Application example : Uncertainties in SEM-DIC testing

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Introduction

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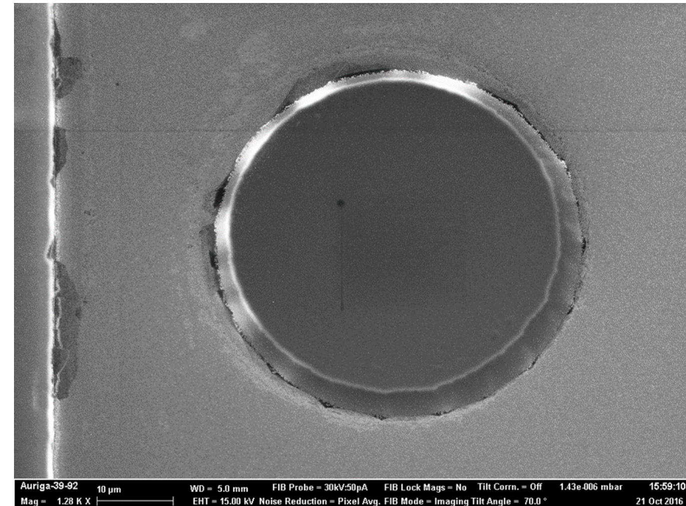
- We want to measure residual stresses in thin layers of Piezoelectric materials deposited on silicon and other substrates

- This is for electronic devices
- Very small objects

  typically micrometres in scale
- Pixel sizes in nm



Residual Stress

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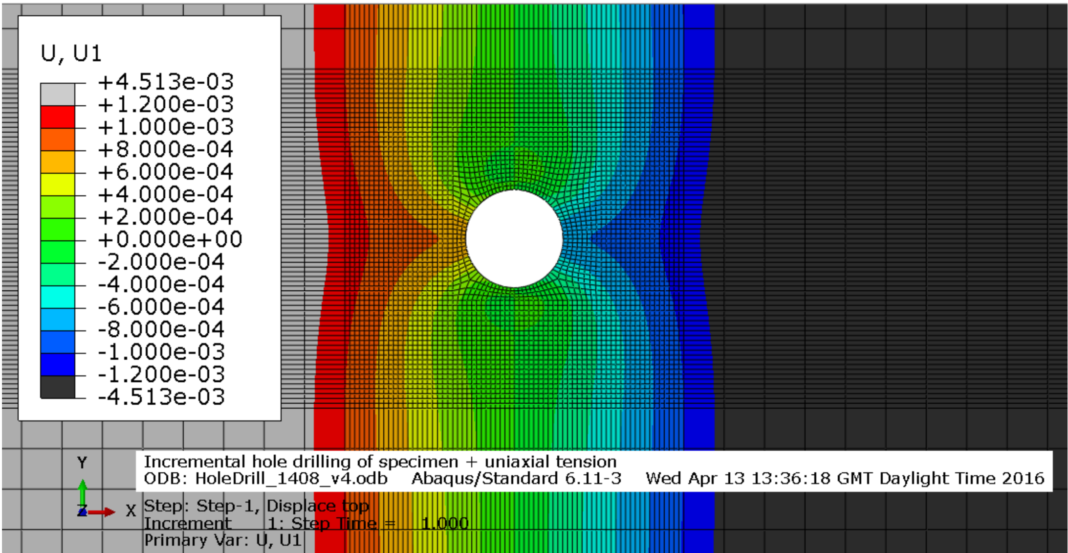
- Residual stress during manufacture is a common problem for many different products.
- Residual stresses can be produced during manufacturing processes involving heat or layer deposition where strains due to thermal expansion are constrained, or where mechanical strains are constrained as in plastic bending for example.
- High levels or residual stress can cause problems with maintenance of close tolerances during machining as removal of highly strained parts of an object cause a redistribution of strains and warping of the object.
- In addition high levels of residual strain can have both positive and negative effects on fatigue resistance due to the change in the internal stress state which might lead to equivalent changes in fatigue life.

Incremental hole drilling to measure residual stress

- Drill into a specimen
- Measure changes in strain or surface displacements near a hole
  - Relief of stress
- Use a model to calculate the apparent residual stress that caused those surface deformations



PETMEM Sample

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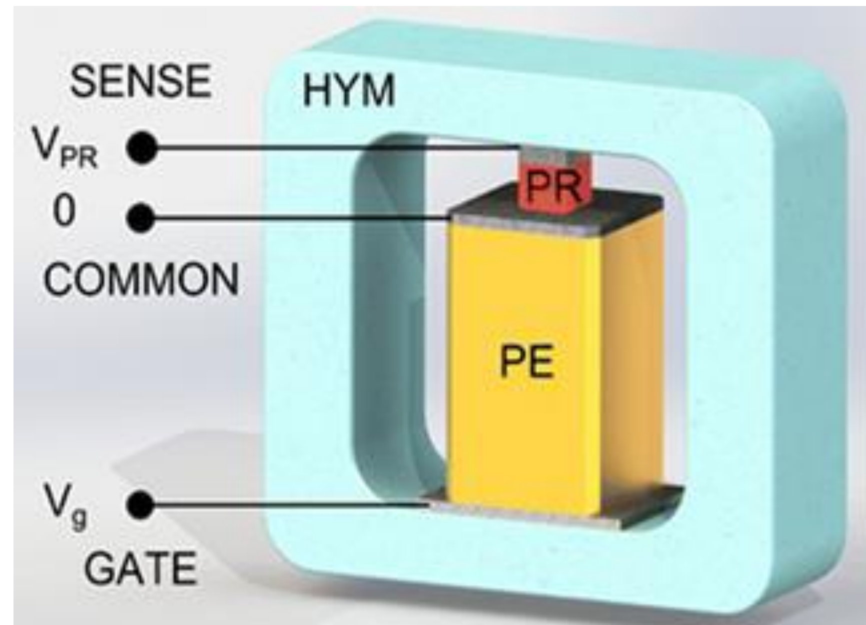
- PETMEM device
- Interested in residual stresses as the device is electromechanical and hence fatigue is important
- Predicted to achieve multi-GHz switching speeds
- At lower power than the comparable generation field effect transistor (FET).

Scale of the device
is micrometres



FIB Machining

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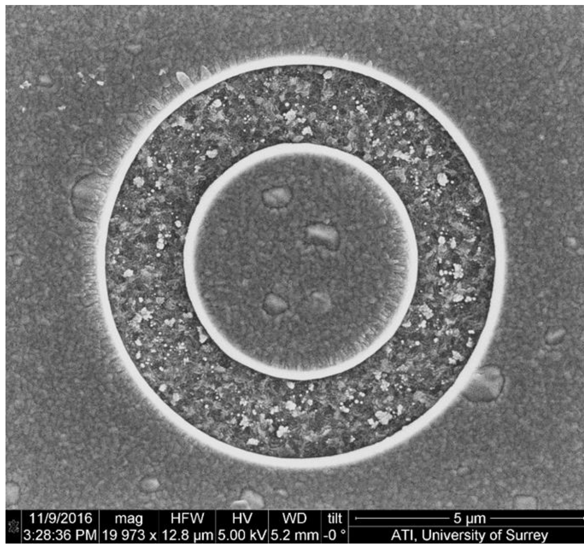
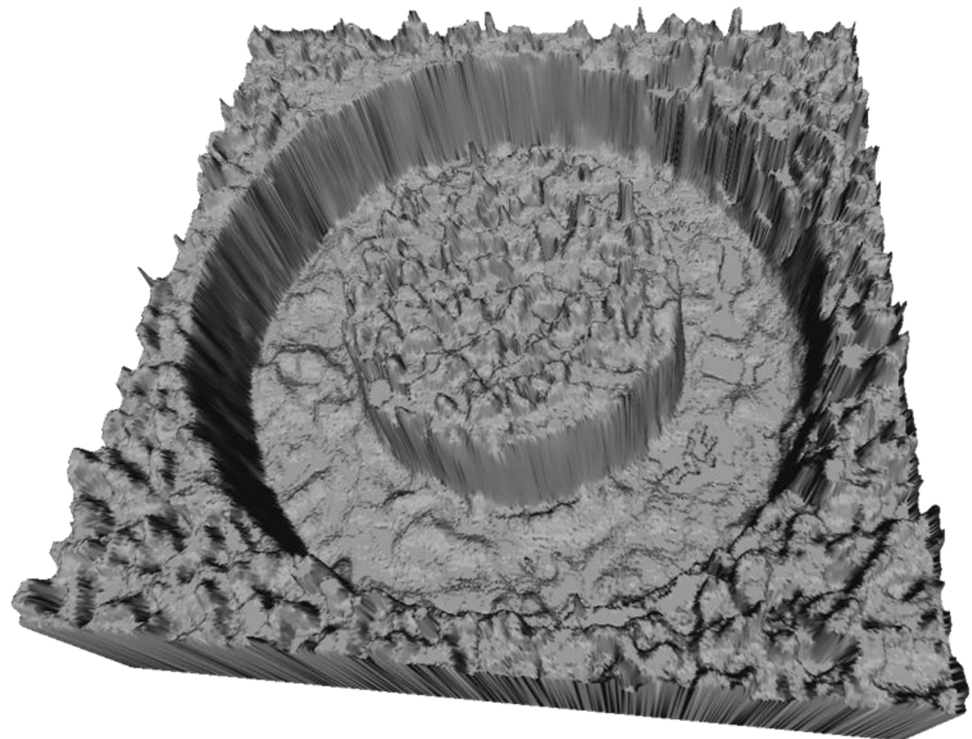
- Using the Scanning Electron Microscope for magnification
- Focussed beam of Gallium ions that machine the surface of a material
- Ideal for residual stress measurements
- For some surfaces can also be used to provide a DIC pattern





DIC Imaging and Processing

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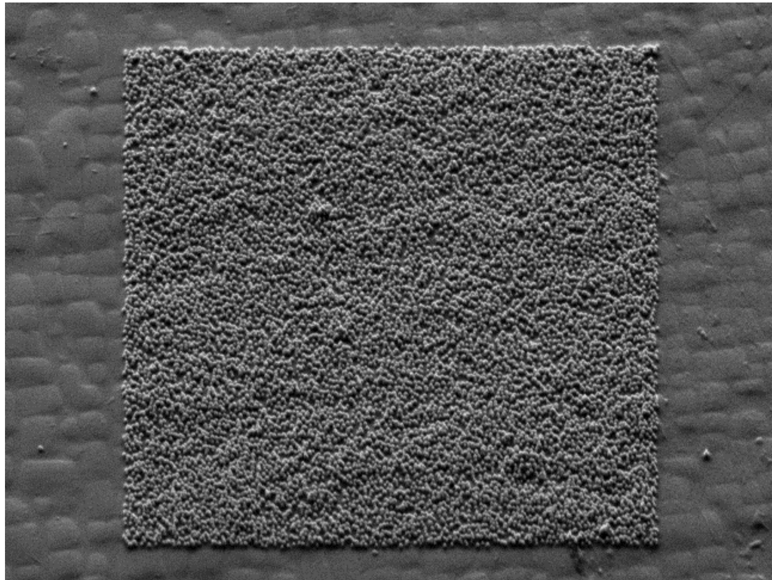

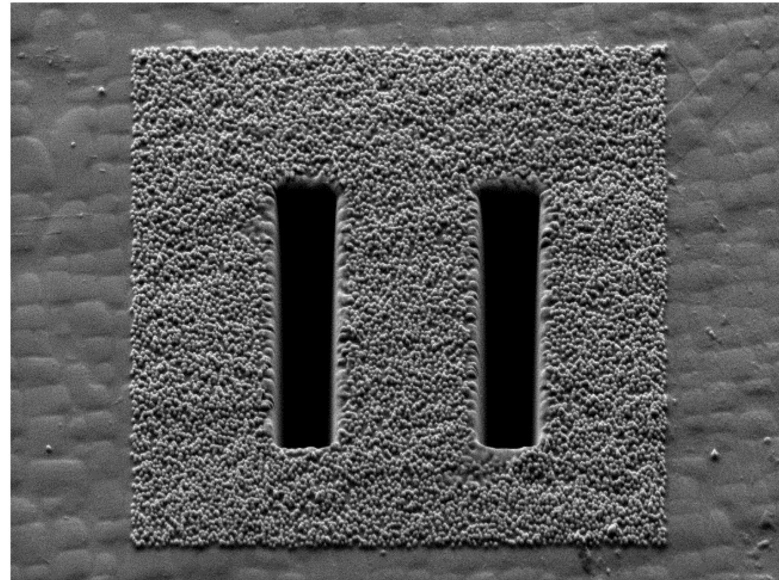

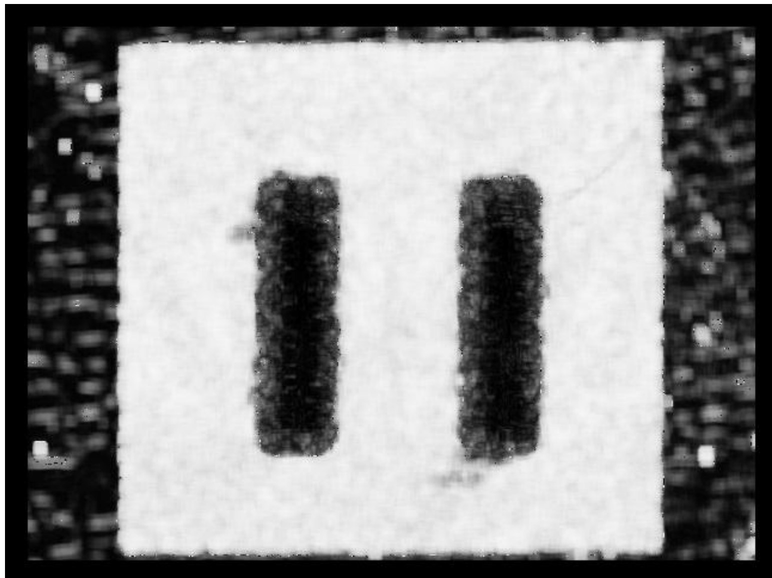

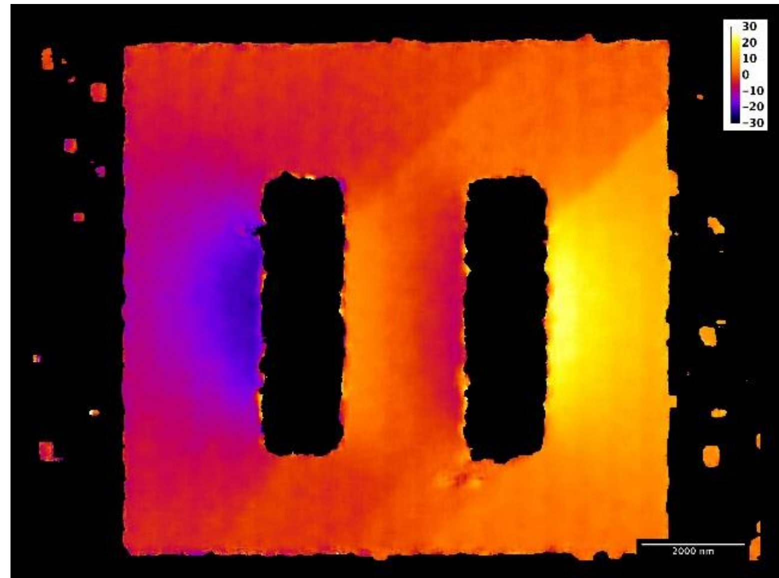

DIC Systematic errors

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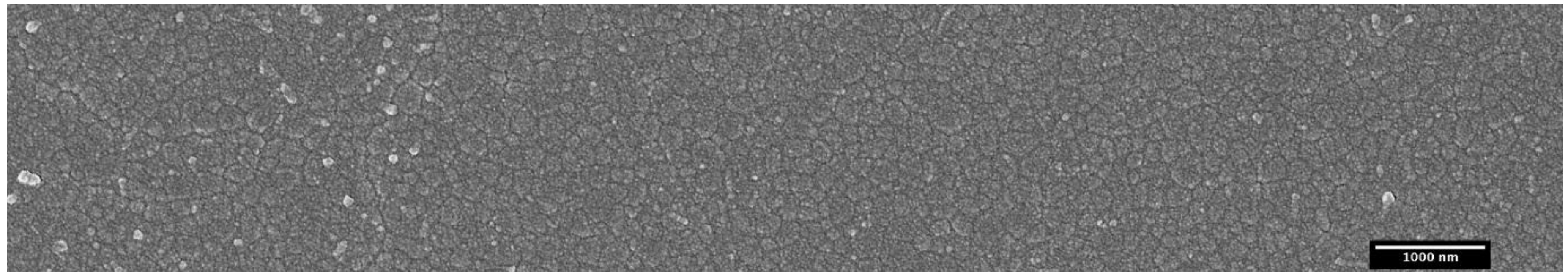
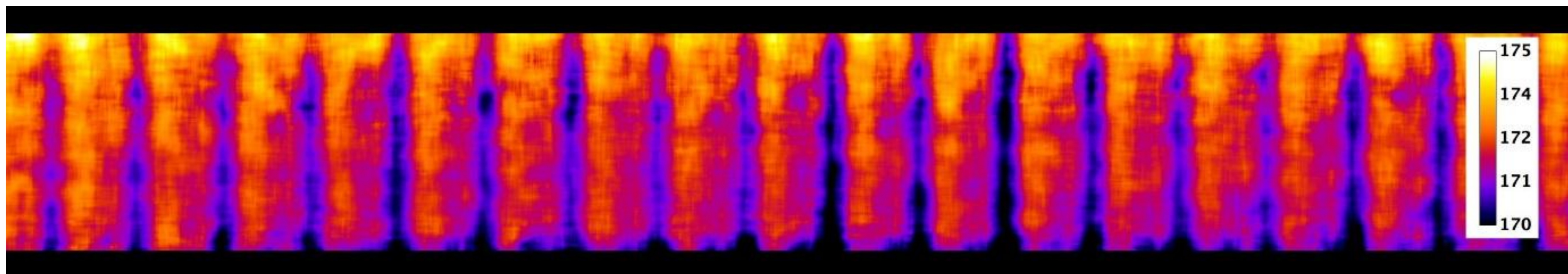
- Systematic banding
- Bands in the same place for the same magnification
- Characteristic number for different magnifications
- It is highlighted by low noise, high quality repositioning of pixels in SEM image generation
- Caused by movement between DIC images





DIC Systematic errors

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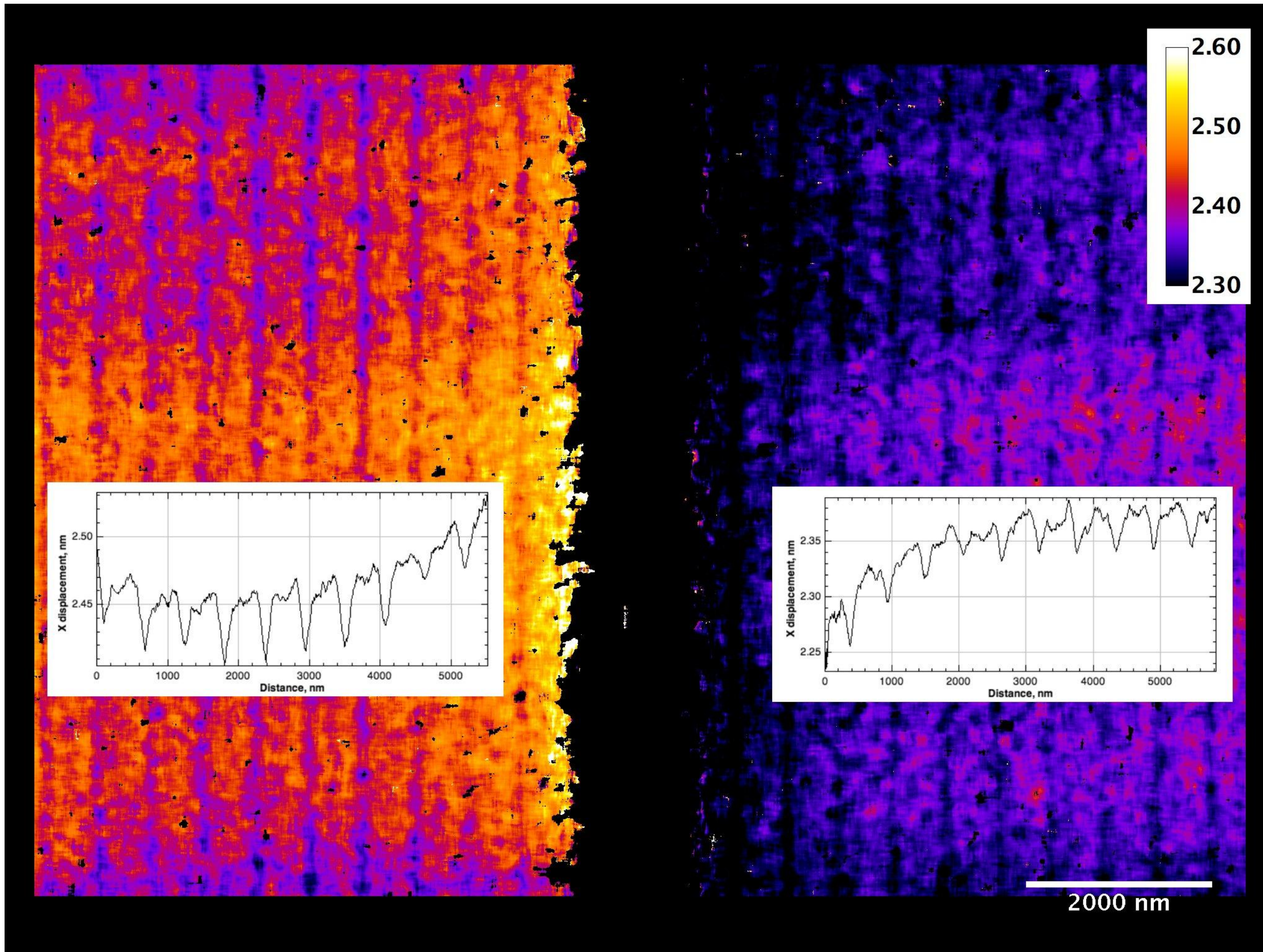

DIC Systematic errors Causes:

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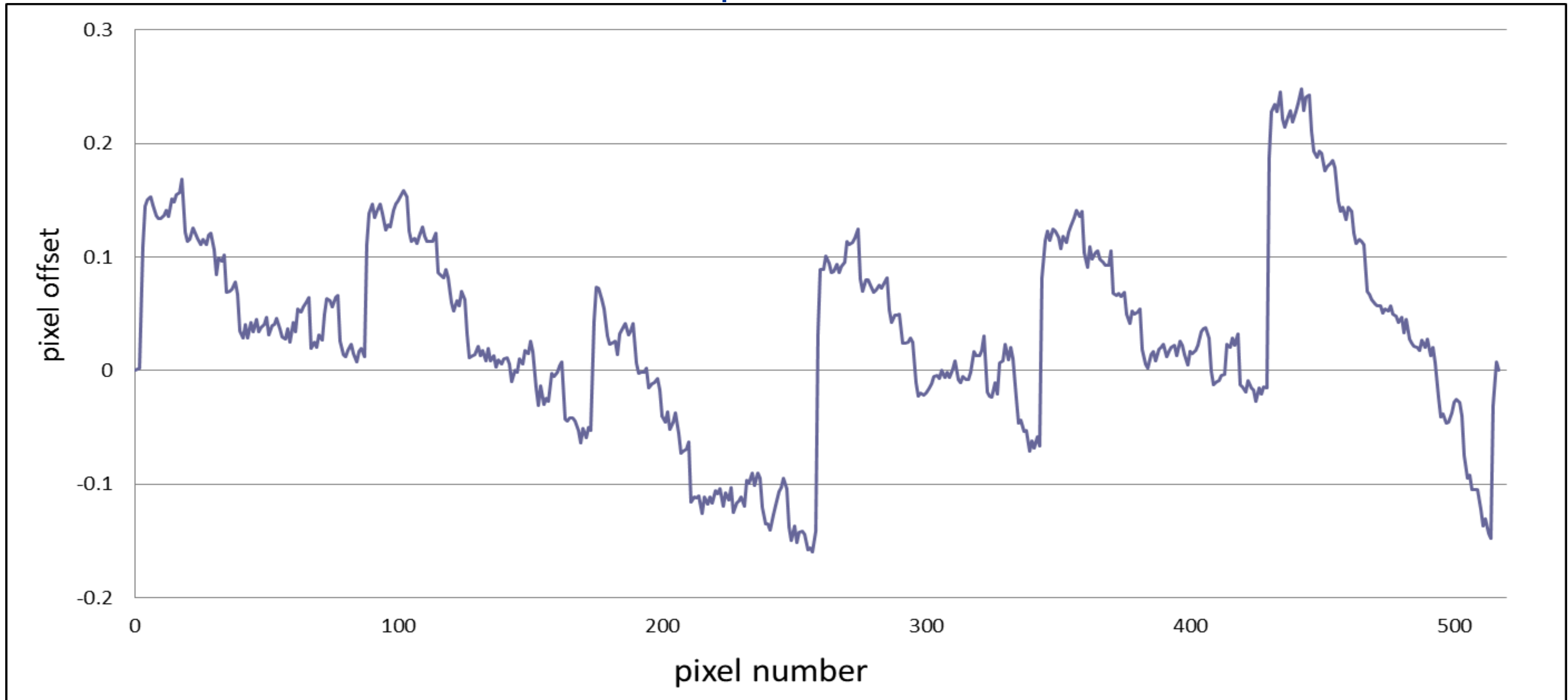
- The effect is caused by systematic sub-pixel errors in the placing of pixels
  - Errors in DAC Chip
  - Leading to sub-pixel errors in pixel placement
- Contrast with imaging using CCD array
- Measurements with the bonnet up!



Correction

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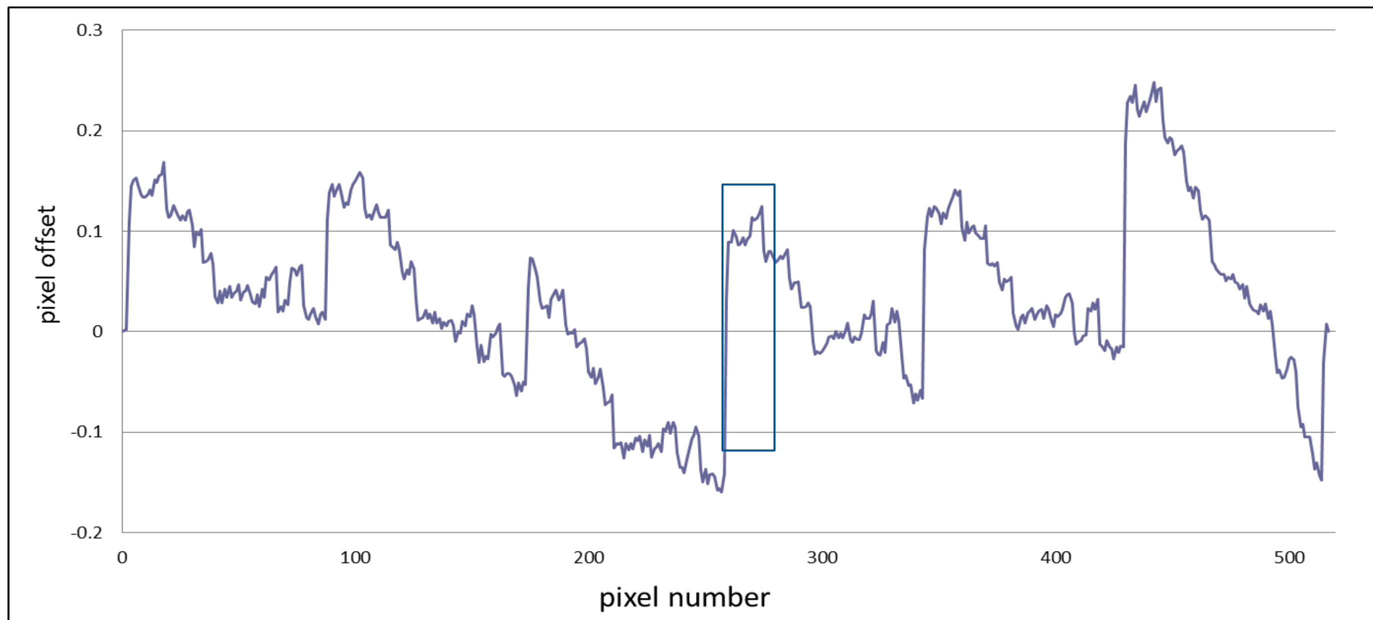
- We can't measure the electrical characteristics of all our SEM's
- The position of the bands coincides mainly with the relative displacement differences over a specific gauge length
  - Convolved with an envelope of width similar to the DIC pixel block size
- Proved hypothesis using simulated images



Correction

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- Use a fit based around the parameters used by the high speed DAC chip to convert digital signals to voltages
- There are 32 + 16 + 5 parameters to fit.
- So we developed a fitting procedure based on images with known lateral displacements
- Complex fitting exercise using images
- Parallel processing system to speed up the process,
  - plus a simplified model to enable parameters to be estimated much more quickly
- Issues with local versus global minimisation and systematic fitting errors due to sub pixel uncertainty
- Modify DIC software to include sub-pixel corrections for every pixel
  - Modifying the b-spline fitting parameters

Correction

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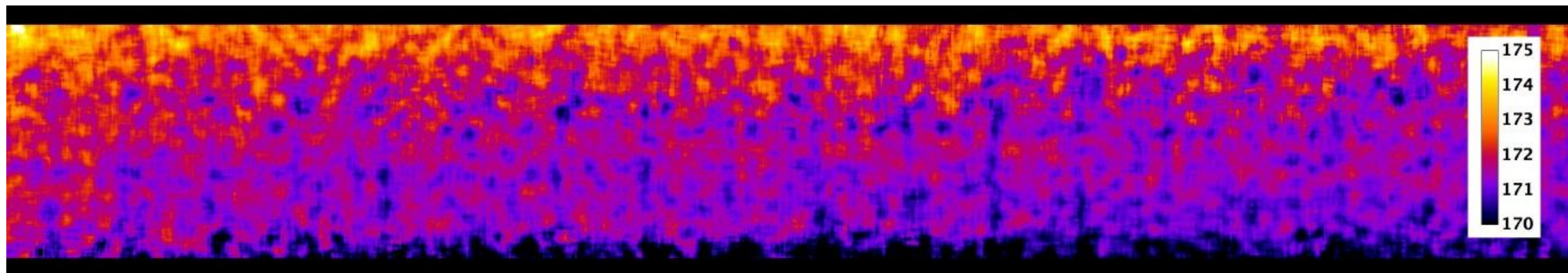
X movement, nm

173
172.5
172
171.5
171
170.5
170
169.5
169

1860 3860 5860 7860 9860 11860 13860 15860

X position, nm

X movement, nm
X movement corrected, nm



DIC Validation

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- Create surface strain field by bending
- Nano-crystalline Nickel alloy,
  essentially isotropic
  uniaxial tensile surface strain field

Model prediction

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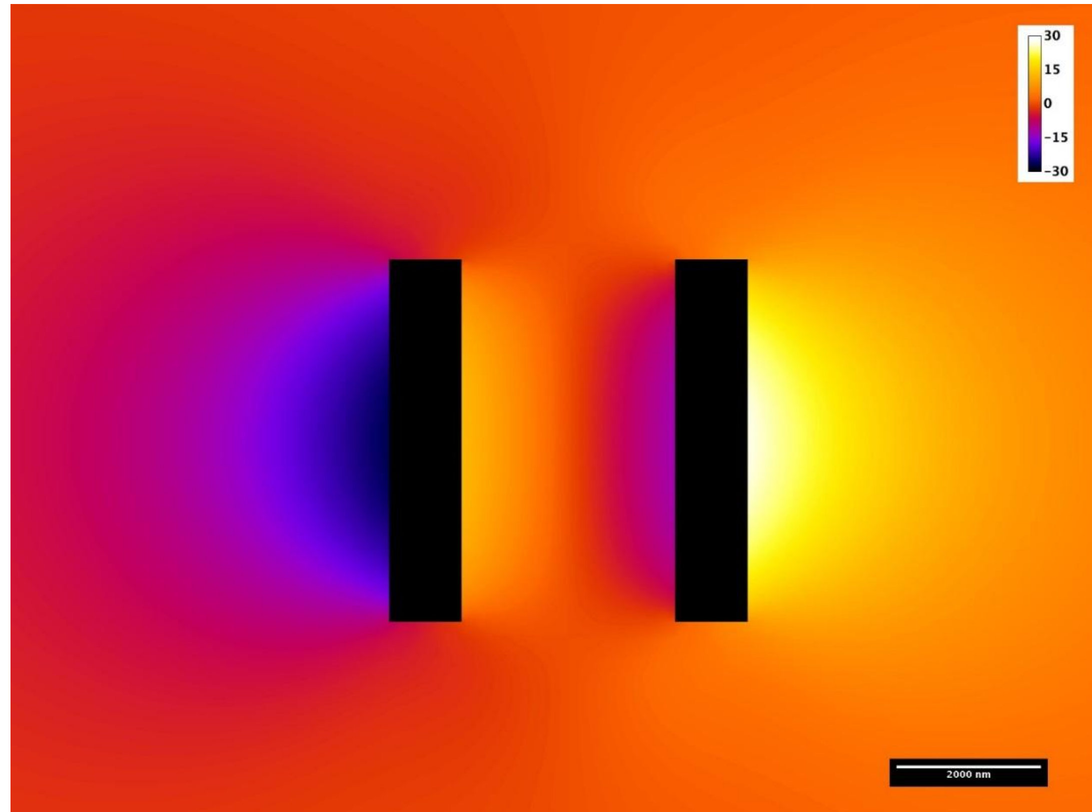
- Two slots
  so use superposition principle
- Scale is in nm



Model Validation

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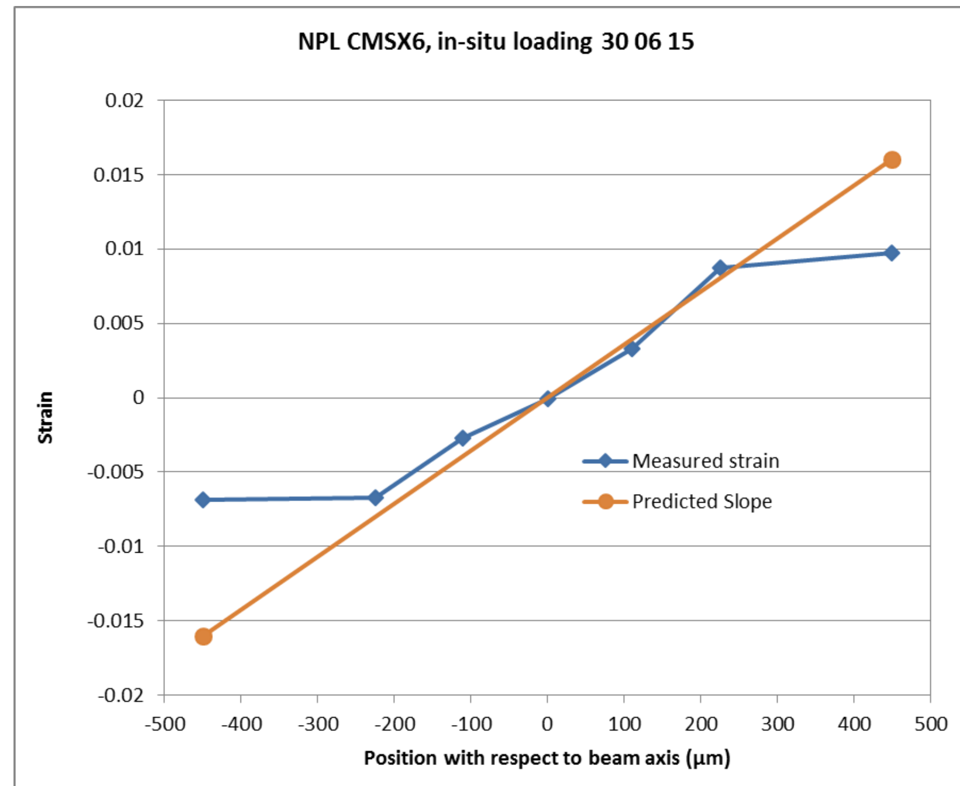
- Validation satisfactory
- Deviation due to plastic deformation at outer edges of the specimen



Piezoelectric film measurements

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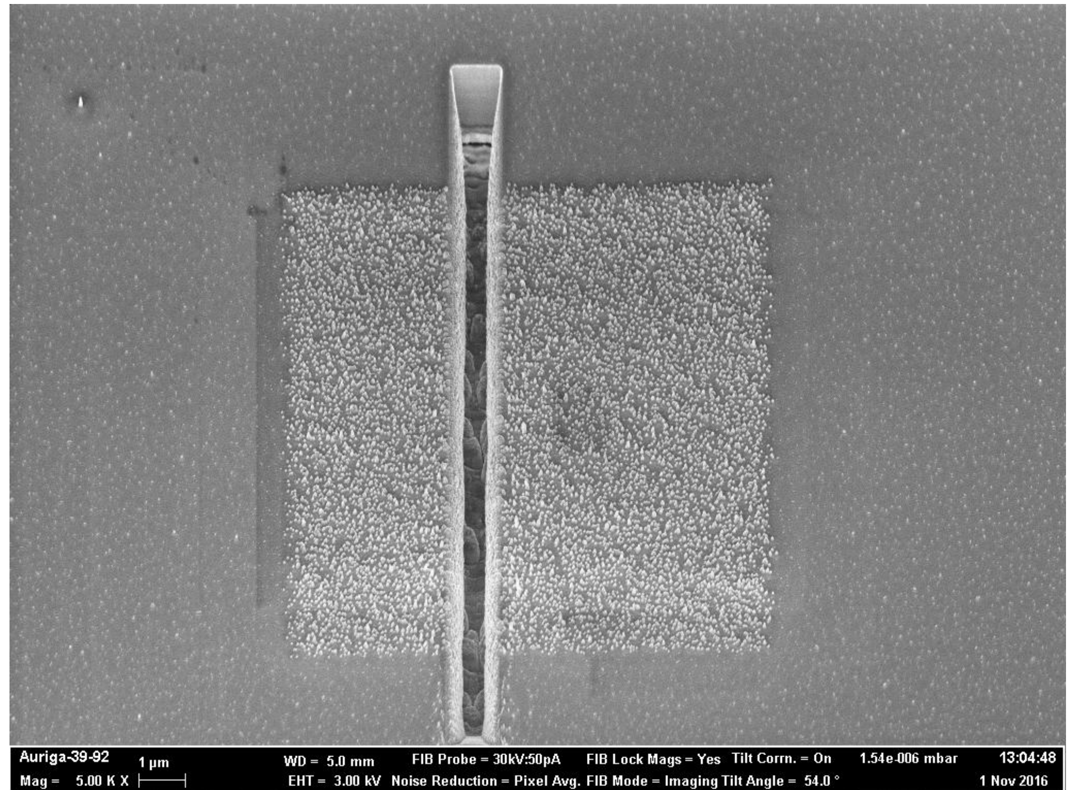
- Piezoelectric material
- Orthotropic
- Biaxial equiaxed residual stress,
  constant with depth
- Pixel size about 5 nm.
- Single long slot
  2D FEA



Piezoelectric film model

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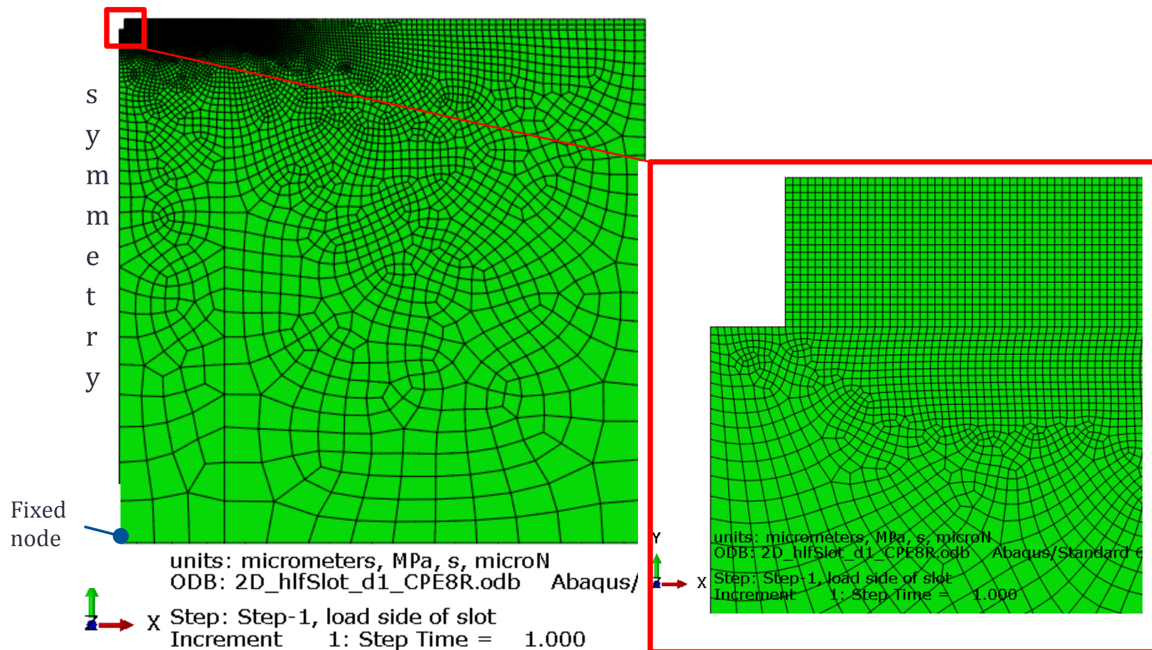
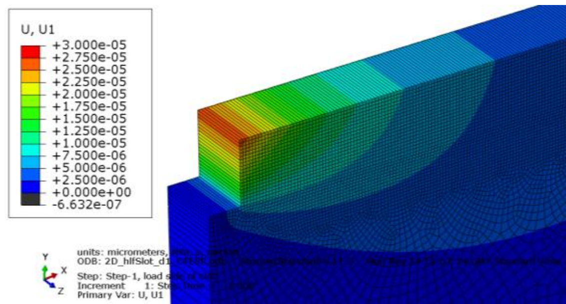
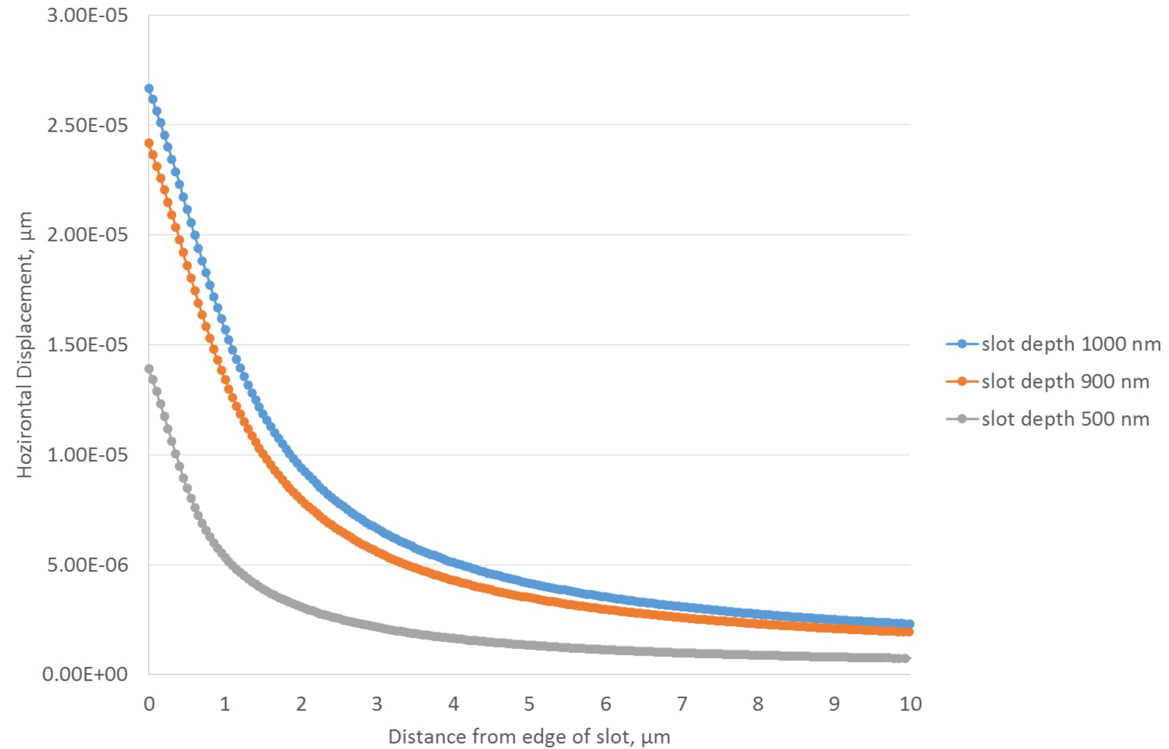
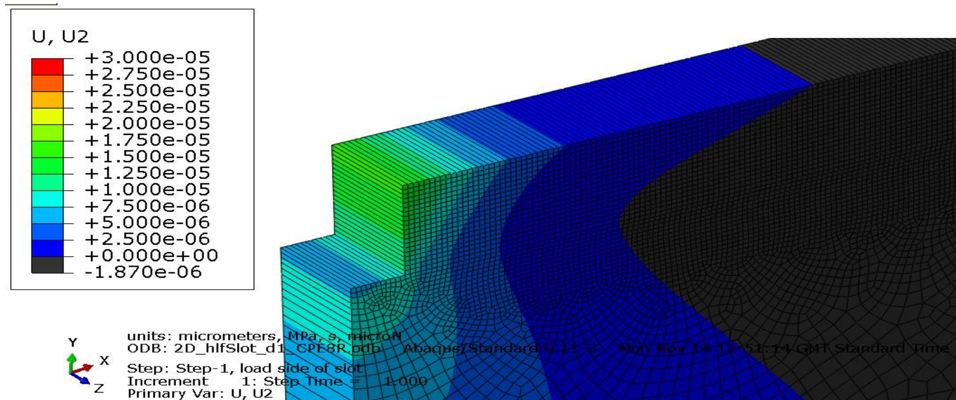
- FE Mesh



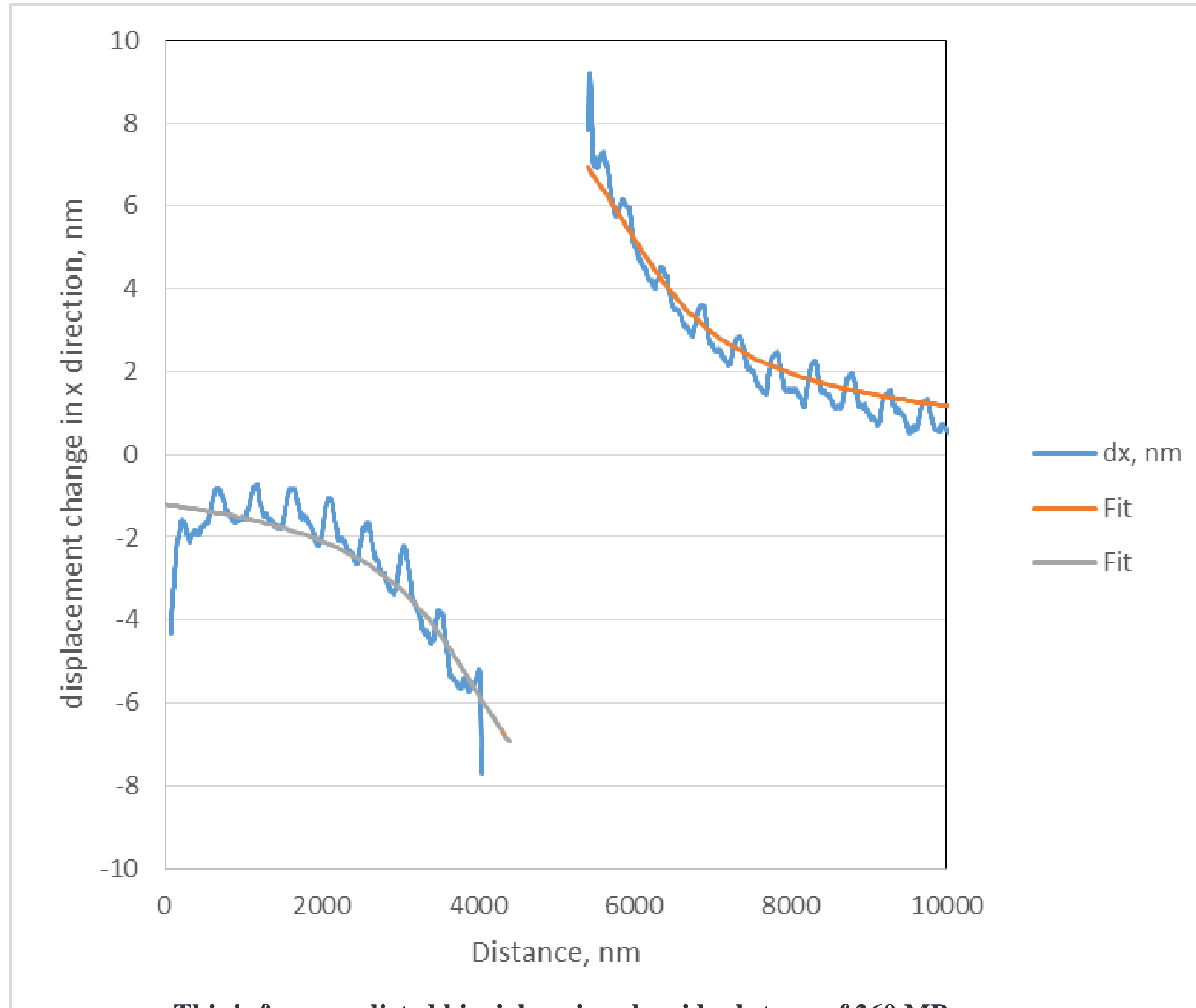
Piezoelectric film predictions







Experimental measurements



This is for a predicted biaxial equiaxed residual stress of 260 MPa.

Experimental measurements

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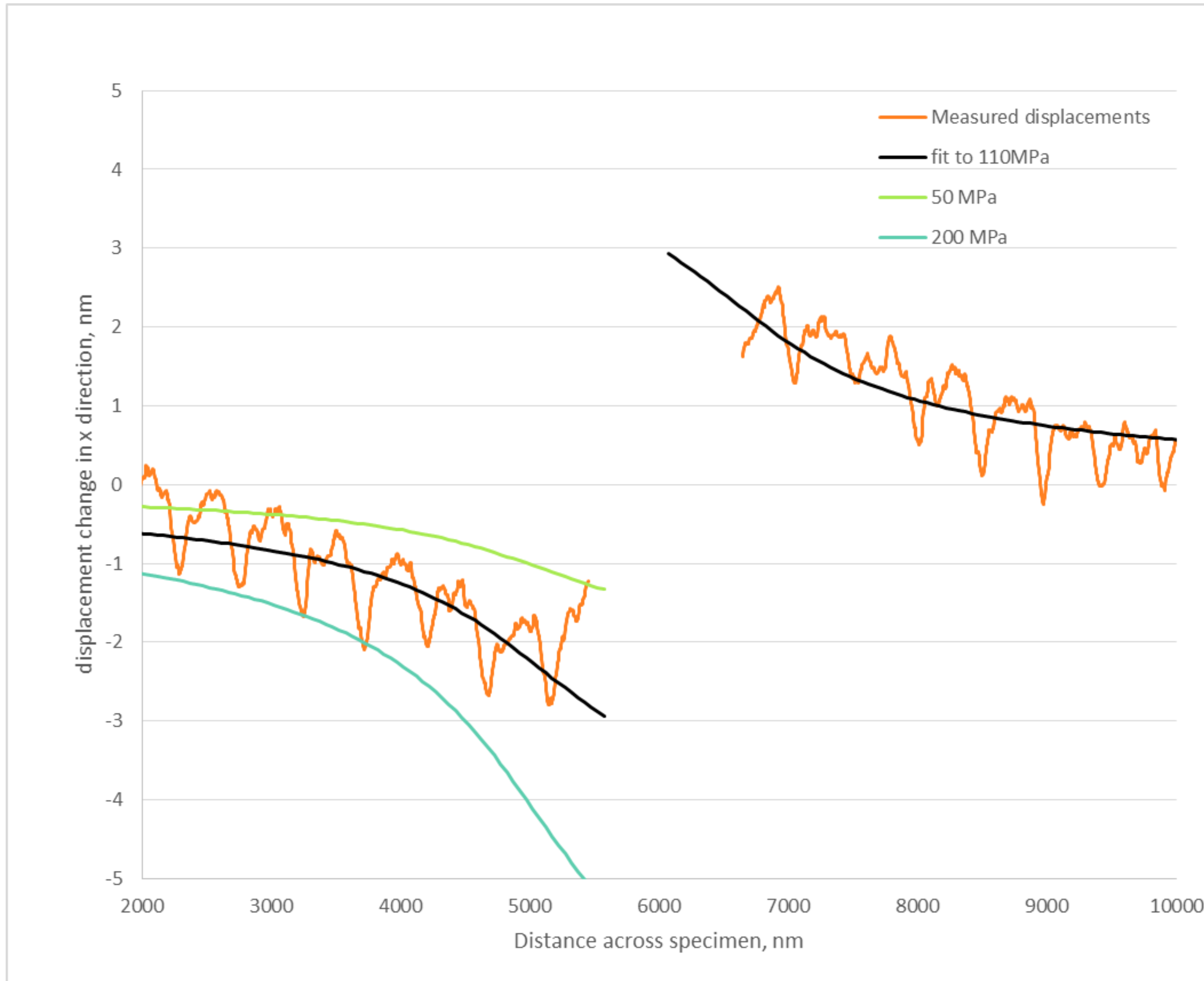

This is for a predicted biaxial equiaxed residual stress of 110 MPa.

Conclusions

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- The systematic cause of banding in SEM micrographs has been identified
- The effect is caused by systematic sub-pixel errors in the placing of pixels
- It is highlighted by low noise, high quality repositioning of pixels in SEM image generation
- It is particularly important in residual stress measurements when the movement is small.
- A technique has been created to correct

  Time consuming
- Shortly to be implemented on a second microscope

Acknowledgements

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