Complete Spatial Characterisation of EUV Wavefronts

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Complete Spatial Characterisation of EUV Wavefronts

1. Characterisation
2. Method
3. Results
4. Outlook

David Lloyd, Kevin O’Keeffe, Simon Hooker
• Successful design and implementation of (optical) experiments requires knowledge of illuminating radiation.

• Beam characterization concerned with:
  o Transverse intensity profile
  o Transverse phase profile
  o Spatial coherence
  o Temporal pulse shape
  o Temporal coherence
• Successful design and implementation of (optical) experiments requires knowledge of illuminating radiation.

• Beam characterization concerned with:
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  o Spatial coherence
  o Temporal pulse shape
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Spatial Properties

Contour of equal phase – a diverging wave has a curved wavefront with a positive radius of curvature.

Diagram of a focussed gaussian beam.

Intensity profile widens with increasing distance.

Space-time coupling may be present and is potentially detrimental to experiments.
Wavefront Characterization

**SWORD**
Spectral Wavefront Optical Reconstruction by Diffraction

- Scan thin slit transverse to propagation direction.
- Retrieve phase profile from centroid position.
- Retrieve intensity profile from transmitted flux.

Images taken from [1]

Our technique measures the wavefront and coherence simultaneously.

Interference fringes from fully coherent phase-matched high harmonic source. Figure taken from [2]

- Coherence defined by correlation by E-field at two separate locations $<E_1E_2^*>$
- Normalised correlation strength is called Complex Degree of Coherence ($\gamma$) and is related to fringe visibility ($\nu$) through:

$$\nu = \frac{2\sqrt{I_1\sqrt{I_2}}}{I_1+I_2} |\gamma|$$

Complete Characterisation

**S**can **I**nterference **M**easurement **T**ransverse **A**nalyses of **R**adiation [4]

- Scan slit in vertical position – continuous change in pinhole separation.
- Incident beam intensity, phase and spatial coherence are retrieved from interference patterns.

Complete Characterisation

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**Complete Characterisation**

**SCanning Interference Measurement for Integrated Transverse Analysis of Radiation** [4]

- Scan slit in vertical position – continuous change in pinhole separation.
- Incident beam intensity, phase and spatial coherence are retrieved from interference patterns.

High Harmonic Generation

• Table-top source of EUV/soft x-ray radiation.
• Intense pulses from a (commercial) Ti-Sapphire laser are focused into a noble gas.
• Non-linear interaction produces a frequency comb extending to an abrupt cut-off.
• Odd multiples of laser frequency (harmonic order labelled by q).
Interference pattern from pinholes has the form:

\[ I(x) = \varepsilon(x) \left[ 1 + V \cos(k_0 x + \varphi) \right] \]
\[ \varepsilon(x) \propto (I_1 + I_2) \]

Interference Analysis

Interference pattern from pinholes has the form:

\[
I(x) = \varepsilon(x) [1 + V \cos(k_0 x + \varphi)]
\]

\[
\varepsilon(x) \propto (I_1 + I_2)
\]

Experimental Demonstration

Harmonic radiation (13 - 35nm)

- SCIMITAR used to characterize HHG from a gas cell.
- Driving laser pulse duration tuneable from 12-50 fs.
- Grating allows spectrally resolved characterization.
- Here we show results for 22fs pulses and harmonic orders up to q=33.

IR laser pulses (\(\lambda=800\text{nm}, E\sim300\mu\text{j}\))

~80mbar Argon.

\(~74\text{cm}\)

X-ray CCD

Grating

<1mm
Increasing photon energy

Interference

q=23

q=33
SCIMITAR - Intensity

$q=29$ Recovered Intensity Profile

- SCIMITAR data
- Gaussian fit

Intensity (arb.)
Position (μm)
Intensity Profiles with Gaussian fits

Intensity (arb.)

Position (µm)

q=23
q=25
q=27
q=29
q=31
q=33
Error bars designate 1-sigma confidence interval.
SCIMITAR - Phase

q=29 Recovered Phasefront

Equivalent to a wavefront with a 1.47m Radius of Curvature
Wavefront Curvature with Harmonic Order

Error bars designate 1-sigma confidence interval.

Measured source – slit distance.
q=29 |γ| with Pinhole Separation

FWHM of harmonic intensity

Magnitude of CCF

Pinhole Separation (µm)
SCIMITAR – Spatial Coherence

Magnitude of CCF vs Pinhole Separation (µm) for different values of q:
- q=23 (Blue stars)
- q=31 (Red stars)

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Summary

- SCIMITAR simultaneously retrieves:
  - Transverse intensity profile
  - Spatial phasefront
  - Spatial Coherence left-right of beam centre

- SCIMITAR is applicable to a wide range of light sources.
- We have demonstrated the technique by characterizing HHG.

Future Work

- Relate results to full theory of partially coherent diffraction (c.f Gaussian – Schell model).
Thank you

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Incoherent Radiation

Two pinhole “interference” from an incoherent wavefront:

\[ I(X) = I_1 \text{Sinc} \left( \frac{kXa}{2z} + \frac{a}{2} \frac{d\varphi}{dX} \right) + I_2 \text{Sinc} \left( \frac{kXa}{2z} + \frac{a}{2} \frac{d\varphi}{dX} \right) \]

• Gradient in phase extracted from patterns (similar to SWORD).
• Integrate across transverse direction to retrieve phasefront.
• In this scenario, there is no benefit of using SCIMITAR over SWORD.