# Correlating Stress Development and Nanopattern Formation of Si Thin-Film Under Low-Energy Ion Bombardment

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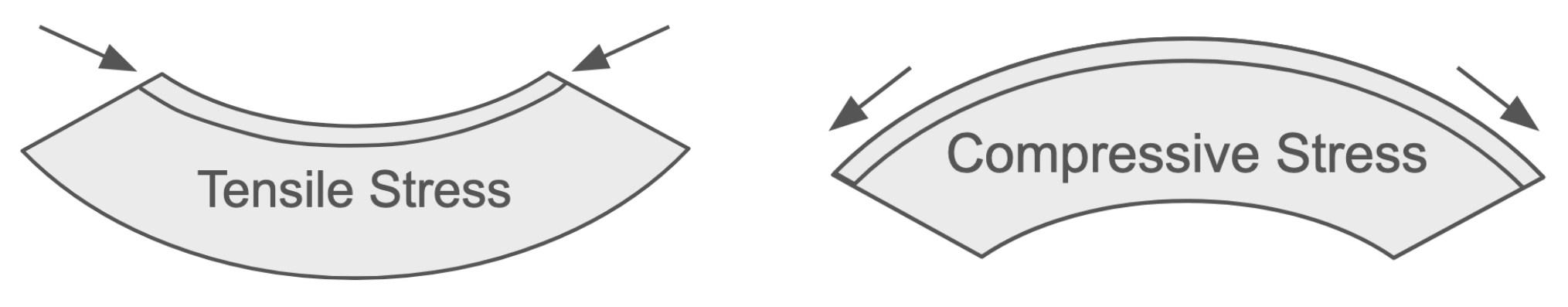
## Introduction

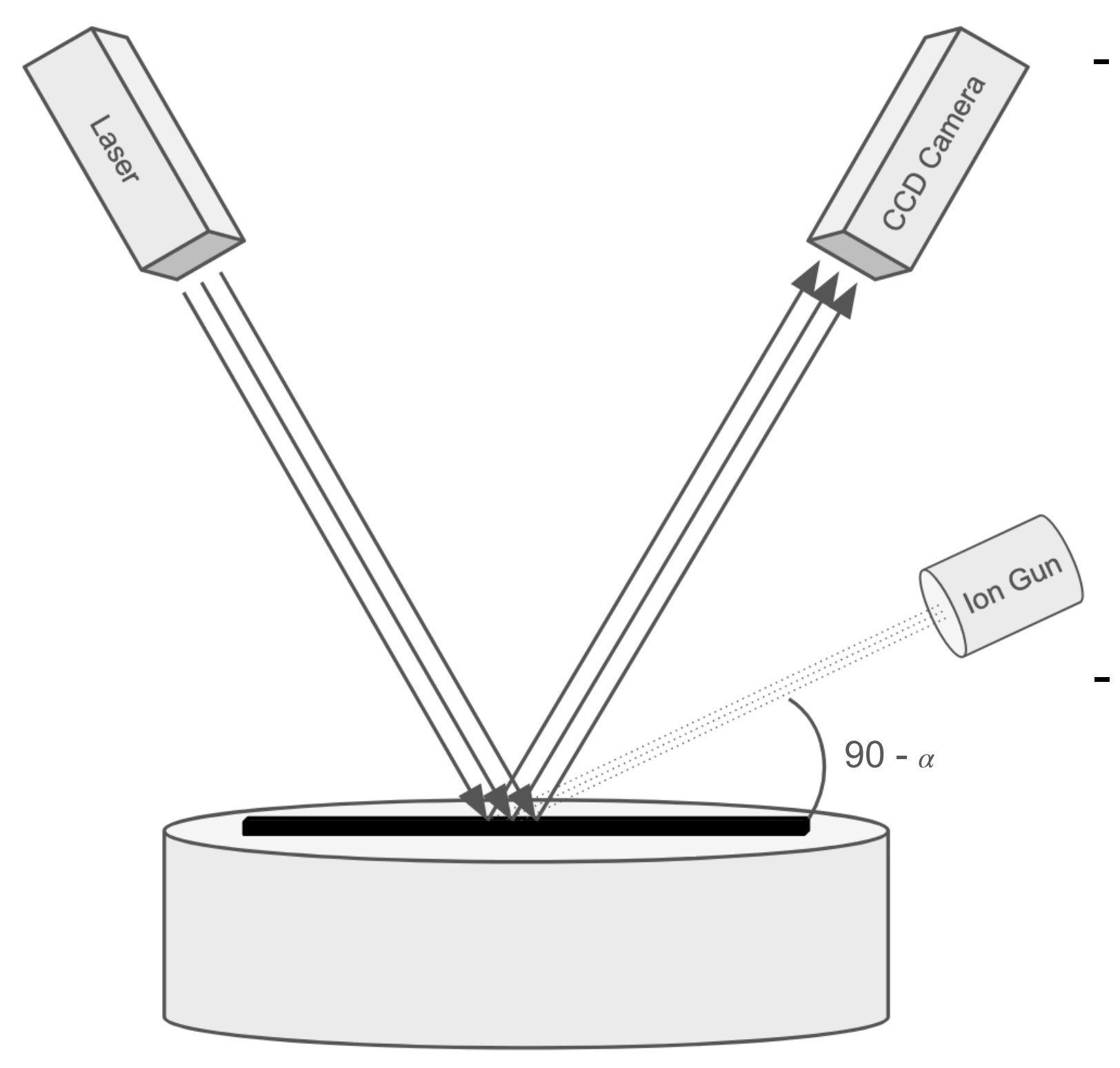
- Ion Beam Sputtering (IBS) is a process in which a beam of ions is used to bombard a target sample
- Nanopattern formation on materials under IBS has long been observed, but is not well understood.
- Stress can cause materials to curve through:



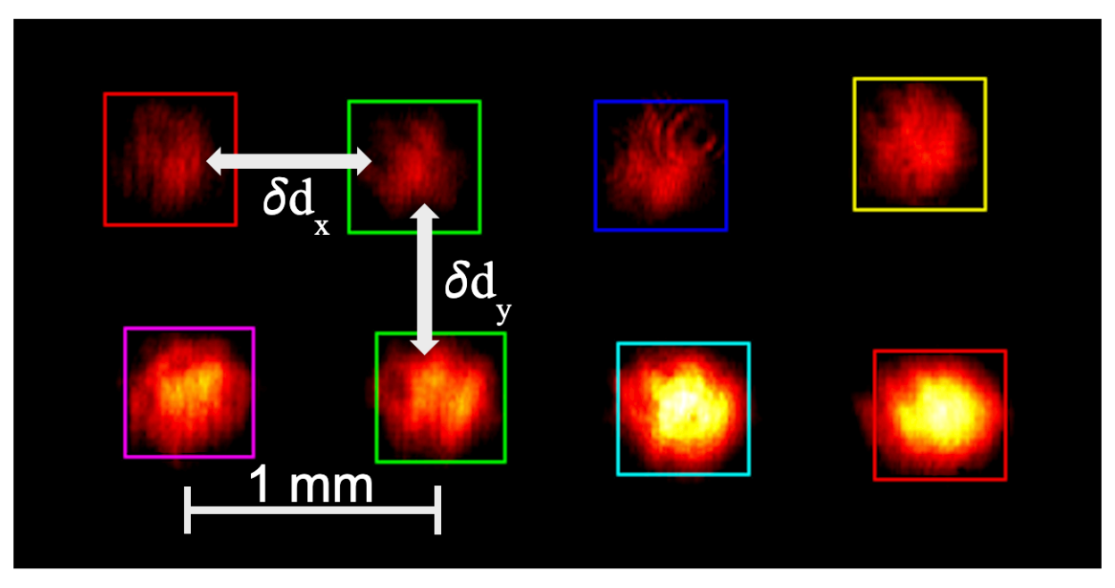
- Presence of impurities in sample material and bombardment process also contributes to stress and is a relevant issue in IBS

## Methods

- Silicon thin wafers were selected to study stress under IBS
- Samples in a clean chamber were used to study pattern formation with less impurities
- Wafers were bombarded with Ar$^+$ ions at $\alpha = 65°$ in a 5x10$^{-5}$ Torr vacuum
- Ion flux was 8.5 x 10$^{12}$ $\frac{\text{ions}}{\text{cm}^2 \cdot \text{s}}$



- Laser beams are reflected off sample and detected by a camera.
- Ion gun bombards sample with ions.
- Stress from bombardment causes the sample to curve. Stress can be determined by measuring material curvature.
- Curvature was detected using a Multi-Beam Optical Stress Sensor (MOSS). This system measures the change in spacing between reflected beams, therefore allowing us to calculate Mean Differential Spacing (MDS).



$\frac{\delta d_x}{d_0}$ - X MDS

$\frac{\delta d_y}{d_0}$ - Y MDS

$\delta d > 0$ Compressive Stress $\delta d < 0$ Tensile Stress

- Material stress was calculated using Stoney's equation:

$$\sigma_x = \left(\frac{\delta d_x}{d_0}\right)\left(\frac{1}{12 L \cos(\alpha)}\right)\left(\frac{E_s h_s^2}{h_f (1-\nu_s)}\right)$$

$$\sigma_y = \left(\frac{\delta d_y}{d_0}\right)\left(\frac{\cos(\alpha)}{12 L}\right)\left(\frac{E_s h_s^2}{h_f (1-\nu_s)}\right)$$

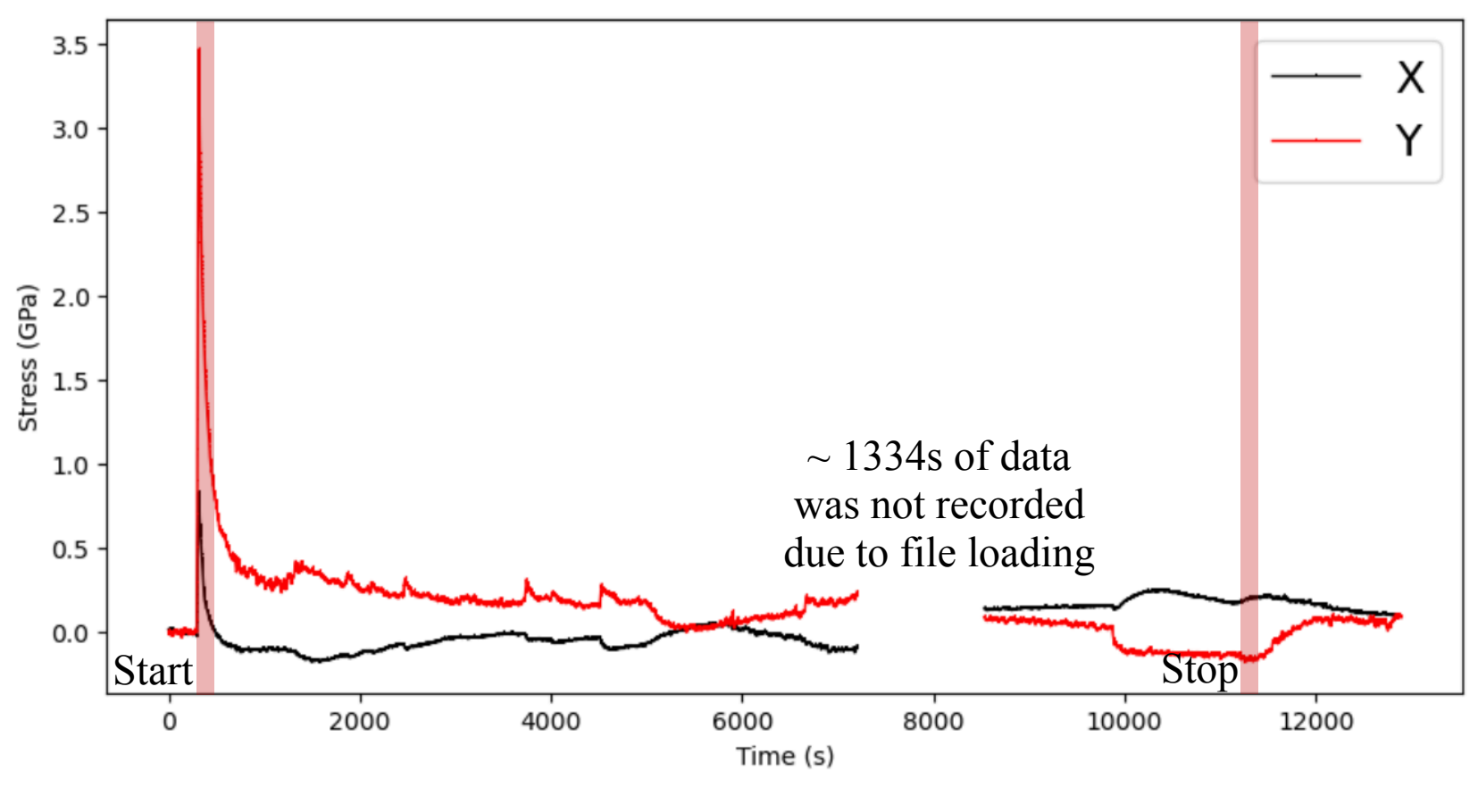
$E_s$ - Young's Modulus
$\nu_s$ - Poisson's ratio
$h_s$ - substrate thickness
$h_f$ - film thickness
$\alpha$ - the incident angle of the laser beam
$L$ - the distance between sample and camera
$\sigma$ - x/y stress

## Results

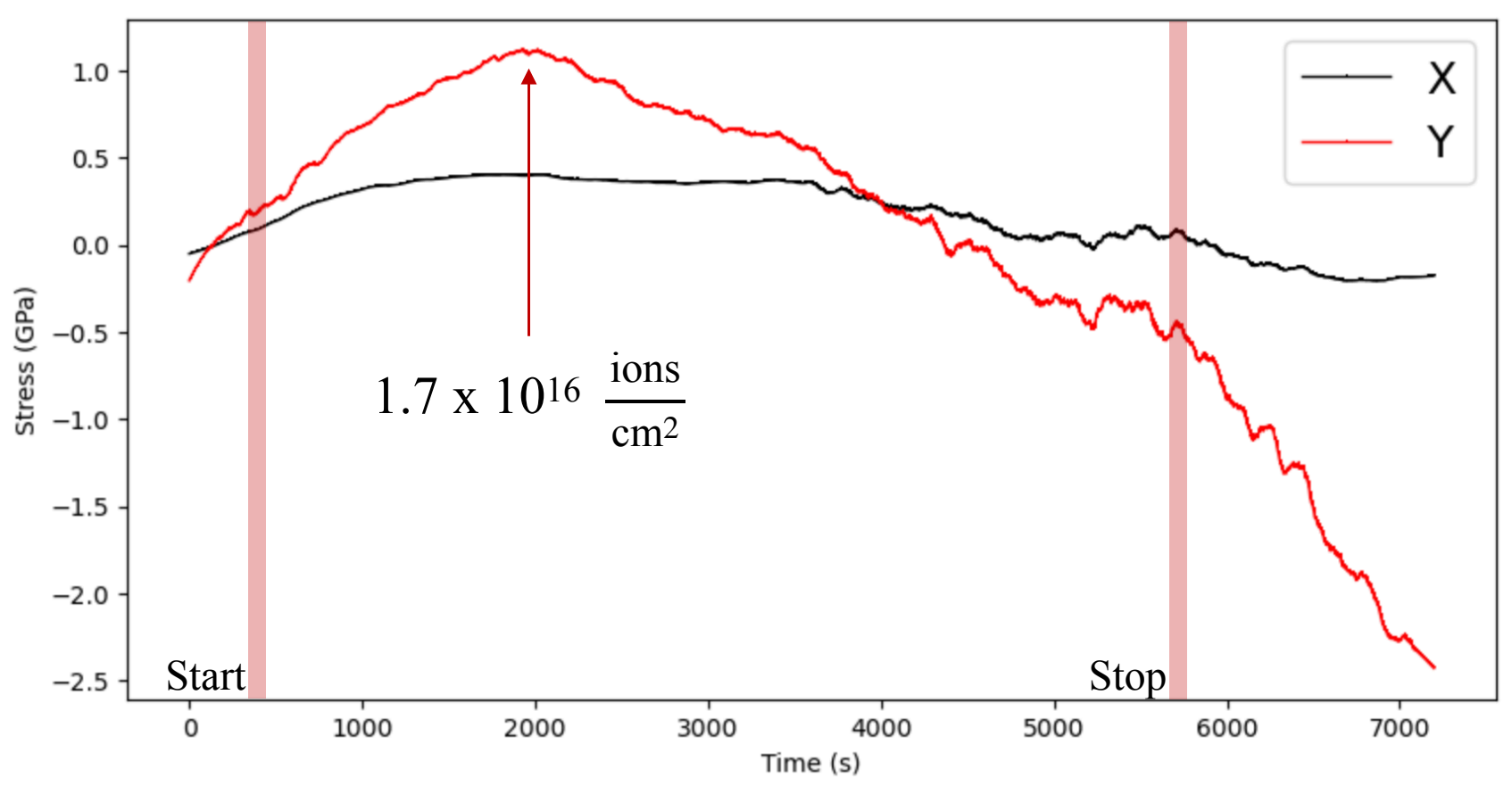
### Stress Development in Samples

- Samples underwent a 5 minute reference period and a 30 minute post-bombardment period with no bombardment occurring
- Stress sharply increases and decreases during beginning in 3 hour bombardment which is not typical behavior
- Stress appears to initially increase, reach a maximum, and then decrease during 90 min bombardment

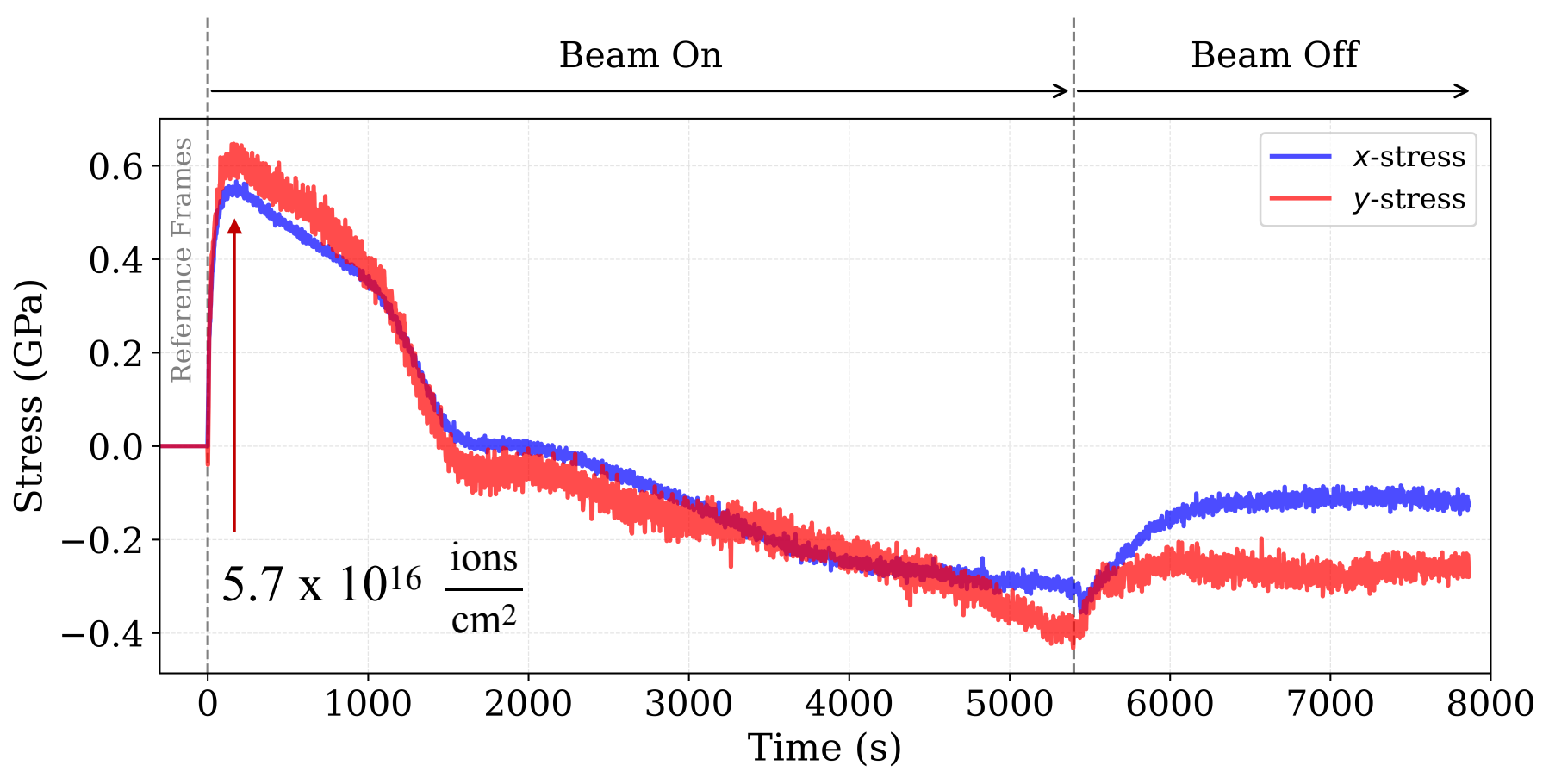
3 Hour Sample



90 Minute Sample



90 Minute Impurity Sample

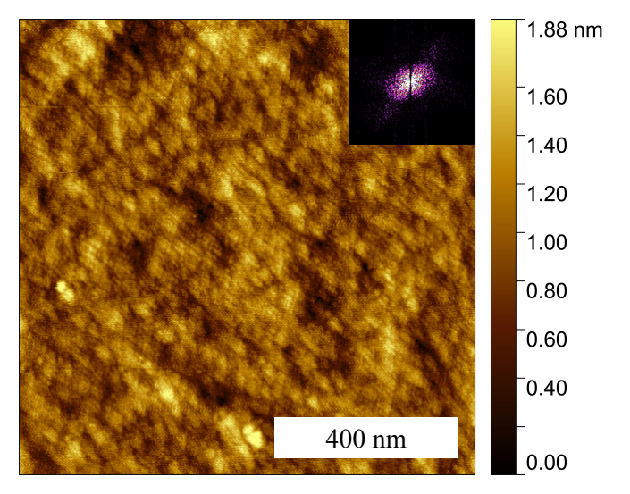


- Sample which contained impurities shows similar stress development to 90 min sample

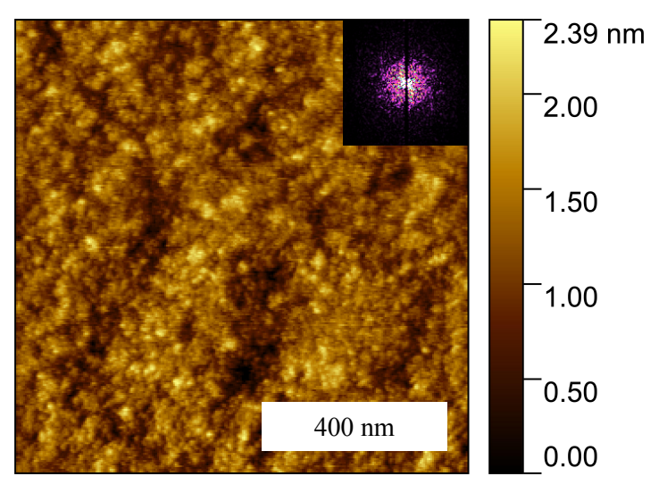
### Atomic Force Microscopy (AFM)

- AFM scans surfaces with a tip that measures the force interactions between the tip and the sample

3 Hour Sample



90 Minute Sample

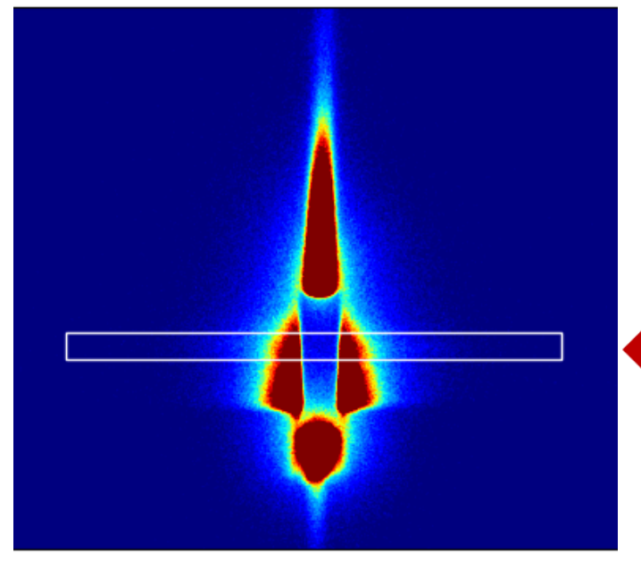


- Images show some pattern development, but no uniform ripples which is confirmed by 2D Power Spectral Density (PSD) images

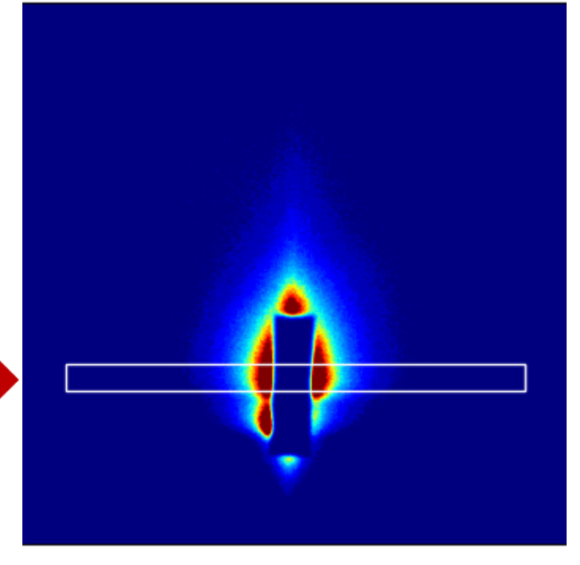
### Grazing-Incidence Small-Angle X-ray Scattering (GISAXS)

- GISAXS allows for analysis of thin film layer, whereas AFM only analyzes surface morphology
- A focused x-ray beam is incident on the thin film surface of a substrate
- Scattering from sample is then recorded and used for analysis

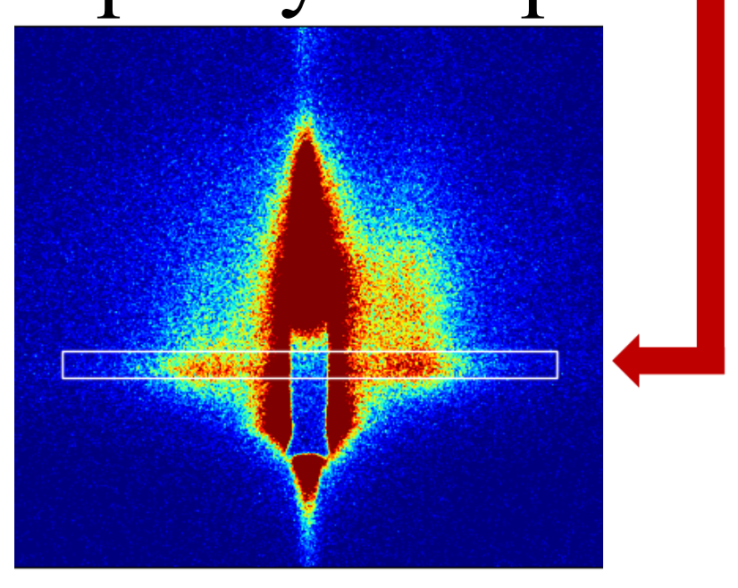
3 Hour Sample



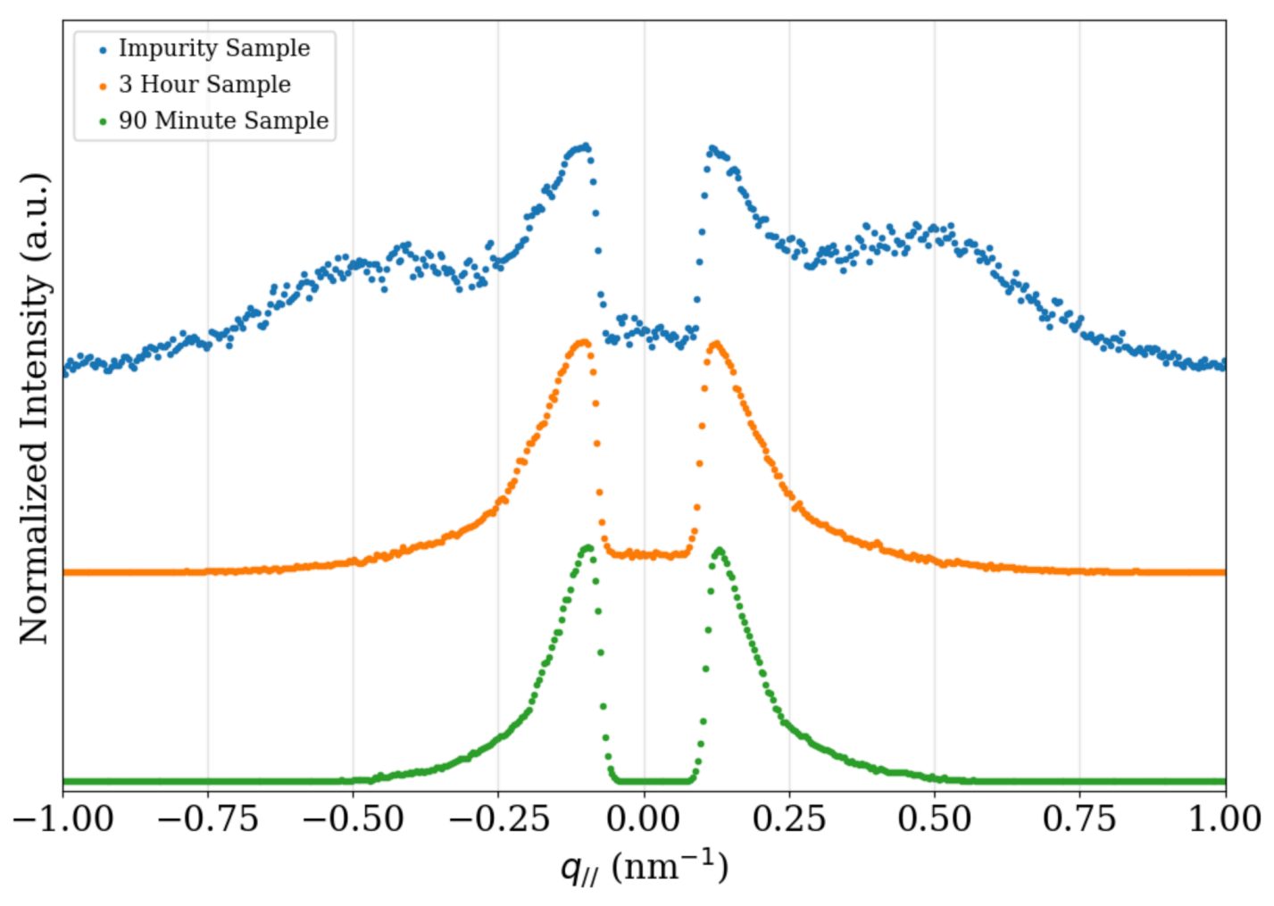
90 Minute Sample



Impurity Sample



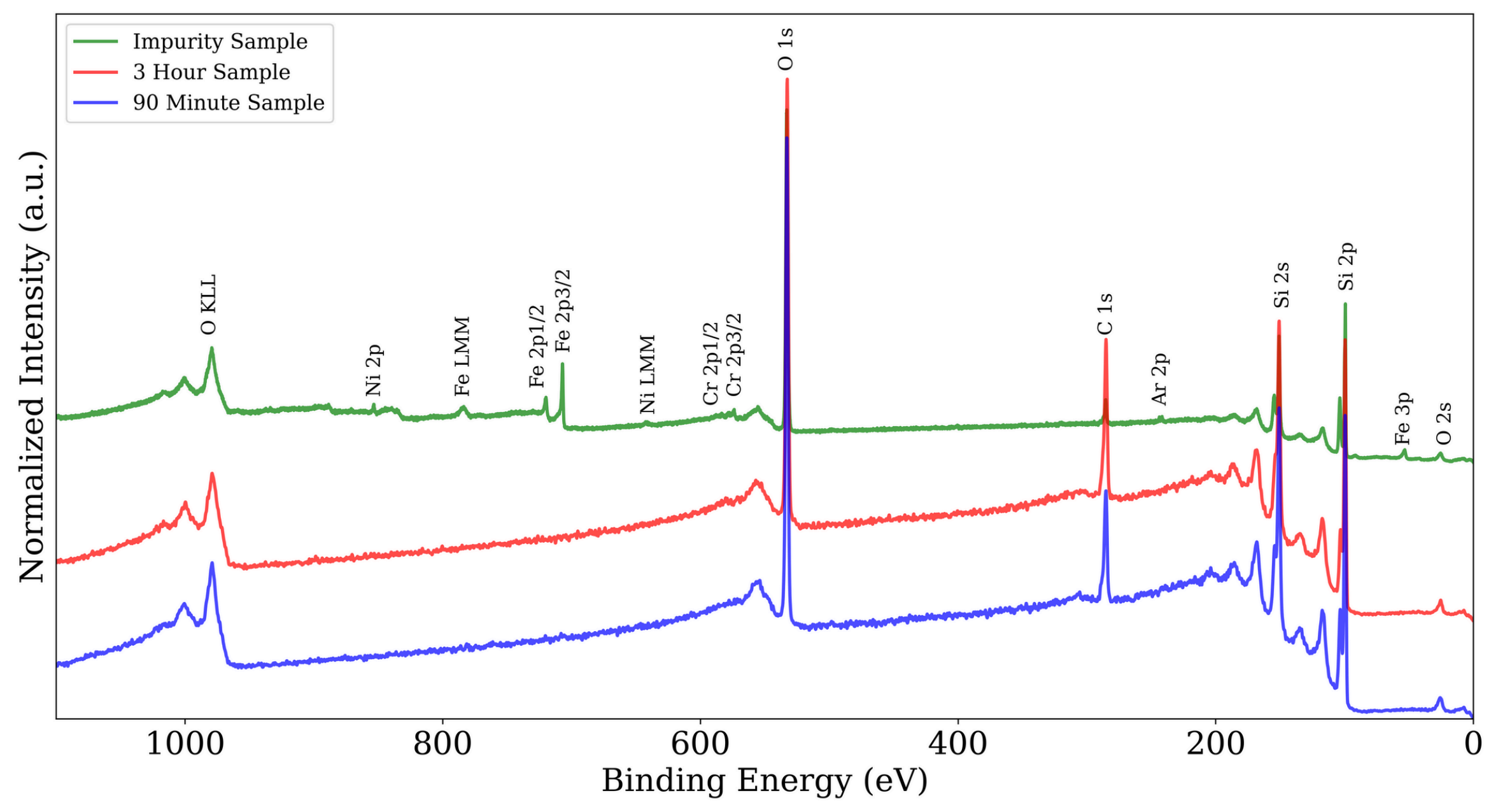
- Yoneda Wing is a region of enhanced x-ray scattering from the sample surface



- Impurity sample with ripples has clear Yoneda wing and intensity peaks, whereas 90 minute and 3 hour sample without ripples show no clear Yoneda wing and smooth intensity curves

### X-Ray Photoelectron Spectroscopy (XPS)

- During XPS, sample is irradiated with x-rays which causes emission of photoelectrons
- Kinetic energy of such photoelectrons is measured and used to determine binding energies which allow for identification of elements within sample



- Graph peaks show that 90 minute and 3 hour samples contained no impurities

## Discussion/Conclusions

- Stress development was observed in bombarded samples, but no direct correlation with nanopattern formation was evident under current conditions
- Increasing ion fluence could produce more uniform patterns
- Optimization of experimental conditions is still ongoing

## Acknowledgements

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## References

Li, H., Jiang, B. et al. The Independence of Nanopattern Formation and Stress Evolution During Low-Energy Ar$^+$ Bombardment of Si. *In Preparation 2025*