Today’s Outline - November 28, 2016

- Presentation schedule
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- Grating interferometry
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- Coherent diffraction imaging
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Final Exam information
Wednesday, December 7, 2016, room 213 SB
09:00  Johan Nilsson – High-energy surface x-ray diffraction for fast surface structure determination
09:20  Kathy Ho – In situ synchrotron x-ray imaging on morphological evolution of dendrites in Sn-Bi hypoeutectic alloy under electric currents
09:40  Jason Lerch – X-ray PIV measurement of deep vein blood flow in a rat
10:00  Shokoufeh Asalzadeh – Structural evolution of platinum thin films grown by atomic layer deposition
10:20  Stoichko Antonov – Visualization of a lost painting by Vincent van Gogh using synchrotron radiation based x-ray fluorescence elemental mapping
10:40  Henry Gong – Three-dimensional imaging of crystalline inclusions embedded in intact maize stalks
11:00  Runzi Cui – Spherical quartz crystals investigated with synchrotron radiation
13:00 Nicholas Goldring – Reactivity of LiBH$_4$: In situ synchrotron radiation powder x-ray diffraction study
13:20 Anthony Llodra – Imaging instantaneous electron flow with ultrafast resonant x-ray scattering
13:40 Gongxiaohui Chen – Rotation of x-ray polarization in the glitches of a silicon monochromator
14:00 Sarah Aldakheel – Synchrotron radiation diffraction enhanced imaging of chronic glomerulonephritis mode
14:20 Bo Liu – Chain stiffness of stilbene containing alternating copolymers by SAXS and SEC
14:40 Krishna Joshi – Transition elements and nucleation in glasses using x-ray absorption spectroscopy
15:00 Yang Liu – Visualization and quantification of electrochemical and mechanical degradation in Li ion batteries
15:20 Yiqing Zhang – TBD
Grating interferometry

Full field phase imaging can be achieved using an interferometric technique
Grating interferometry

Full field phase imaging can be achieved using an interferometric technique. The Talbot effect: vertical grating illuminated by a plane wave.
Grating interferometry

Full field phase imaging can be achieved using an interferometric technique
Talbot effect: vertical grating illuminated by a plane wave

for a vertical grating of period $p_1$ illuminated by a wavelength $\lambda$ the
transverse wave number is $k_x = \frac{2\pi}{p_1}$
Grating interferometry

Full field phase imaging can be achieved using an interferometric technique. The Talbot effect: a vertical grating illuminated by a plane wave.

For a vertical grating of period $p_1$ illuminated by a wavelength $\lambda$ the transverse wave number is $k_x = \frac{2\pi}{p_1}$.

Propagating the wave downstream as described previously.
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Propagating the wave downstream as described previously,

$$\tilde{\psi}_x \sim e^{ik_x^2z/(2k)}$$

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$$\sim e^{i\left(\frac{2\pi}{p_1}\right)^2 z/(2k)}$$

$$\sim e^{i2\pi \lambda z/(2p_1^2)}$$
Grating interferometry

Full field phase imaging can be achieved using an interferometric technique.

Talbot effect: vertical grating illuminated by a plane wave.

For a vertical grating of period \( p_1 \) illuminated by a wavelength \( \lambda \) the transverse wave number is \( k_x = \frac{2\pi}{p_1} \).

Propagating the wave downstream as described previously the repeat distance, called the Talbot distance, is given by \( d_T = \frac{2p_1^2}{\lambda} \).

\[
\tilde{\psi}_x \sim e^{i\frac{k_x^2 z}{(2k)}}
\]
\[
\sim e^{i\frac{(2\pi / p_1)^2 z}{(2k)}}
\]
\[
\sim e^{i2\pi \lambda z / (2p_1^2)}
\]
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for $p_1 = 1\mu m$ and $\lambda = 1\AA$ we have a Talbot distance, $d_T = 20\text{mm}$

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for an absorption grating

\[ \tilde{\psi}_x \sim e^{ik_x^2 z/(2k)} \]
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For $p_1 = 1 \mu m$ and $\lambda = 1 \AA$ we have a Talbot distance, $d_T = 20 mm$.

For a partial phase grating, the pattern of transmission may be repeated at rational fractions of $d_T$.

\[ \tilde{\psi}_x \sim e^{i k_x^2 z/(2k)} \]
\[ \sim e^{i (2\pi/p_1)^2 z/(2k)} \]
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for $p_1 = 1\mu m$ and $\lambda = 1\text{Å}$ we have a Talbot distance, $d_T = 20\text{mm}$

for a full $\pi$ phase grating the lateral period is doubled

$$\tilde{\psi}_x \sim e^{ik_x^2z/(2k)}$$

$$\sim e^{i(2\pi/p_1)^2z/(2k)}$$

$$\sim e^{i2\pi\lambda z/(2p_1^2)}$$

the pattern of transmission may be repeated at rational fractions of $d_T$
The Talbot interferometer consists of two gratings, a phase grating of lateral period $p_1$ (G1) and an absorption grating of lateral period $p_1/2$ (G2) which in combination, measure the distortion of the phase field due to the sample.
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Talbot interferometer operation

With no sample in place, the pink blocks are the intensity at \( d = \frac{p_1^2}{8\lambda} \) downstream from a \( \phi = \pi \) grating.

Detector Pixel

\[ x_g \]

\[ p_1 \]
Talbot interferometer operation

With no sample in place, the pink blocks are the intensity at $d = \frac{p_1^2}{8\lambda}$ downstream from a $\phi = \pi$ grating.

As the absorption grating, (G2) is moved laterally, the pink triangles show the ideal intensity observed at the detector as a function of $x_g$. The real intensity is more sinusoidal because of finite beam size when the sample is in place the intensity is reduced and shifted by refraction to the blue blocks and curve.
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\[ d = \frac{p_1^2}{8\lambda} \]

Detector Pixel
Talbot interferometer operation

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As the absorption grating, \( (G2) \) is moved laterally, the pink triangles show the ideal intensity observed at the detector as a function of \( x_g \). The real intensity is more sinusoidal because of finite beam size.

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Three positions of the absorption grating are all that is needed to obtain the information to produce absorption, dark field and phase contrast images.
We can define the visibility function as
Visibility

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\[ V = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \]
We can define the visibility function as

\[ V = \frac{l_{\text{max}} - l_{\text{min}}}{l_{\text{max}} + l_{\text{min}}} \]

for the ideal intensity \( V \equiv 1 \).
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with the sample in place, the visibility is necessarily smaller due to absorption
Grating interferometry

Plastic containers filled with water (left) and powdered sugar (right). (a) absorption image, (b) phase contrast image, (d) dark field image.
Grating interferometry

Plastic containers filled with water (left) and powdered sugar (right). (a) absorption image, (b) phase contrast image, (d) dark field image.

visibility of zero leads to the speckling in (b) as can be seen from the red line in (c)
Grating interferometry

The different contrasts are easily seen in the image of a chicken wing.
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The absorption contrast (left) is most like a conventional radiograph.
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The absorption contrast (left) is most like a conventional radiograph

the phase contrast (right) is sensitive to changes in angle of the surface and buried interfaces
Grating interferometry

The different contrasts are easily seen in the image of a chicken wing.

The absorption contrast (left) is most like a conventional radiograph.

The phase contrast (right) is sensitive to changes in angle of the surface and buried interfaces.

The “dark field” image lights up where there is a large amount of scattering.
Tomography with a Talbot interferometer

The Talbot interferometer may be used for tomography as well.

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The Talbot interferometer may be used for tomography as well. The sample is rotated and the phase data is recorded in the usual way.

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SAXS from a sphere

For incoherent beam, illuminating a small particle (a sphere), we have the typical small angle pattern which shows broad features described in a previous chapter.
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Coherent Scattering from Multiple Spheres

If the beam has coherence at least on the order of the size of the arrangement of the seven spheres shown, one obtains
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![Plot](image)

The left image shows the “speckle” pattern given by the interference of the coherent beam with the seven spheres. The right image is the full pattern including the SAXS from individual spheres. The speckle changes with a different arrangement of spheres, which can be seen when the speckle appears below a glass transition at 145 K.
Coherent Scattering from Multiple Spheres

If the beam has coherence at least on the order of the size of the arrangement of the seven spheres shown, one obtains

![Graph 1](image1.png)

on the left is the “speckle” pattern given by the interference of the coherent beam with the seven spheres,
Coherent Scattering from Multiple Spheres

If the beam has coherence at least on the order of the size of the arrangement of the seven spheres shown, one obtains

\[ T = 295 \text{K} \]
\[ T = 145 \text{K} \]

on the left is the “speckle” pattern given by the interference of the coherent beam with the seven spheres, on the right is the full pattern including the SAXS from individual spheres.
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Coherent Scattering from Multiple Spheres

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\[ T = 295 \text{K} \quad \text{and} \quad T = 145 \text{K} \]

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1st iteration:
\[ A'(Q) = \sqrt{I(Q)} \exp[i\varphi(Q)] \]
Random phase \( \varphi(Q) \)

Constraints: Real Space
- Positive?
- Real?
- Apply support

Constraints: Q Space
- \(|A(Q)| = \sqrt{I(Q)}|\)

\( \rho'(r) \)

\( \rho(r) \)

\( A(Q) \)

\( A'(Q) \)

\( FT \)

\( FT^{-1} \)
Iterative Reconstruction

start with experimental data and a randomly generated phase
Iterative Reconstruction

start with experimental data and a randomly generated phase

intermediate step shows partial phase retrieval but distorted scattering pattern
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start with experimental data and a randomly generated phase

intermediate step shows partial phase retrieval but distorted scattering pattern

convergence to reconstructed phase, scattering and real space image
Gold nanoparticle imaging by CXI

Real Space

Reciprocal Space
Gold nanoparticle imaging by CXI
Lattice dynamics by CXI

X-ray detector

Diffracted X-ray pulses

Pump pulses

Coherent X-ray pulses

Nanocrystals