Determining Thin Film Roughness with Extreme Ultraviolet Light

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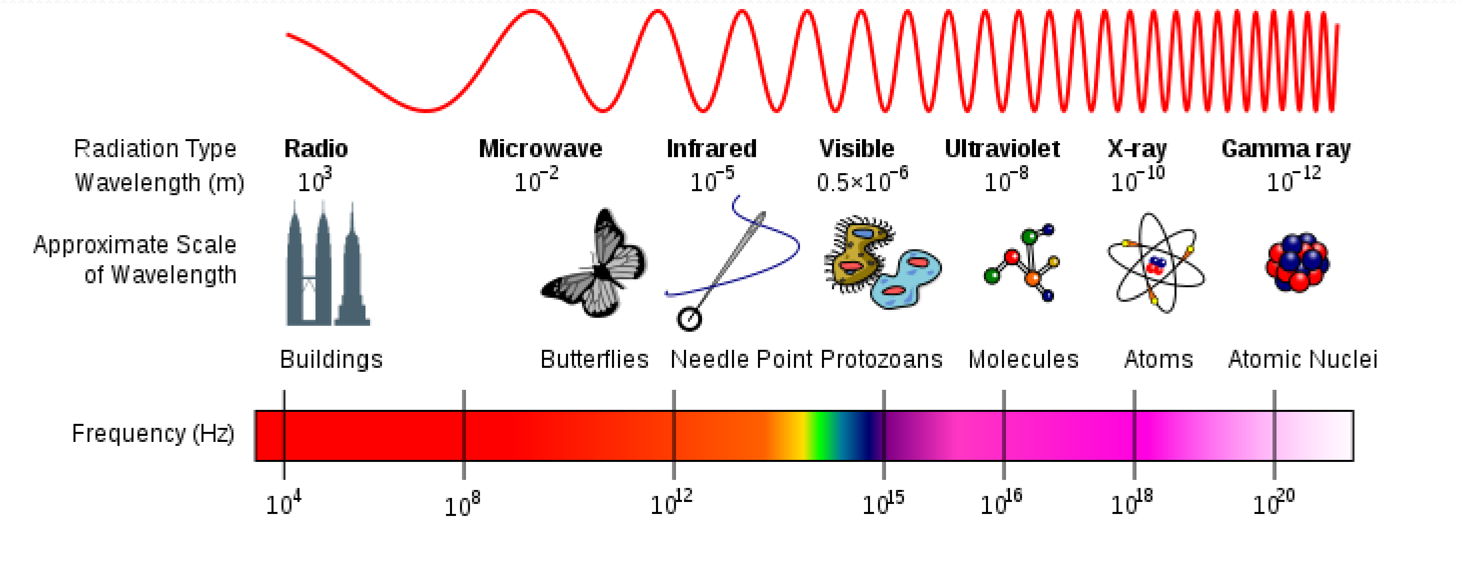
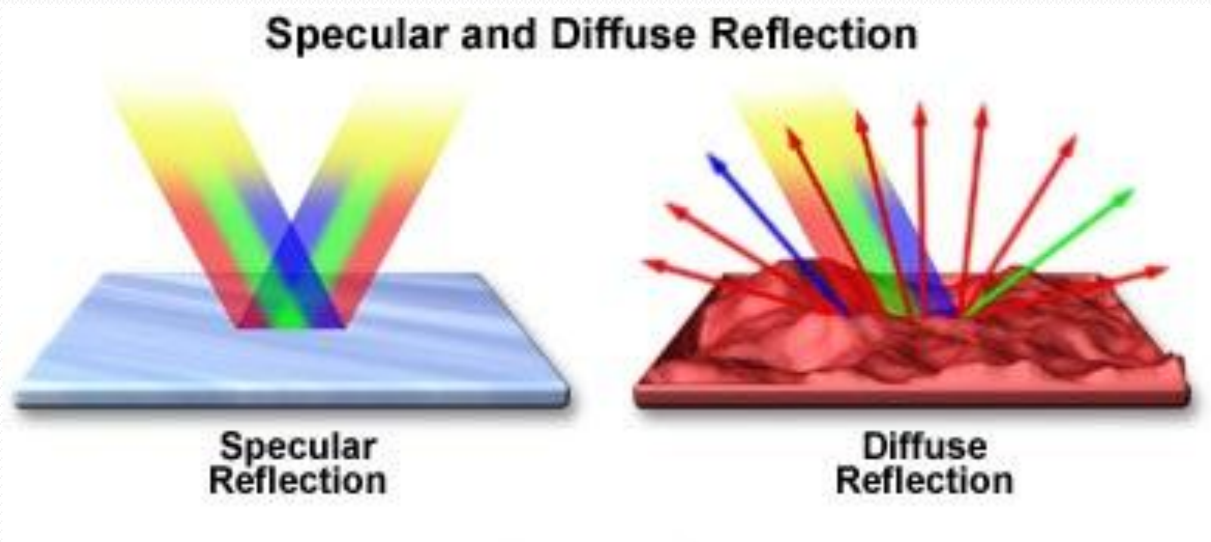
Extreme Ultraviolet (EUV)

- EUV Wavelength: about 1nm to 60nm.
- Absorbed strongly by almost every medium.



Nonspecular Reflection



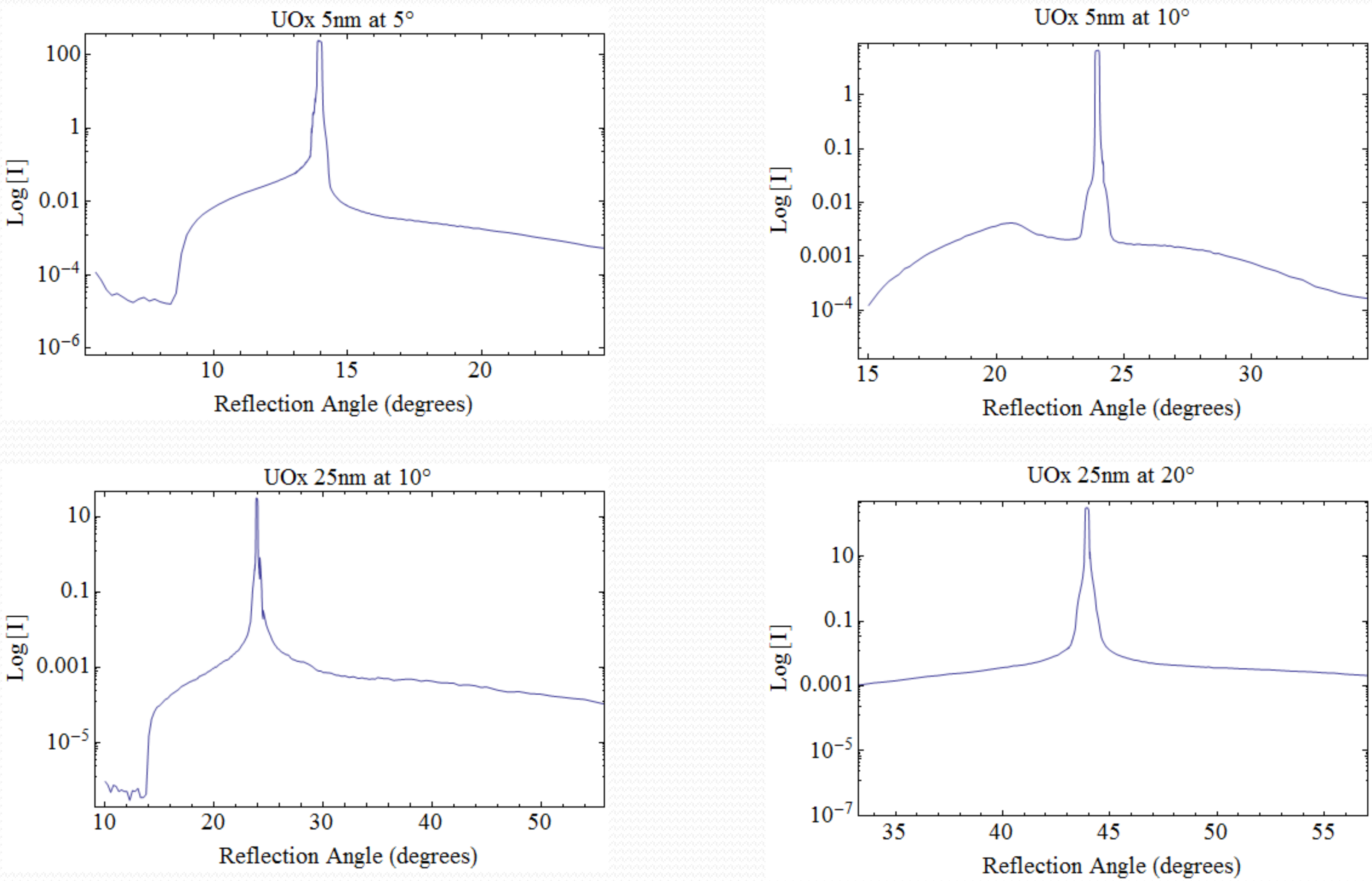
Data Acquisition

- Lawrence Berkeley National Laboratory.
  - Collected data at the Advanced Light Source beamline 6.3.2.
- Collected data from two samples of UO_x (Uranium Oxide)
  - Thicknesses of 412nm & 44nm
- 4 scans for each sample, each with different wavelengths and different angles.

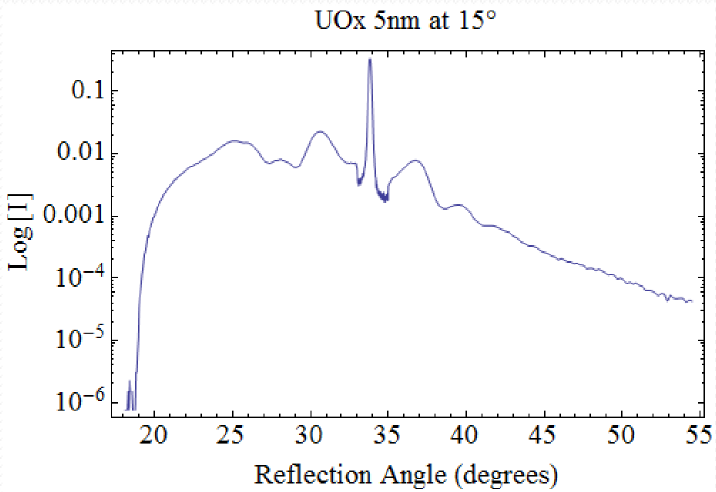
Data

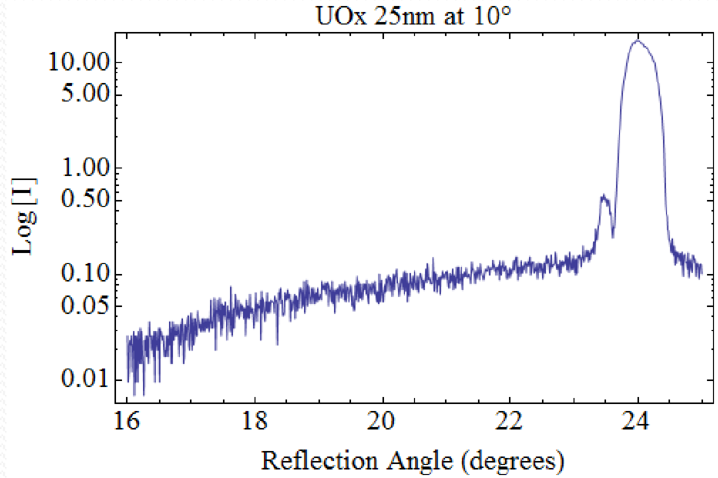
- Channel Electron Multiplier (CEM)
  - Limited to about 100,000 photon counts.
  - Data taken with different filters to decrease photon count.
  - Renormalized points to get smooth reflection data. We have data that spans up to 6 decades.

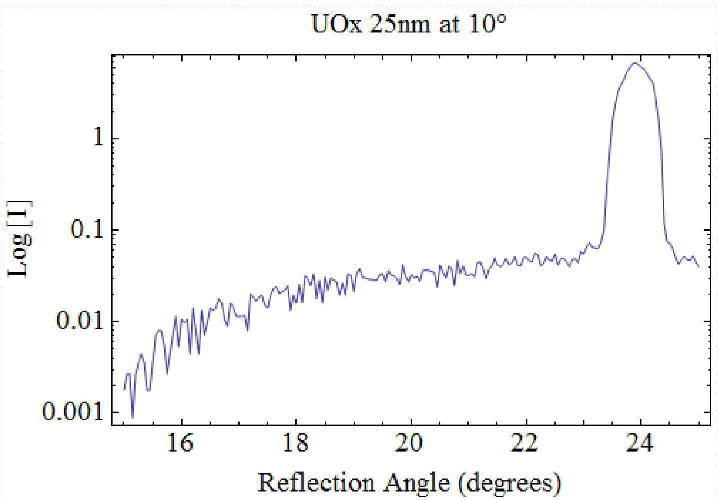
UOx 412nm Thickness

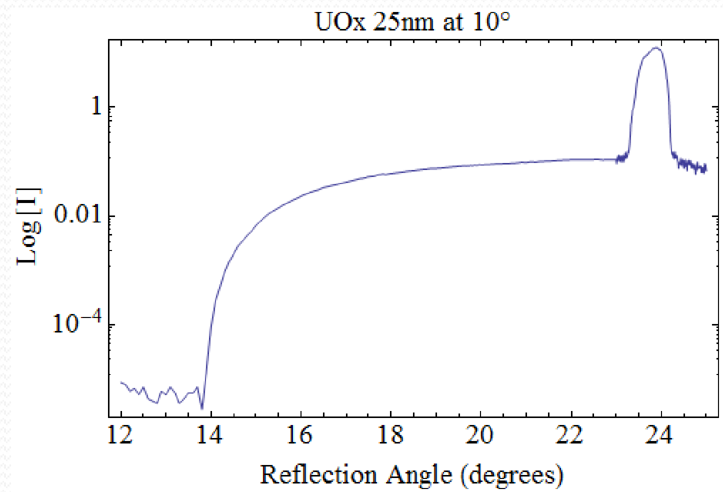


UOx 44nm Thickness





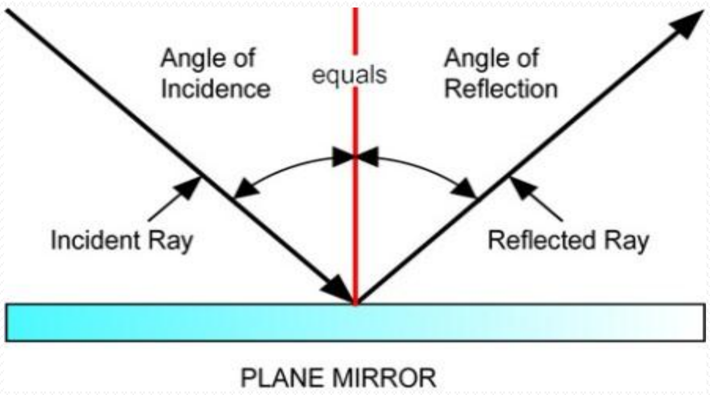




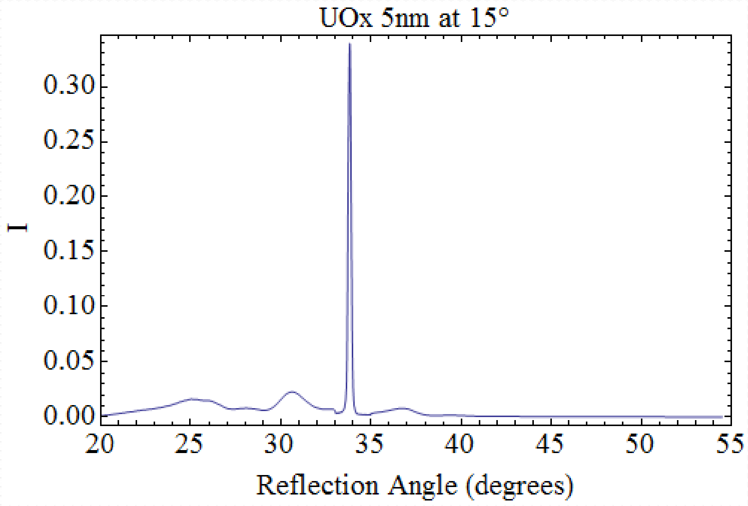
Data Analysis

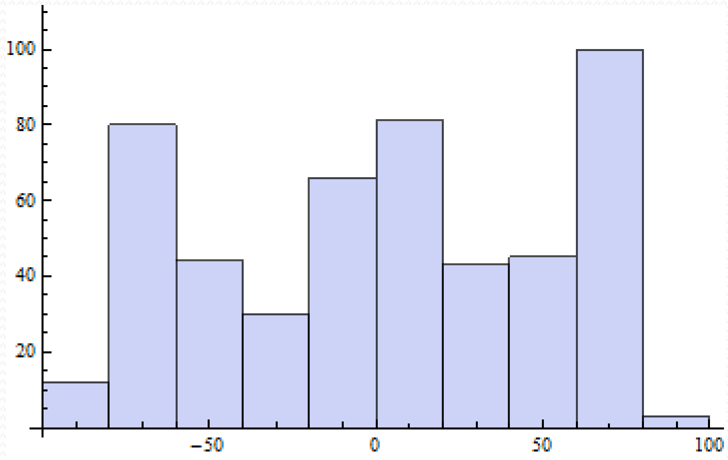
- Compared these results to 3 different calculation.
- Creating a surface that has RMS roughness and PSD determined by AFM data that has been collected.
- The 3 methods that we have used are
  - Geometrical Optics
  - Physical Optics
  - Physical Optics without Kirchhoff Approximation
    - No results from this yet

Geometrical Optics



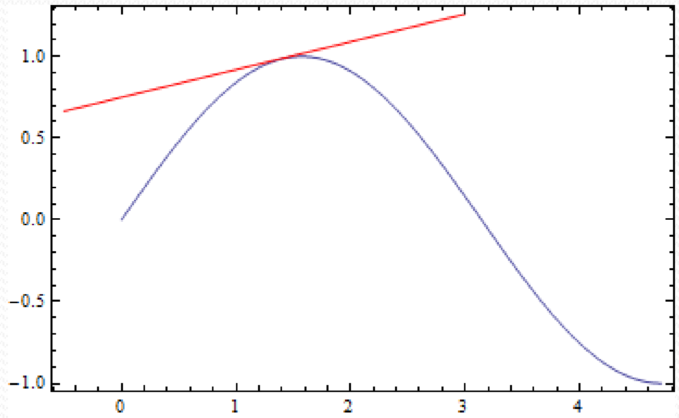
- The Results that we got from geometrical optics did not correspond with the data collected.
- This must not be good enough for our surfaces.





Physical Optics

- Kirchhoff Approximation



- Assume a plane wave incident on a locally planar surface.
- Calculate the currents induced on the surface.
- This approximation works if the surface is smooth compared to the wavelength.

Physical Optics

- Use Maxwell's equations to calculate the radiated fields.

$$\nabla \cdot \mathrm{D} = 0$$

$$\nabla \cdot \mathrm{B} = 0$$

$$\nabla \times \mathrm{H} = \frac{\partial \mathrm{D}}{\partial \mathrm{t}}$$

$$\nabla \times \mathrm{E} + \frac{\partial \mathrm{B}}{\partial \mathrm{t}} = 0$$

These are turned into boundary integral equations by using the divergence theorem.

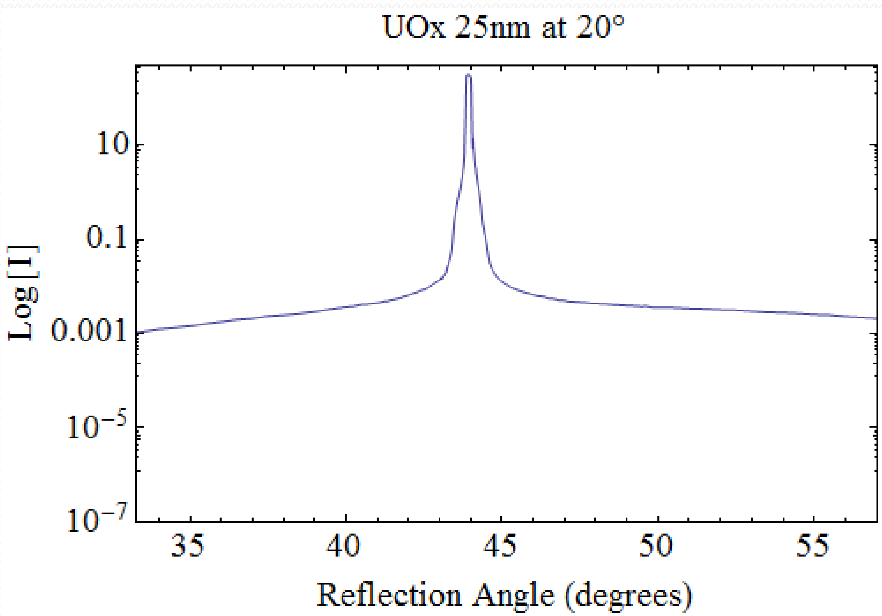
$$\int_V (\nabla \cdot \mathbf{A})\, dV = \oint_S (\mathbf{A} \cdot \hat{\mathbf{n}}) dA$$

- Slit allows 2D calculation rather than 3D.
- These calculations were done for a perfect conductor. Very similar to calculations for a dielectric.

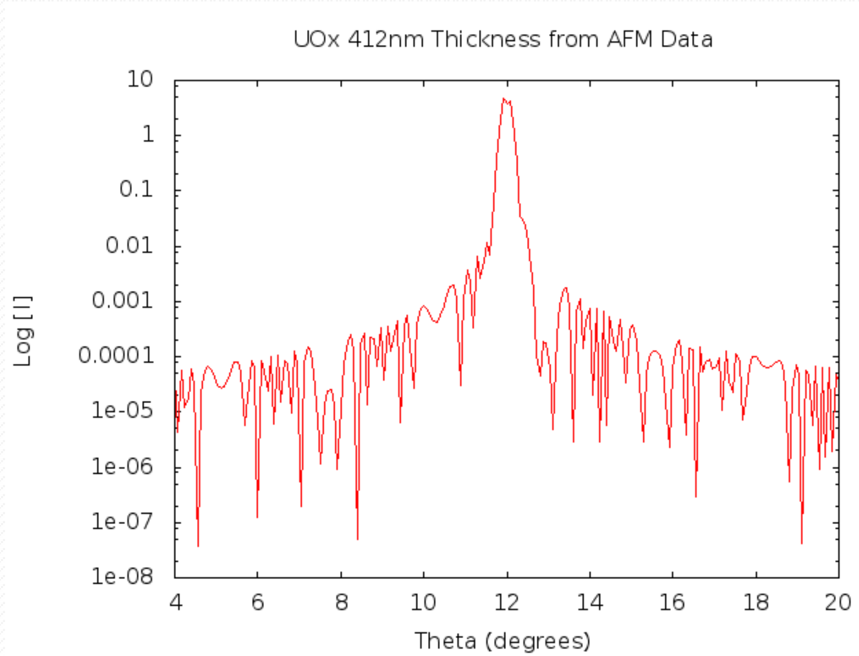
Reflection vs. AFM

- 412nm Thickness

Measured



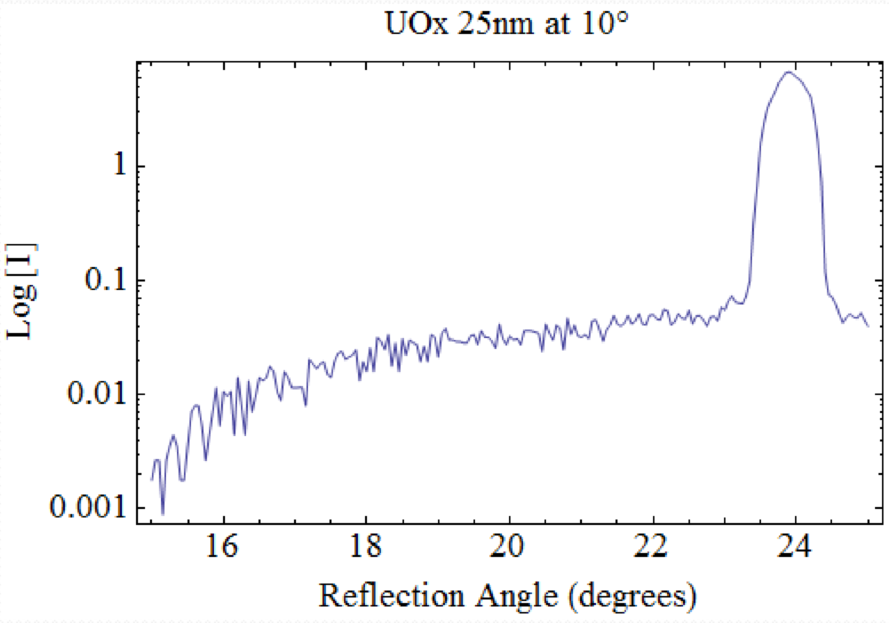
Calculated



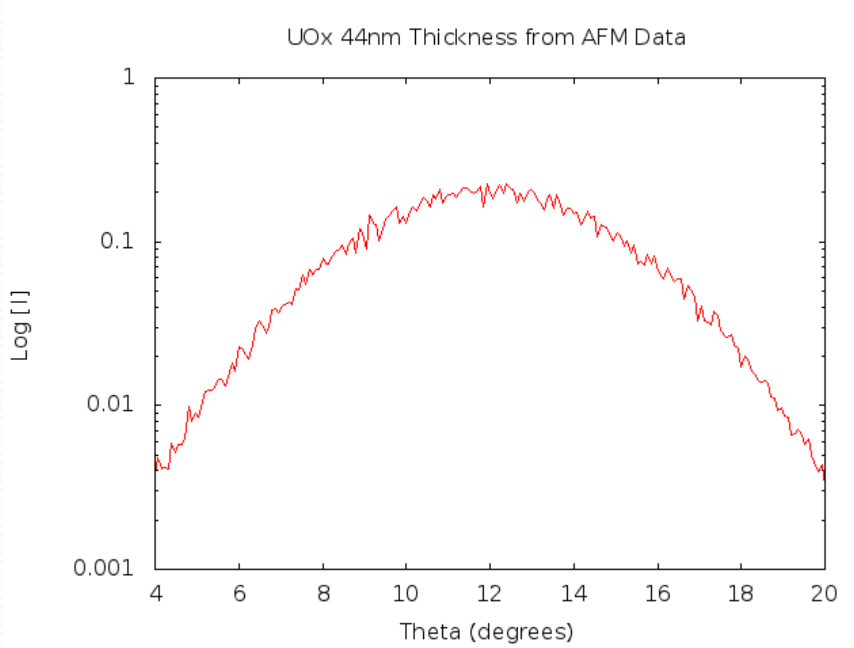
Reflection vs. AFM

- 44nm Thickness

Measured



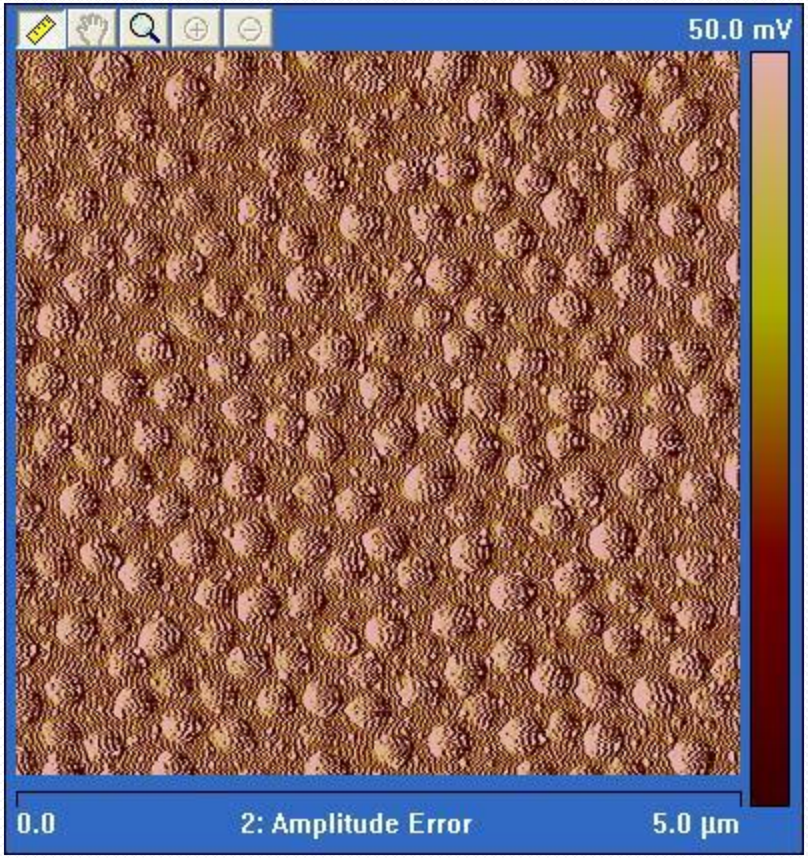
Calculated



Reflection vs. AFM

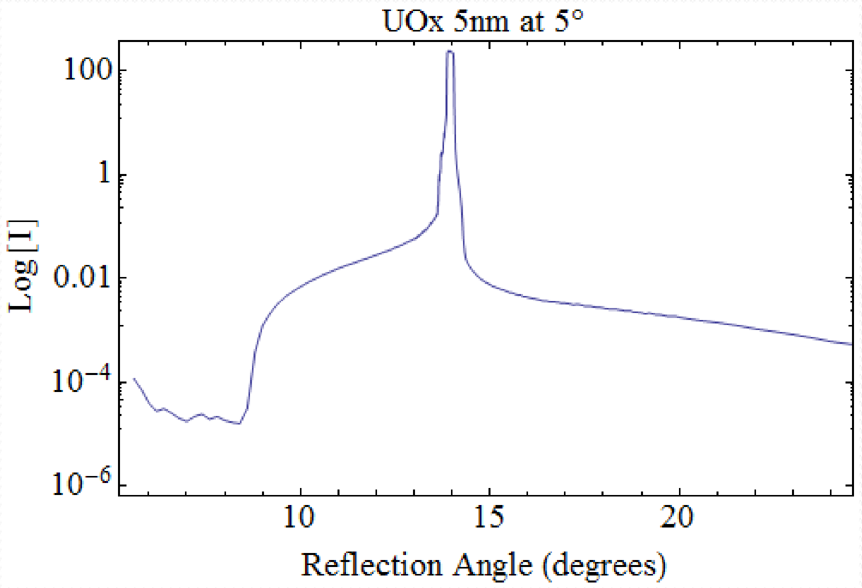
- 44nm Thickness
- AFM Data
  - RMS: 16.0 nm
  - PSD: 2.8 □m⁻¹

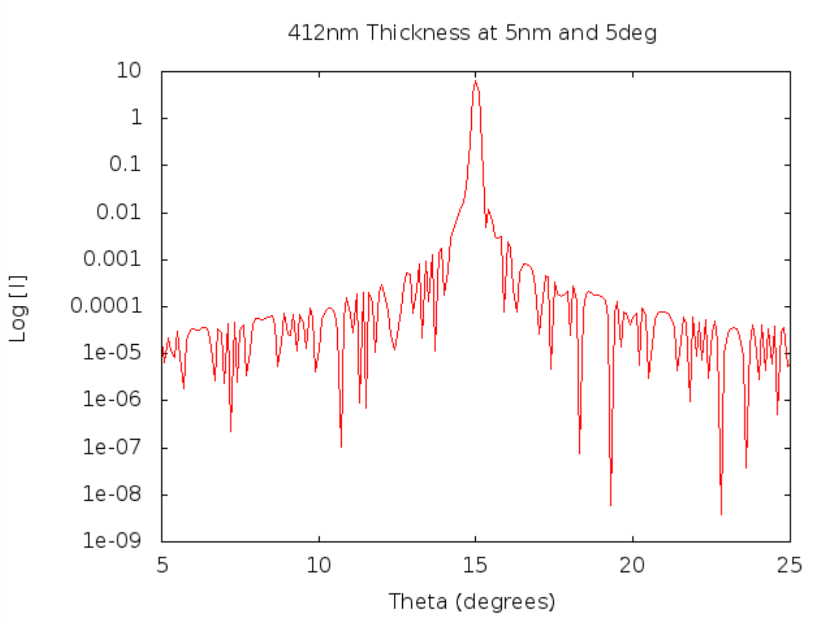
UOx



Fitting Reflection Data

412nm Thickness

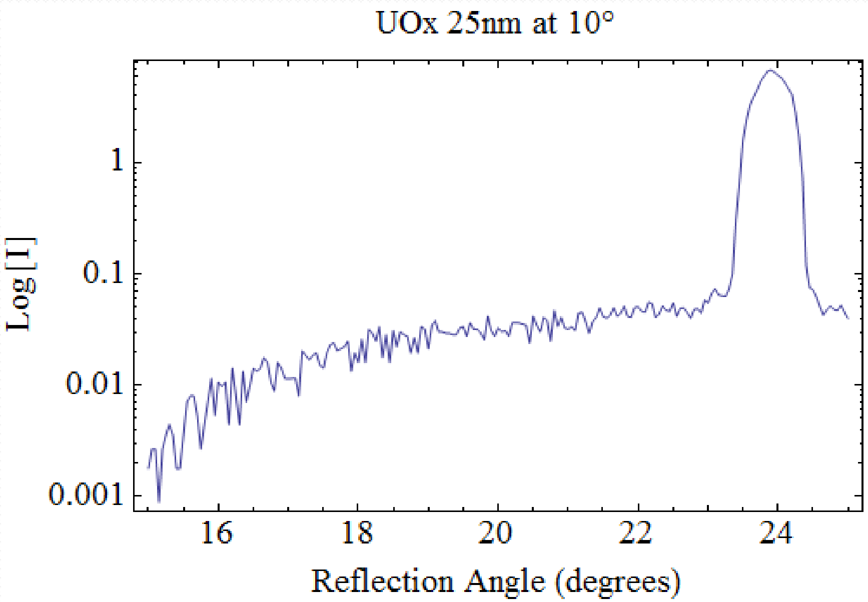


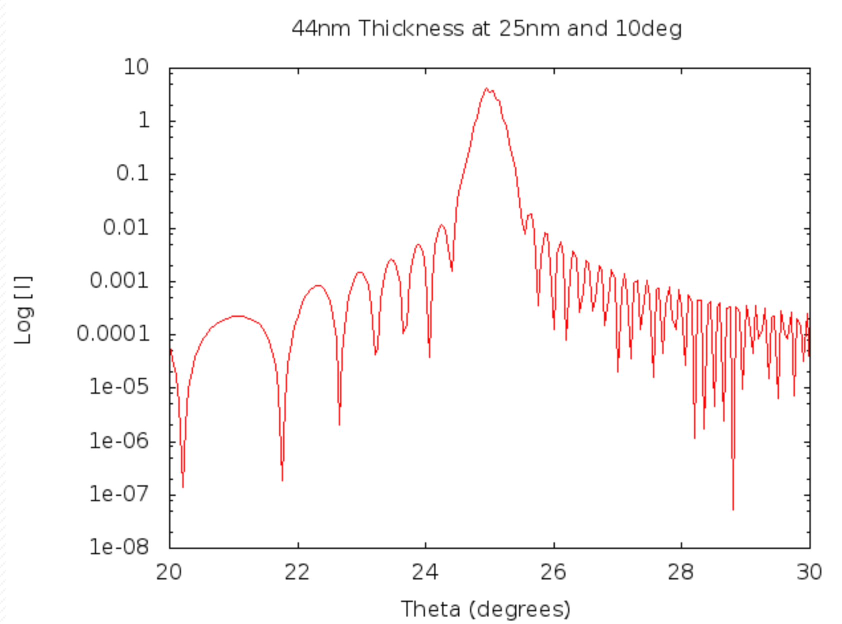


	AFM:	Calculation:
RMS:	6.97nm	5nm
PSD:	0.2□m^{-1}	0.2□m^{-1}

Fitting Reflection Data

44nm Thickness





	AFM:	Calculation:
RMS:	16nm	10nm
PSD:	2.8□m^{-1}	0.2□m^{-1}

Conclusion

- Another method of measuring surface roughness that compliments existing methods such as AFM.
  - This gives us insights that other methods don’t give us.

Acknowledgements

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- Greg Hart
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- Brigham Young University REU Program

Data Normalization

- Normalization
  - Width of the beam at the detector is 1.09˚.
  - Calculate how much of the entire scan entered the detector.

$$\lambda = \frac{\int_{a}^{b} R \, d\theta}{\int_{-\infty}^{\infty} R \, d\theta}$$

- Where a and b are 1.09˚/2 away from the peak.

Data Normalization

- Normalization
  - Reflectivity of the sample at a particular angle.

$$\text{Reflectivity} = \frac{\mathrm{I}}{\mathrm{I}_0}$$

$$\frac{dR}{d\theta} = \frac{\text{Reflectivity}}{\lambda} = \mathrm{R}'$$

  - Normalized beam is $\frac{d^2\mathrm{R}}{d\theta^2}$

$$\frac{d^2\mathrm{R}}{d\theta^2} = \mathrm{R}\frac{\mathrm{R}'}{\int_{-\infty}^{\infty} \mathrm{R}\, d\,\theta}$$