Coherence at Short Wavelength

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Coherence and high brightness sources

Is this more than a pedagogical exercise?

Coherent scattering and imaging with soft x-rays

Speckle pattern of Co:Pt film at $\lambda = 1.6$ nm: Pierce, et. al., PRL 90 175502 (2003); 94, 017202 (2005).

$H_2$ speckle pattern of nano-swiss-cheese at $\lambda = 0.1$ nm; Patton, et. al., PRL, 73, 013202 (2006).
Longitudinal and Transverse Coherence

Source with limited coherence

Spatial filtering improves transverse coherence

Spectral filtering improves longitudinal coherence

Spatial and spectral filtering leads to a 'textbook' wavefront

Lasers offer good longitudinal and transverse coherence, but short wavelength lasers are not yet readily available.

Transverse Coherence and Minimum Uncertainty

Monochromatic source with limited coherence

Phase space ellipse for the source: \((x, p_x)\) distribution of particle trajectories.

In free propagation the ellipse rotates while conserving area; the pinhole terminates some trajectories.

The segment of the truncated ellipse rotates further; the second pinhole selects the desired phase space area, \(\Delta x \Delta p_x \sim \hbar/2\).

To achieve \(~90\%\) fringe contrast:
\[
F_{coh} = B \left(\frac{\lambda}{2}\right)^2 \frac{(\Delta E/E)}{}
\]

Source characteristics
Transverse acceptance
Longitudinal acceptance

Resulting beam has high transverse coherence
Limitations of Third Generation Sources

- The most recently constructed third generation sources tend to be fully coherent in the vertical direction up to ~0.5 keV;

- This is not true horizontally, and typically the spatial filter passes <1% of the total undulator flux;

- In the first harmonic, the longitudinal coherence of the source is given by the number of undulator periods \( N = \frac{E}{\Delta E} \sim 100 \). A beamline and monochromator can improve this, but this spectral filtering passes at best about 1% of the light.

- The time structure of third generation sources is not optimized for fast or slow timing measurements.
Feasible FEL Performance Goals

10 Hz operation: 5 GW peak power, 100 fs pulse length, 500 uJ (~1e13 photons) per pulse, 5 mW (~1e14 photons/sec) average, 30 meV bandwidth

10 kHz operation: 1 GW peak power, 100 fs pulse length, 100 uJ (~2e12 photons) per pulse, 1 W (~2e16 photons/sec) average, 10 meV bandwidth

1 MHz operation: <1 GW peak power, 100 fs pulse length, <100 uJ (~2e12 photons) per pulse, <100 W (~2e18 photons/sec) average, 10 meV bandwidth

Details

– Each of these numbers are for 300 eV photons in the fundamental; performance at lower energies will be better by up to a factor of about 10.
– The project aims to achieve 1keV photon energies, either with the 2.5 GeV linac shown in slide 1, or by the 3rd harmonic using only the 1.5 GeV linac.
– The 3rd harmonic would contain about 1% of the fundamental power.
– All output will be at or near transform-limited both transverse and longitudinal.
– Synchronization with external lasers will be to about 10 fs.
Why All this Pedagogy?

Coherence $\rightarrow$ Correlations $\rightarrow$ Complexity

- Nonergodicity and memory effects
- Feedback
- (Some) common mesoscale features of complexity
- Anomalous dynamics

One Recent Example: (1/4,1/4,0) Orbital-Order Bragg Reflection in Pr$_{1-x}$Ca$_x$MnO$_4$ Manganites

(with Jessica Thomas and John Hill, BNL; Josh Turner and Mark Pfeifer, UO; Karine Chesnel, ALS)

The energetics of OO domains is not well understood:

• Do the OO domain walls fluctuate near $T_{oo}$?
• Do the domain walls exhibit memory?
• What is the real-space OO domain topology?
Frontiers in *Coherent Soft X-ray Science*

- Fourier holography: imaging in 2D, single shot imaging (Stefan Eisebitt)

- Phase retrieval and diffractive imaging in 2D and 3D; single shot imaging (Stefano Marchesini)

- Photon correlation spectroscopy; nanoscale kinetic phenomena (Jeroen Goedkoop)

- Nanoscale speckle metrology; microscopic memory; photon correlation spectroscopy (Larry Sorensen -> Steve Kevan)
Longitudinal Coherence of with 3rd Generation Sources

Undulator Radiation

\[ \lambda / \Delta \lambda \sim \text{number of periods} \sim 100 \]

Natural bandwidth \( \sim 1\% \)

Coherence length \( \sim 100\lambda \)

Energy range 200-1000eV

Moderate dispersion

8x demagnification of the source

Quality optics to preserve coherence

Coherent flux at 500eV: \( \sim 5 \times 10^{10} \) ph/sec/0.1%BW

Beamline 12.0.2 at the ALS