Towards Current Mapping of Photovoltaic Devices by Compressed Imaging

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Outline

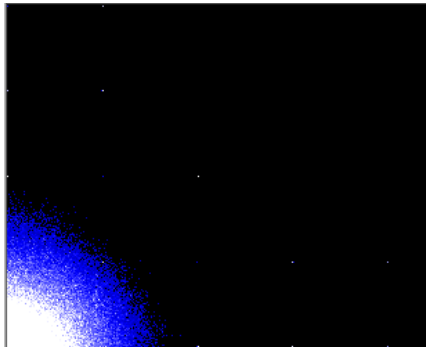
- Summary of compressed sensing theory
- Application on PV spatial characterization
- Prototype experimental setup
- Initial measurements

Compressed sensing theory motivation

- JPEG image compression
- Sample everything (initial picture)
- Discrete Cosine Transform or Wavelet Transform (JPEG2000) – sparse representation
- Compress to store as JPEG, using a small number of coefficients to save space
- Reconstruct using this small amount of coefficients

Sample

Applied PV group CREST



DCT coefficients

Reconstruction using only 2% largest DCT coefficients

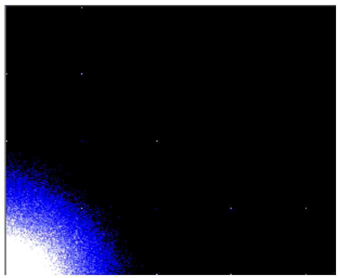
Compressed sensing theory motivation

- In signal compression a huge amount of information is thrown away anyway
- Why measure it in the first place?
- Sample only a compressed version of the signal
- Reconstruct the signal (image)

- Useful in applications where measurements have a high “cost” :
- Expensive detectors
- Limited time
- High sampling rate not possible

Sample

M DCT coefficients



N pixel image - 2% used

Compressed sensing theory: summary

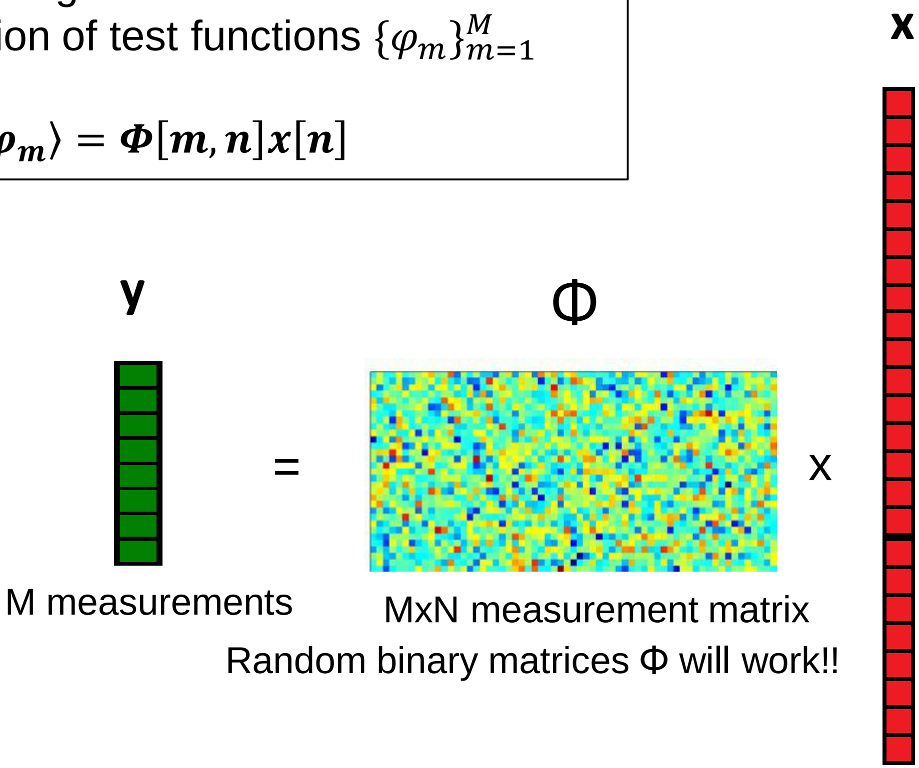
- A Signal x is K sparse in basis φ (i.e. DCT domain)

Step 1

- Acquire a “condensed” representation using M < N linear measurements between **x** and a collection of test functions $\{\varphi_m\}_{m=1}^{M}$
- In other words we measure $\boldsymbol{y}[\boldsymbol{m}] = \langle \boldsymbol{x}, \boldsymbol{\varphi_m} \rangle = \boldsymbol{\Phi}[\boldsymbol{m}, \boldsymbol{n}]\boldsymbol{x}[\boldsymbol{n}]$

Step 2

- Reconstruction: given **y=Φx**
  find **x**
- Infinite solutions
- convex optimisation problem
- ℓ1 minimisation is used to determine **x**
- $\hat{\boldsymbol{x}} = argmin\|\boldsymbol{x}\|_1$ subject to **y=Φx**
- Other norms are also used

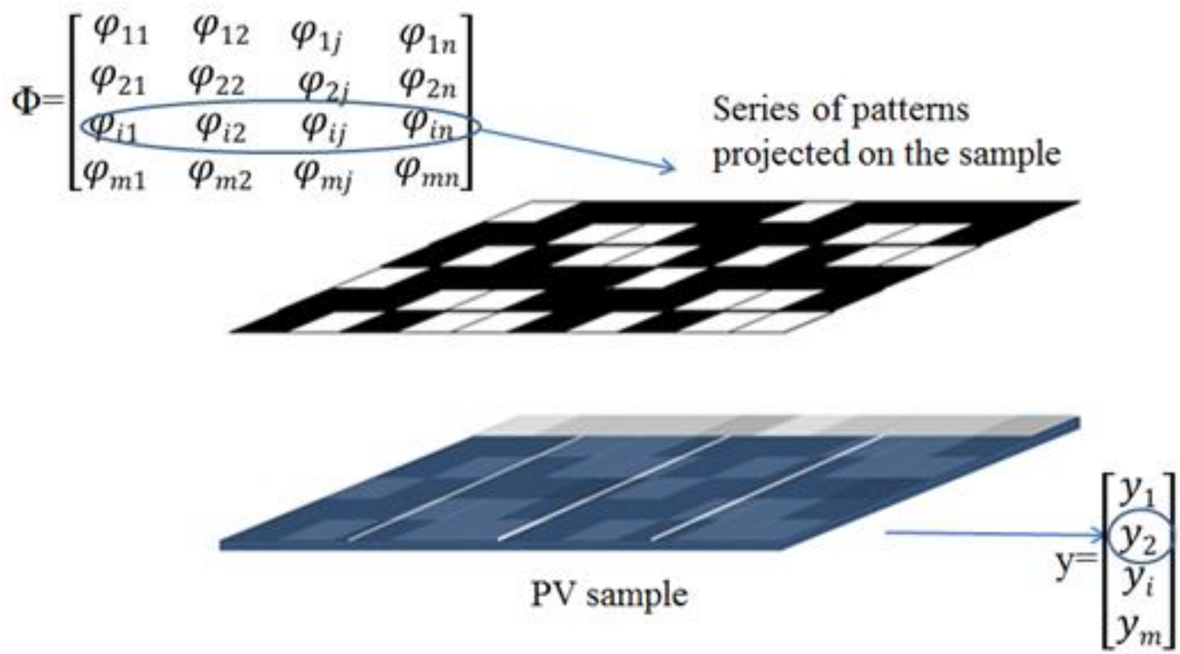


Random binary matrices Φ will work!!

Compressed sensing: Application on PV characterisation

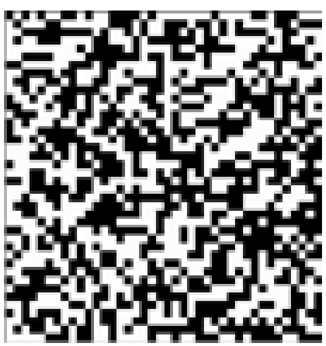
- For a pixel by pixel scan, Light Beam Induced Current (LBIC) measurements can last several hours for mapping the local current of a typical PV cell.
- We can reduce measurement time by making compressed measurements
- Illuminating the cell with a series of patterns which measure the necessary coefficients

- Reconstructing image using ℓ1norm (or any other algorithm that works)
- Fewer measurements are needed for producing a current map



Compressed sensing: Application on PV characterisation

- Every row of Φ is a binary random pattern that will be projected on the sample, measuring the current response.
- The patterns and the image are represented in a vector form
- m measurements to measure the K necessary coefficients for a successful reconstruction K<<m<<n=$\sqrt{N}\ x\sqrt{N}$



Random binary pattern

m measurements

$$y=\begin{bmatrix} y_1 \\ y_2 \\ y_i \\ y_m \end{bmatrix}$$

Reconstruction using ℓ1 minimisation

solution

$$\hat{x}=\begin{bmatrix} x_1 \\ x_2 \\ x_i \\ x_n \end{bmatrix}$$

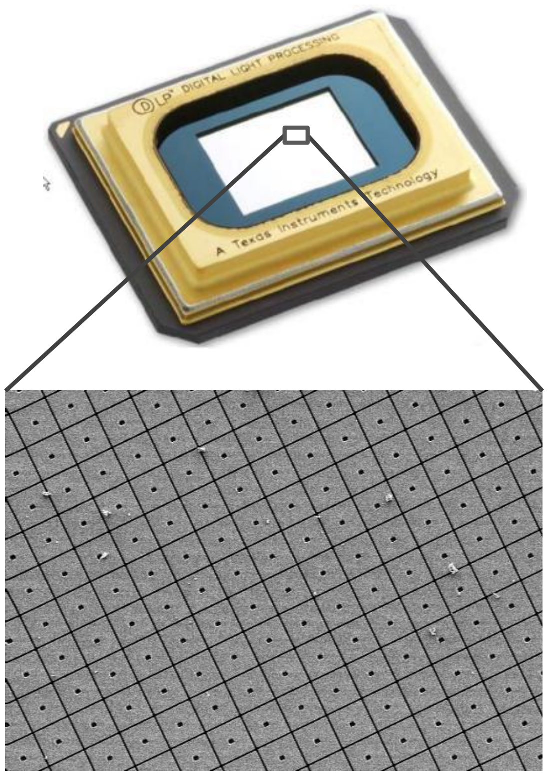
$$\mathbf{y} = \Phi\mathbf{x}$$

Measurement vector

Sensing Matrix

Unknown

Digital Micromirror Device – DMD Pattern generator

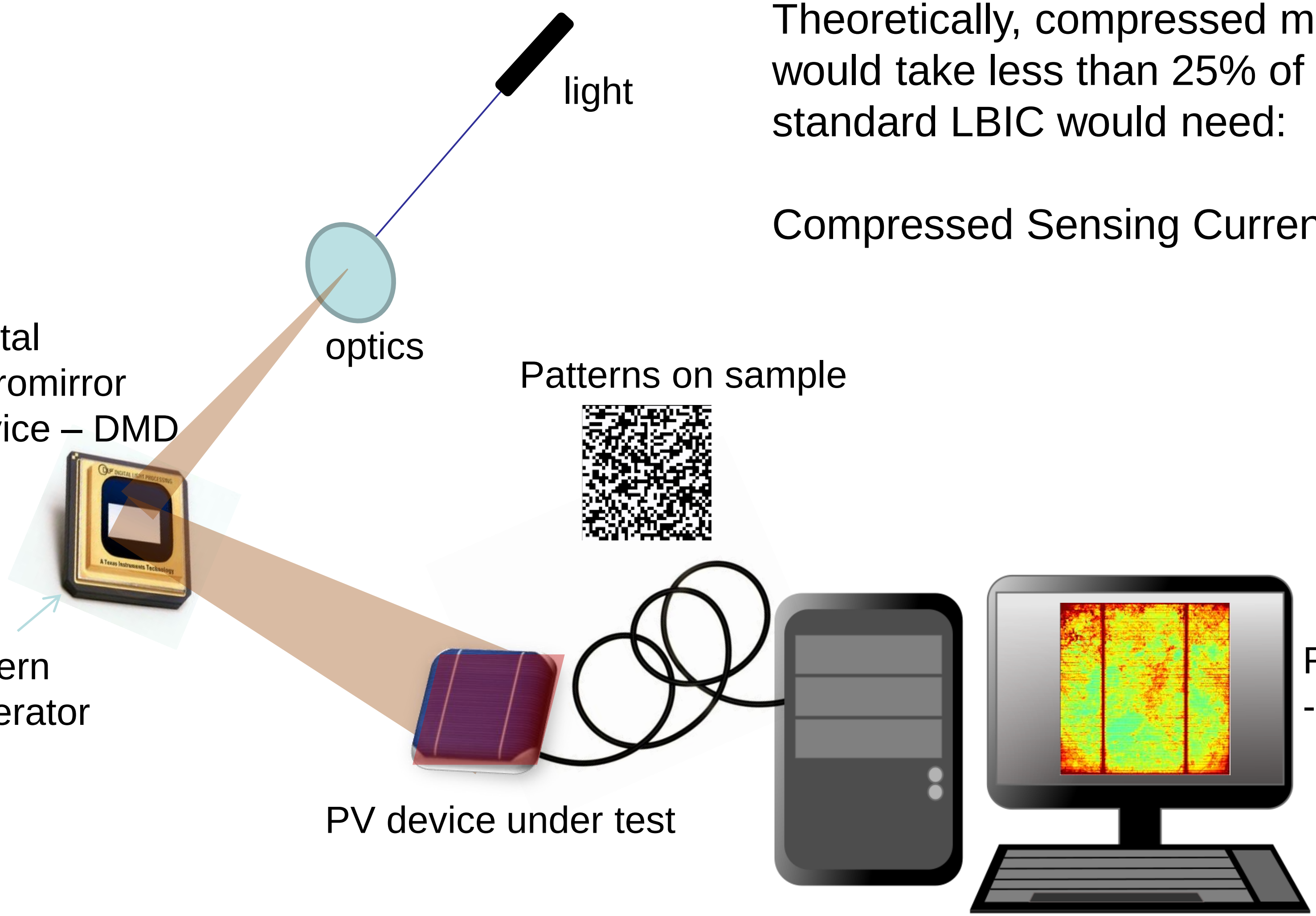


- Array of microscopic mirrors
- +12^{o} / -12^{o} mirror state On/Off
- Aluminium micromirror ~10µmx10µm (size)
- Response time: ~16 µs - very fast sampling can be achieved
- Resolution:
- from 800x600 up to1920x1080 pixels

Compressed sensing: Application on PV characterisation

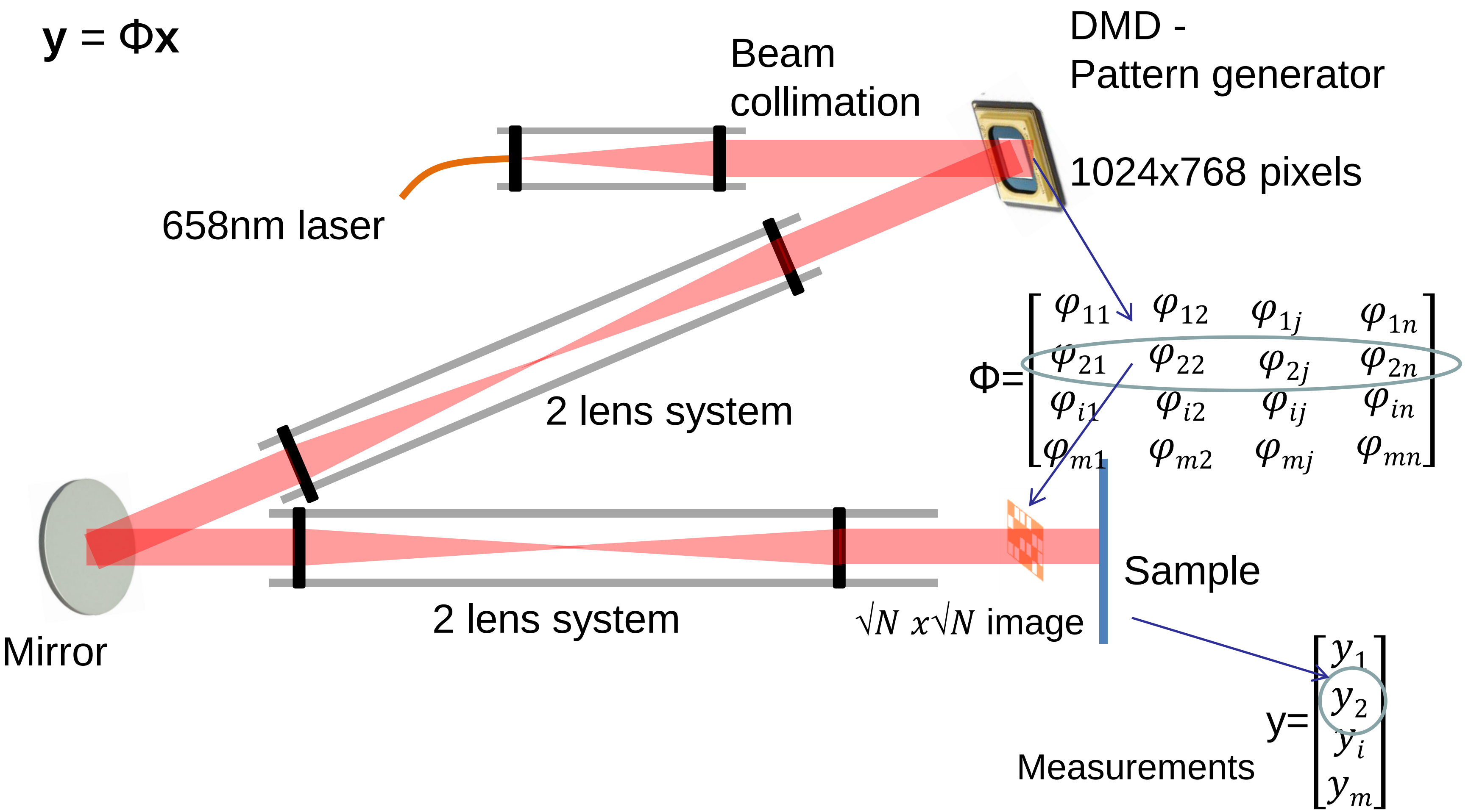
Theoretically, compressed measurements would take less than 25% of the time standard LBIC would need:

Compressed Sensing Current Mapping



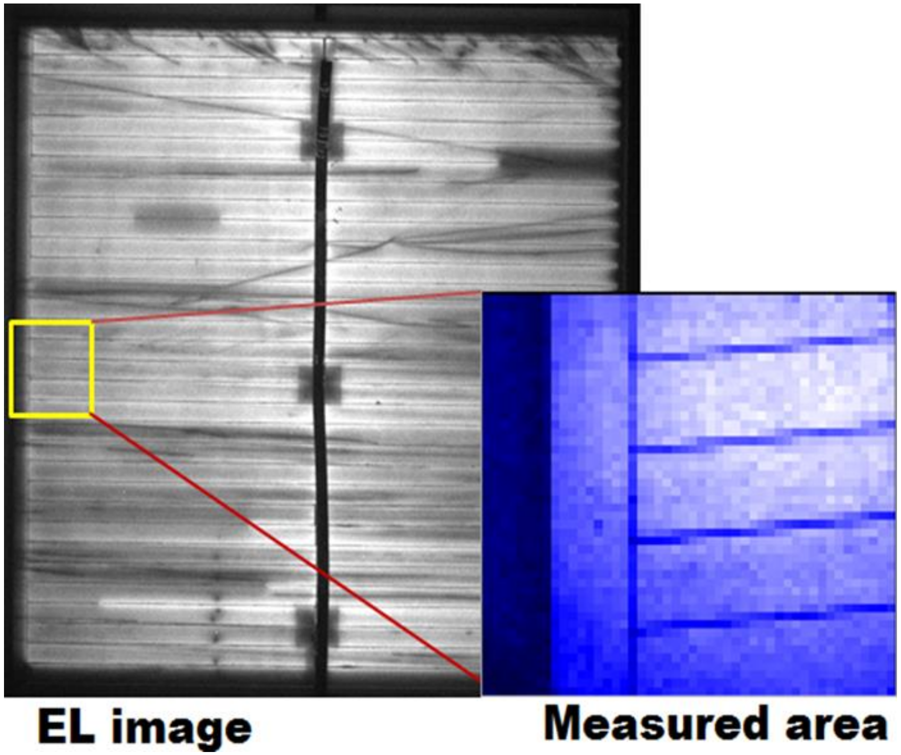
Prototype setup in NPL

y = **Φx**



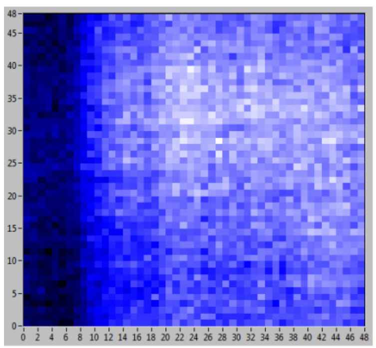
Initial measurements

- Ribbon mc-Si cells were encapsulated and characterised in CREST
- CS-LBIC measurements with the experimental setup in NPL.
- The CS-LBIC experimental setup can currently only scan a small area of the cell 1cmx1cm
- Small distortion of reconstructed image due to misalignment of the projection plane
- Non uniform irradiance on the sample



Initial measurements

- Number of measurements is expressed as a percentage of the image's pixels (in reality this is the number of measurements a raster scan would need)
- Using a 658nm laser source no defects are visible
- 48x48 current map (2304 pixels) – 160μm resolution



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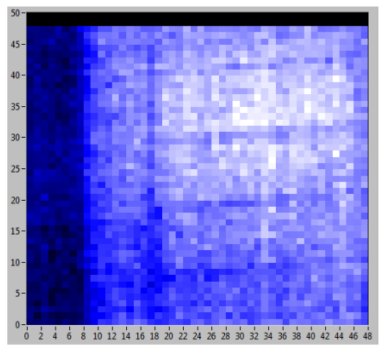

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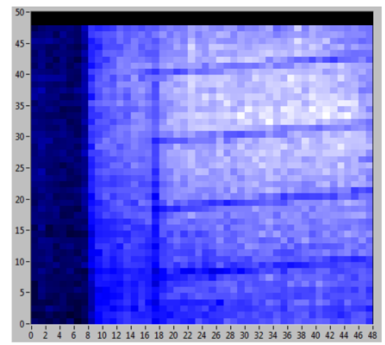

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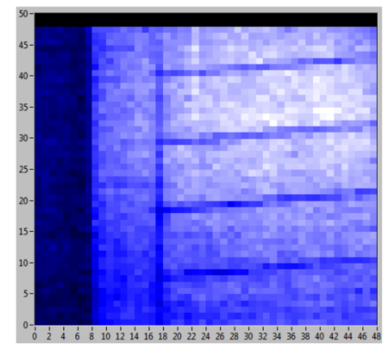

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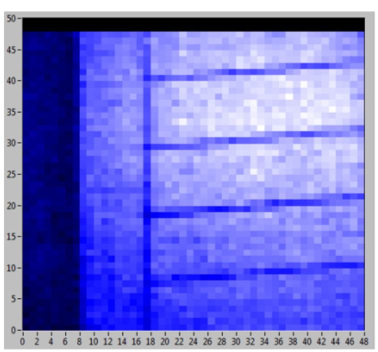

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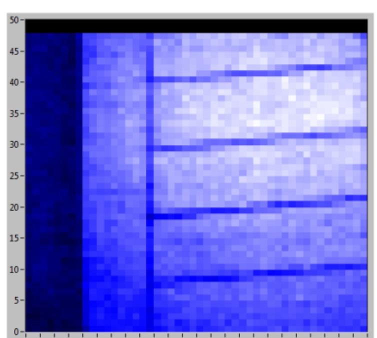

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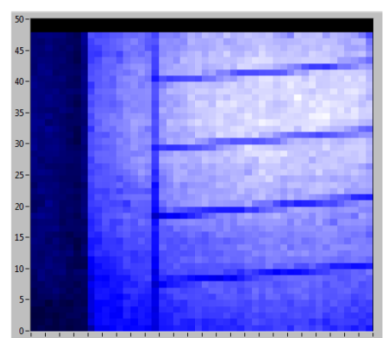
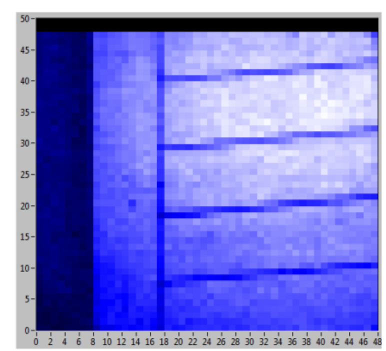


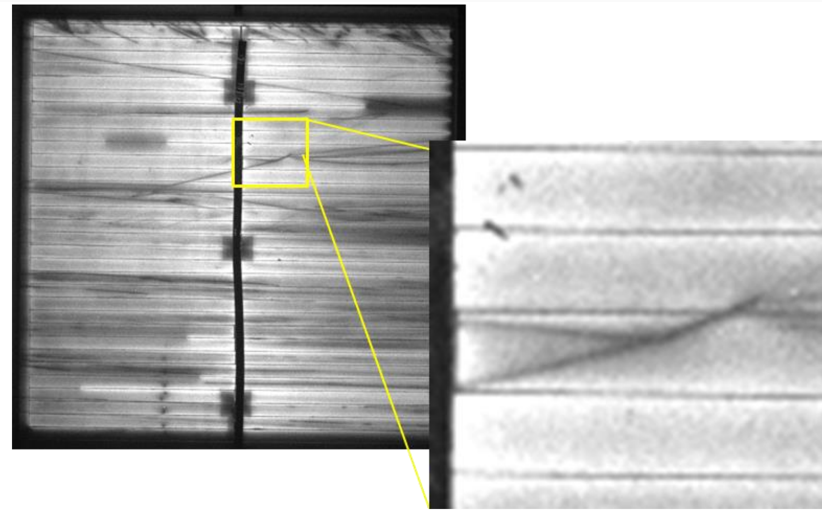
70%

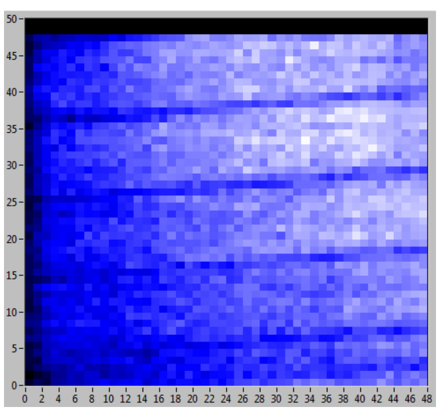


80%

Initial measurements

- Using a 785nm laser source on an area of the sample that contains a crack
- 48x48 current map – 160µm resolution





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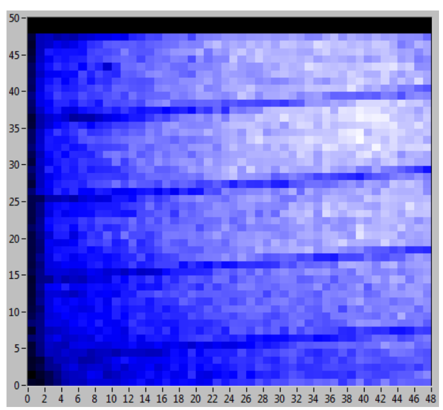

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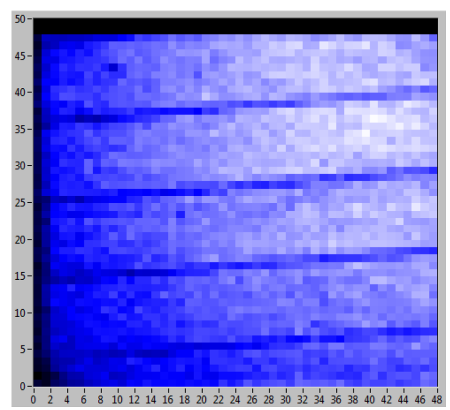

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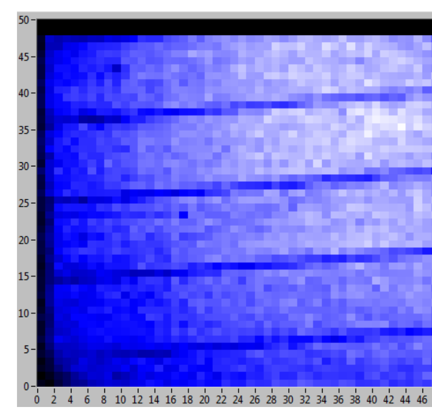

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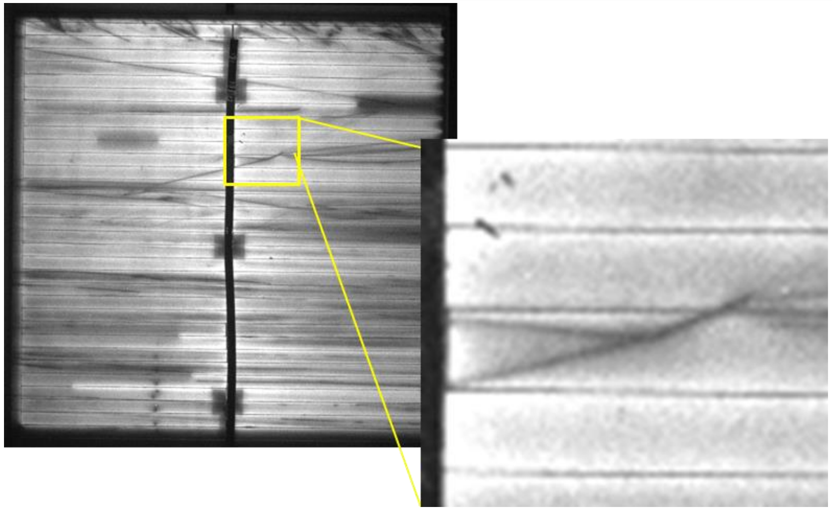
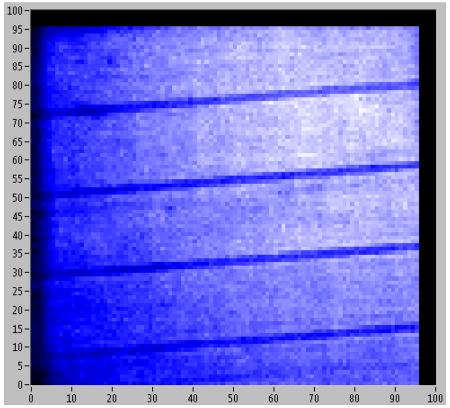
Initial measurements

- 785nm laser
- 96x96 current map (9216 pixels) – 80μm resolution
- Defects are clearly visible, even with the current non-uniform irradiance on the sample





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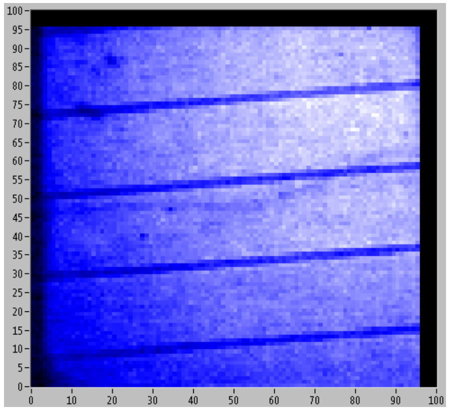

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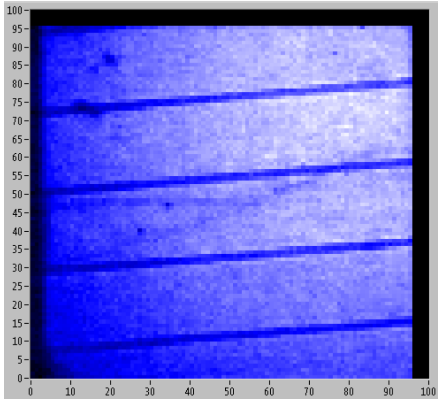

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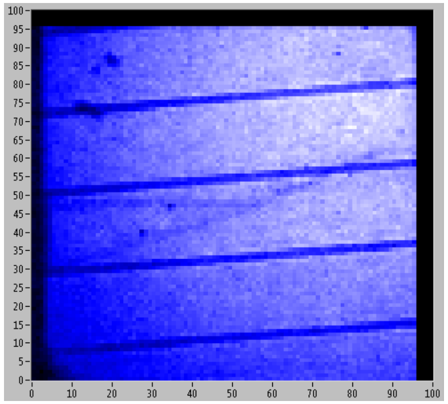

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Conclusions

- Compressed sensing theory applied for current mapping of PV devices
- CS-LBIC measurements are feasible – prototype measurement setup demonstrated
- Fewer measurements and the very fast response of the DMD kit can result in faster current mapping comparing to standard LBIC systems
- Still in development - Optimised version of the experimental setup will provide more accurate results.

Thank you for your attention