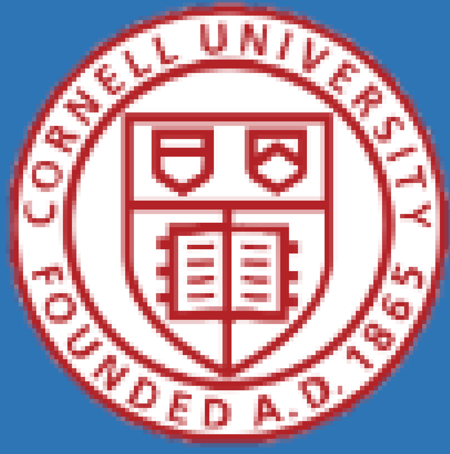

Measuring Strain at Sharp Interfaces Using 4D-STEM

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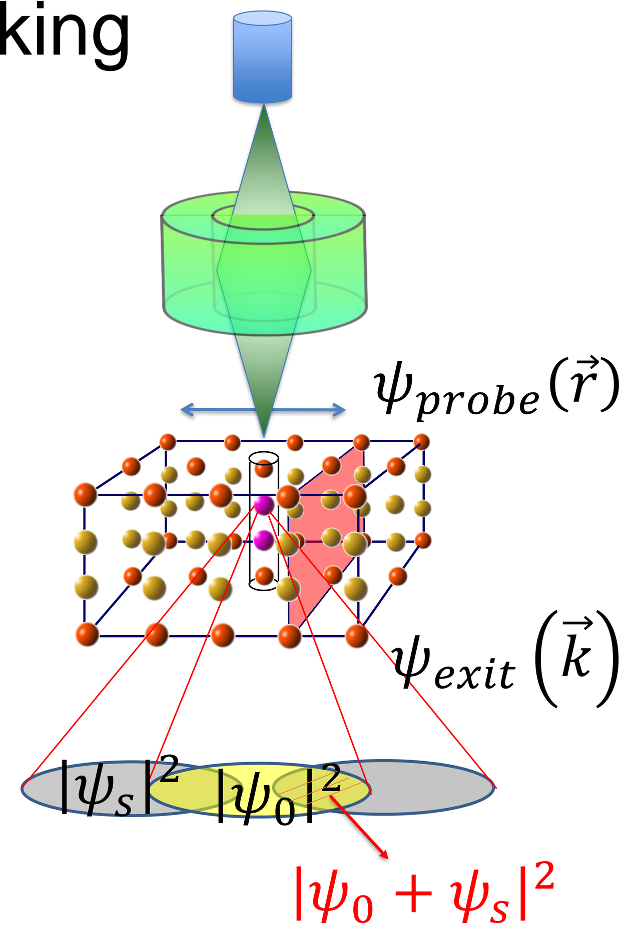
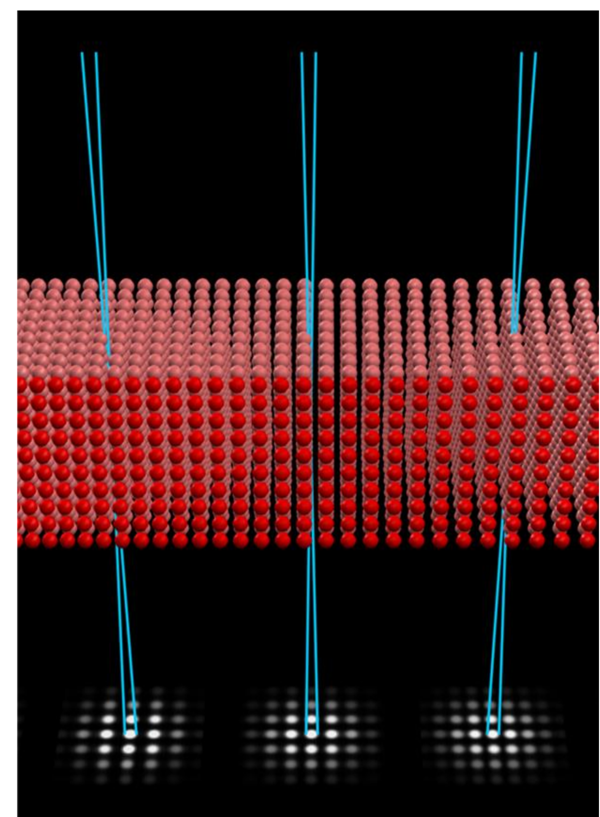
Introduction

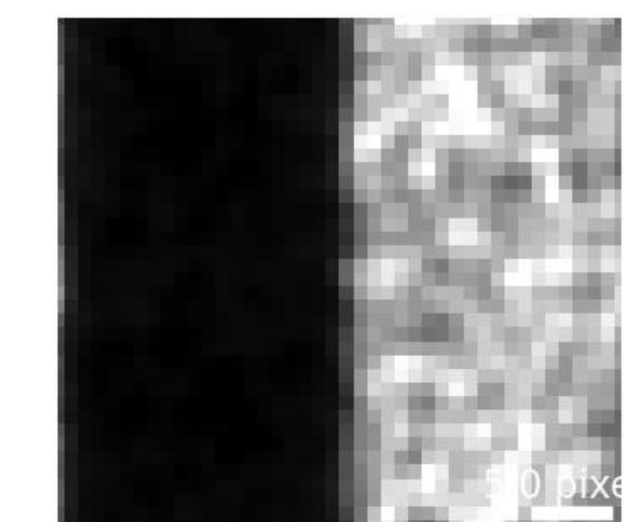
- Si and Ge doped Si are widely used in transistors. The sharp transition between two material creates unique strain ($\Delta x/x$). Understanding it allows making better transistor.
- Strain can be measured by 4-Dimensional Scanning Transmission Electron Microscopy or 4D-STEM.
  - Atomic distance is inversely proportional to Bragg peak distance.



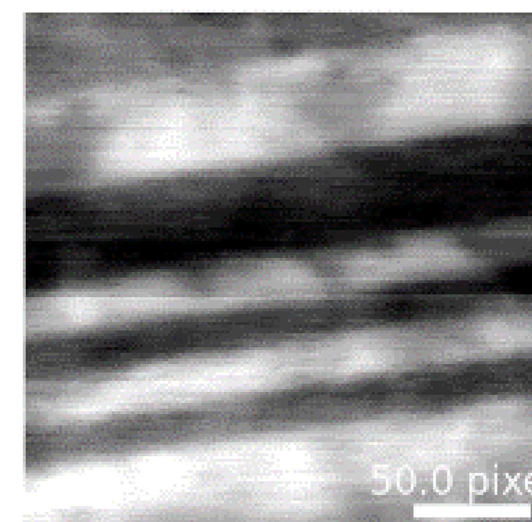


4D-STEM
Electron beam scans across the sample.

- Interference between electron waves at overlapping Bragg disks provides phase information.
- Traditional iterative ptychography uses a large convergence angle to create overlapping Bragg disks



Si (black)/ Si-Ge (white)
Simulated Sample



Si (black) / Si-Ge (white)
Experimental Sample

Methods

Cross Correlation

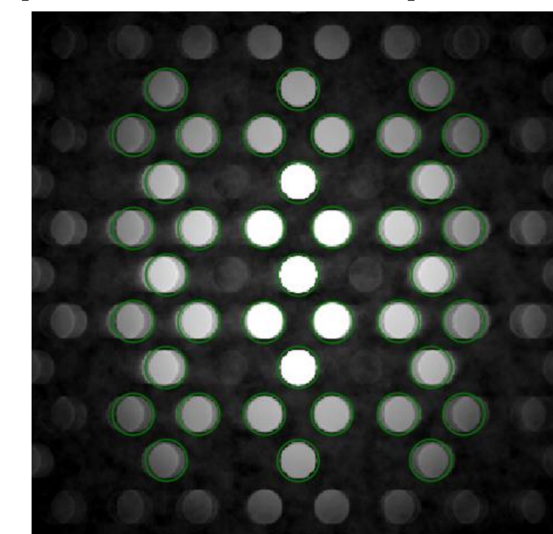
- Cross correlation with a kernel can find the location of the Bragg peaks.
- Calculate the difference between the individual Bragg peaks patterns with the average pattern to measure strain.

DPC

- $\varepsilon_x = \frac{d\phi}{dx}/G_x$, where ϕ is the phase shift of the scattered electron beam, G is the diffraction space position vector.
- The phase shift is correlated with the center of mass of the Bragg disk. We reconstructed the phase and calculated the strain from each of the Bragg disk, then averaged the strain.

Iterative Bragg Ptychography

- Bragg ptychography uses a small convergence angle, which has nonoverlapping Bragg disks. But blurry Bragg disks occur if strained.
- The iterative method guesses the sample phase, compares it with data, and updates.



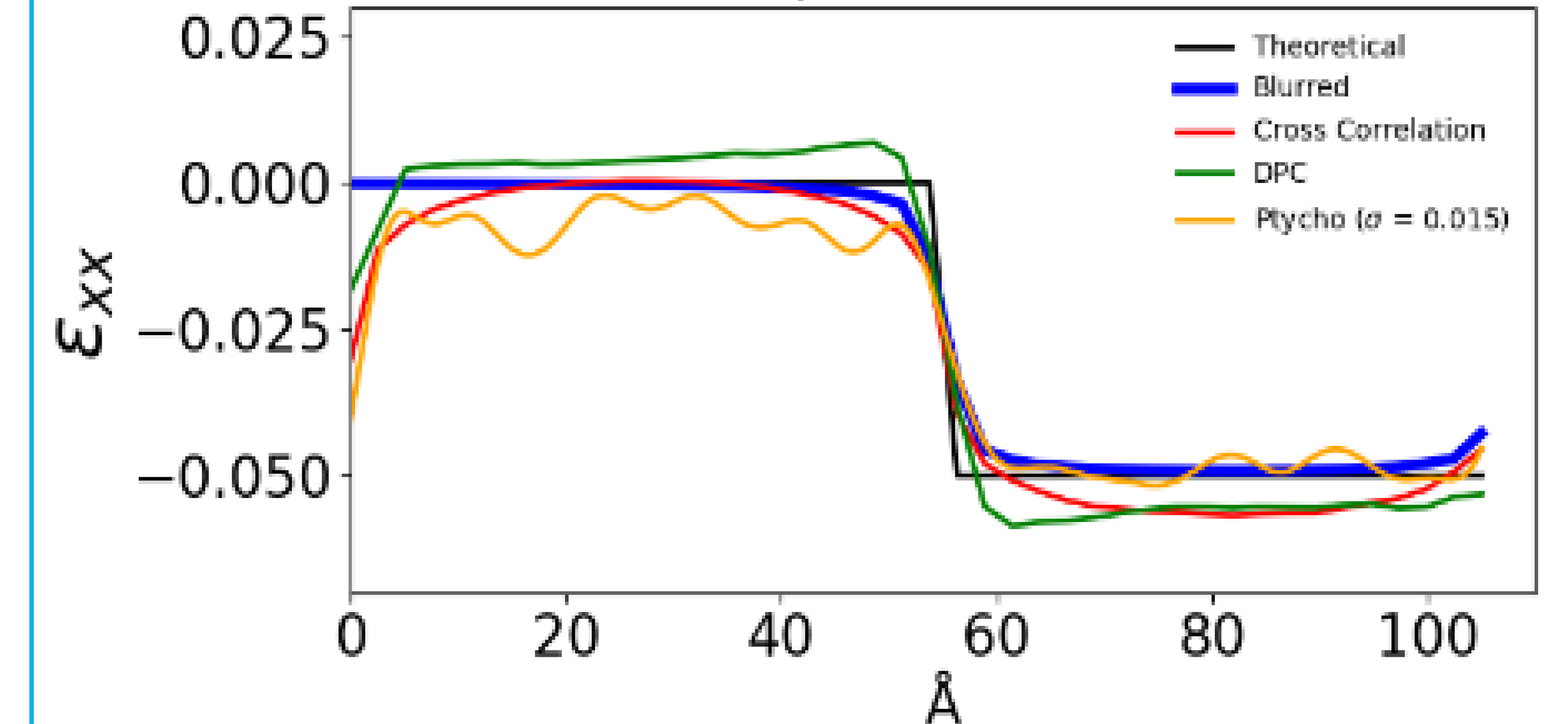
Blurry disks at the Si/Si-Ge transition using small convergence angle

Future Work

- Blur out the Gibbs fluctuations in ptychography
- Apply ptychography to experiment
- Quantify errors in different approaches

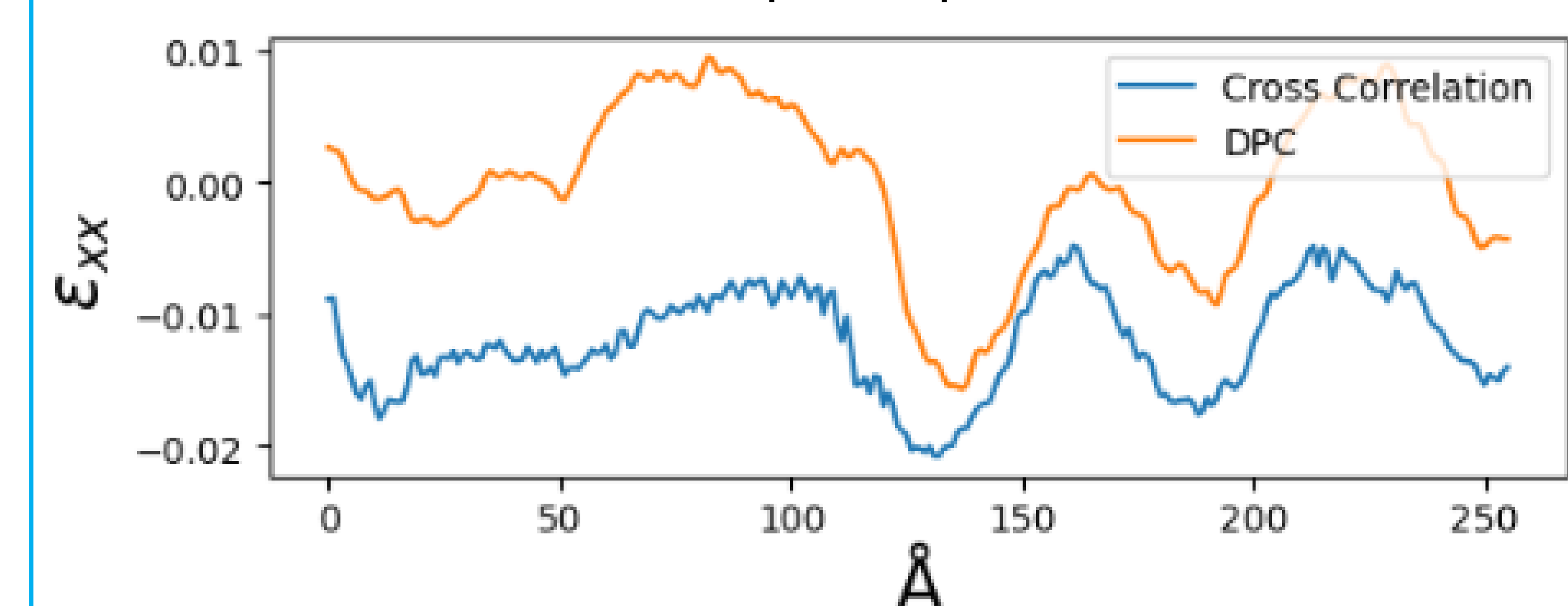
Results

X Strain Map in Simulation



- Blurred: Accounts for the diffraction limit of the lens by convolving strain map with the probe
- Best resolution: ptychography
- Gibbs phenomenon due to sharp interface
- Overlapping Bragg disks at the interface allow ptychography, but cause ineffective location identification in cross correlation

X Strain Map in Experiment



- Similar strain transition from layer to layer but has different magnitude

Acknowledgement

Thanks to Shake Karapetyan for the Si/Si-Ge experimental sample and PARADIM for the REU opportunity.

Citation

1. Mahr, C., et al. (2021). Accurate measurement of strain at interfaces in 4D-STEM: A comparison of various methods. Ultramicroscopy, 221, 113196. https://doi.org/10.1016/j.ultramic.2020.113196
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