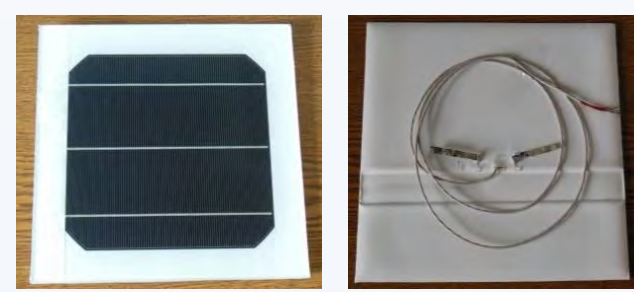
Monochromatic X-ray diffraction imaging: The crystal will only diffract if the monochromatic wavelength is tuned to the Bragg condition. As a result, typically only one non-degenerated reflection per given crystal orientation and X-ray wavelength will reflect. Experimentally more challenging, this method will produce significantly less background, it is easier to analyze, and has in general a much higher effective spatial and angle resolution. By measuring the bandwidth in which the crystal reflects, also called rocking curve, the strain/stress can be directly measured. This technique will be typically applied at synchrotrons with a bright source. However, it can also be applied using the characteristic line of a X-ray tube in combination with crystal optics which produces collimated light.

The BNL team has developed both experiments to evaluate the best solution and can provide alternatives if a given beamline is temporarily down. We are also evaluating options to create laboratory-based and in-line production systems.

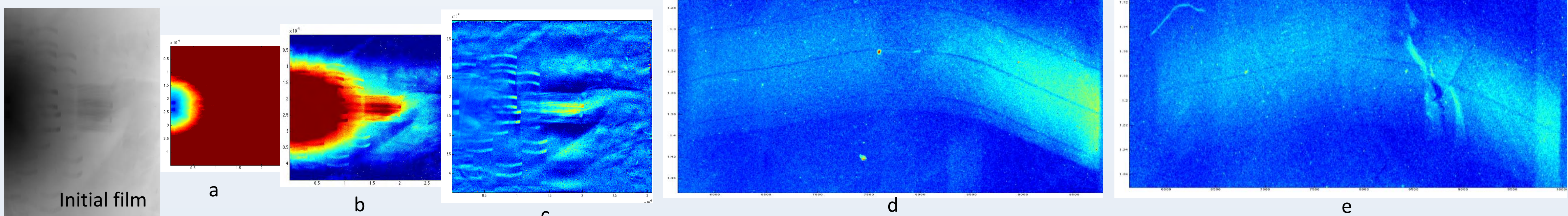


EXPERIMENTAL WORK

We have proved the use of X-ray topography on a commercial single cell mini-module (reference cell). White beam X-ray topography in transmission geometry has been taken with distance sample-to-film ~ 20 cm. The beam size for this experiment was 25mm x 5mm.

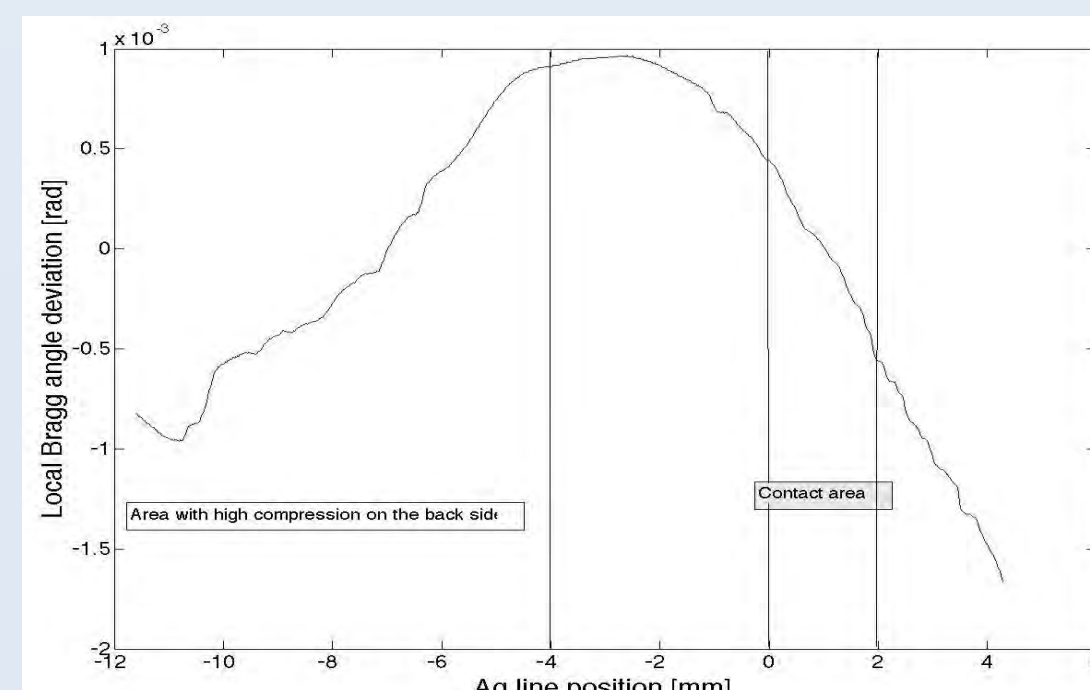
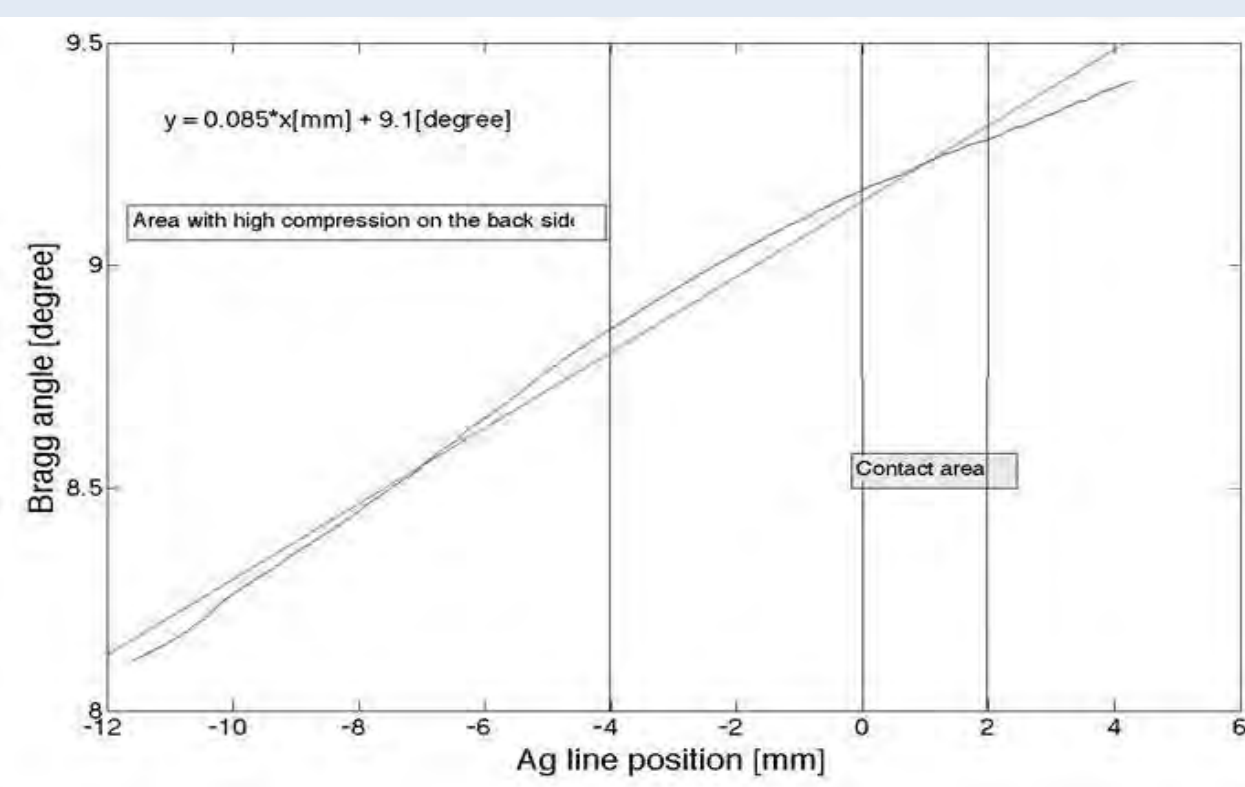


Pictures on the right: Single exposure transmission X-ray topographs (left) $g=(7,-1,1)$, g being the diffraction vector; (right) $g=(7,1,1)$ (using 8mm Al filter). Crack (C) nucleated from low angle grain boundary (LAGB). The crack directions are along the traces of the $\{110\}$ cleavage planes. Bending of metallization lines (M) points to stresses in the silicon. The bending varies depending on diffraction vector indicating inhomogeneous stresses.



Above: On the left the initial film taken at the beamline.
a) First processing stage of our topograph film. Raw data.
b) Second step, after subtracting the average of several horizontal lines from the top and bottom of image a.
c) Removing the remaining background by linear fit a polynome of 11th degree for each column.

Above and right: Zoom-in sections from figure c, with details of the contact lines (d), micro-crack and the low angle grain boundary (e). The highly distorted image of the beam shows clearly the shadows of the three illuminated Ag-lines and the vertical shadow line representing the busbar. The enlarged section (f) shows an area of 4.5mm x 3.5mm. The individual pixel represents a $4 \times 4 \mu\text{m}^2$ area on the film. The crack appears to be localized under the busbar.



Left: Using the position of the middle contact line from figure d above, the Bragg angle for each pixel in the line was calculated and plotted versus the beam width. The result shows a strong bend of the wafer in direction of the scattering vector which can be approximated with a linear function. This linear function represents a cylindrical bend. Note: "Contact area" identifies the location of the large busbar. "Area with high compression on the back side" identifies the compressed area on the back of the cell.

Proposed Setup at NSLS-II: 8-ID

AVAILABILITY

Near term use (1 year): Capability to scan a full commercial module at the ISS beamline at BNL-NSLS II, with high throughput data analysis capabilities.

Long term use (5 years): Providing high throughput services for research and industrial partners and developing FEA models for specific compound (module structures).

Development of in-line tools in collaboration with industry to support a better module quality at manufacturing level and improved reliability in time.

