Paraxial SGM beamlines for coherence experiments at the Advanced Light Source

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Abstract

Beamlines have been designed for coherence experiments at the ALS based on brightness preserving spherical grating monochromators. The operation is almost paraxial so that a very simple scheme can deliver the modest spectral resolution required, with just two focusing optics, one of which is the spherical grating.

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Introduction

Coherent scattering and imaging require maximum brightness and modest (R=1,500) spectral resolution. Source brightness is preserved with optical schemes that avoid distorting the phase-space of the photon beam and with monochromators providing no more dispersion than actually required for the required spectral resolution. Two independent monochromators are planned for this program at the ALS [1]. One serves energies up to a maximum of 3keV for coherent imaging of radiation sensitive materials [2]. The other provides polarized coherent scattering (from organics and magnetic materials [3]) from 250eV up to 1650eV.

In each case the sample will be of the order tens of microns across, and must be coherently illuminated by light from a spatial filter in which an image of the source is made on the monochromator exit aperture, about the same size as the sample. The sample is typically just downstream of this and the scattered light is collected by an imaging detector in the far-field.

Optical design

The elliptical undulator has 34mm period and provides linear polarization control across the full energy range, and circular polarization up to 950eV. Only the high brightness radiation on-axis will be used. The radiation source is small (≈8µm rms) in the vertical direction and should not be de-magnified. This puts the exit aperture (≈10µm) far downstream. Spectral resolution must be only moderate, so the monochromator is small (≈1.5m long).

Horizontally-dispersing paraxial spherical grating monochromators [4,5] are adopted for the following reasons:

1) Stationary exit slits. We do not consider any design that requires slits to move because the exit slit aperture is the source of coherent illumination and integral to the experiment.

2) Horizontal deflection at the grating separates experiments on the floor.

3) Rejection of light horizontally, outside the on-axis coherent fraction, at the monochromator entrance slit. This allows control of the spectral resolution independent of the phase space acceptance at the exit slit, by varying the width of the entrance slit. You can trade flux against resolution without affecting the spatial coherence.

4) The difficult task of preserving the vertical brightness is carried out in the sagittal direction where figure errors of the reflective surfaces spoil the brightness less, by a factor of the sine of the grazing angle.

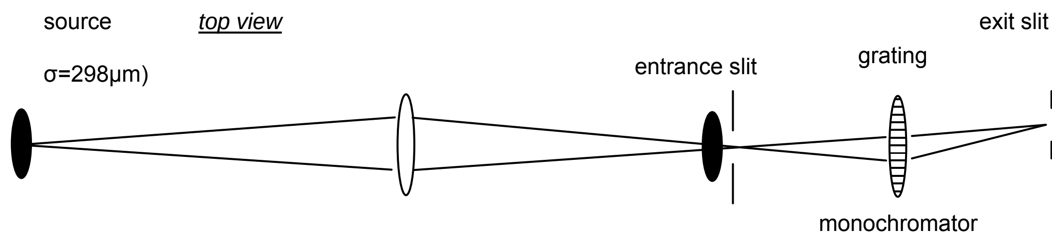

Figure 1. Optical scheme

Only the coherent fraction of the light is used and it illuminates the grating close to the optical axis so the system is almost paraxial and the depth of focus is large. The defocus contribution to the spectral resolution is given by:

$$\frac{\partial\lambda}{\lambda} = \frac{dw_{FW}\left[\frac{\cos^2\alpha}{r} + \frac{\cos^2\beta}{r'} - \left(\frac{\cos\alpha + \cos\beta}{R}\right)\right]}{\lambda}$$

Where d is the grating groove spacing, r and r' are entrance and exit arm lengths, R is the grating radius and w_{FW} is the full length of the illumination along the grating. This contribution is kept small by choosing the radius and grating line density for a given energy range so that operation is quite close to the zero order position. The difference between the incident (α) and diffracted (β) angles is then small (less than one degree) and the angular range through which the grating rotates is also small. This keeps the monochromator from going too far out of focus and the resolution degradation is acceptable. See Figure 2.

A toroidal mirror (≈15m from source) forms a horizontal image at the horizontally defining entrance slit (≈25m from source), where, to a large extent, the coherent fraction is selected. Further selection can be made at the diffraction grating (≈26m from source) by limiting the horizontal and vertical angles collected, with adjustable blades. This stop can close to limit the angular spread of the illumination and ensure proper operation of the exit aperture (≈27.5m from source) as a diffractive spatial filter. The grating makes a horizontal image and the toroid makes a vertical image of the source at the exit aperture.

The two horizontally dispersing monochromators will each require several small spherical gratings. With selection of only the coherent fraction there is no cooling required of the grating. However, some experiments can be anticipated with the entrance slit admitting the whole beam, in which case heat removal (tens of Watts) will be required at the grating.

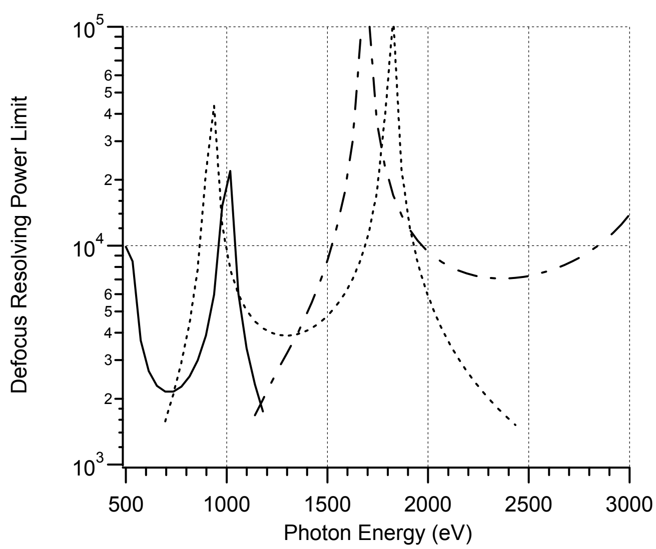

Figure 2. Defocus limit to the resolving power in the coherent imaging branch. The three gratings are illuminated with the undulator central cone diverging from the entrance slit, set for R_{FW} =1500 (2.35 times r.m.s.) Diffraction at the slit is included.

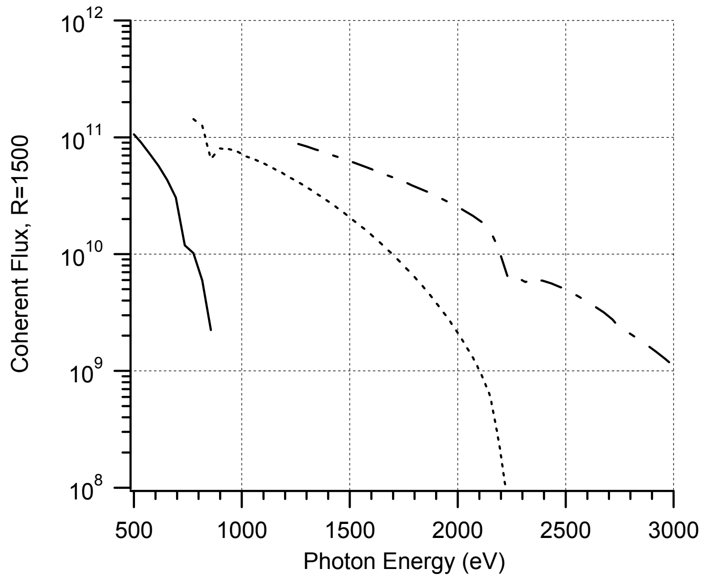

Figure 3. Coherent flux with linear polarization at R $_{FW}$ =1500 in the imaging branch.

Availability of gratings

All gratings will be small spherical substrates. Perhaps 100mm x 30mm x 30mm. Use of gratings at high energy requires a large included angle (178 degrees for operation up to 3000eV) and coarse gratings are required for the nominal resolving power (R=1500). No gratings coarser than 80lines/mm are considered because of known difficulty maintaining accurate groove profiles for very coarse gratings.

If the gratings are ruled they must have a very shallow blaze angle to be efficient operating close to zero-order in this special geometry. Careful computation using GSOLVER [6] leads to a blaze angle requirement of about 0.3º in every case. This is not available by ruling in metal. Blaze angle reduction by variable-speed reactive ion etching through a ruled gold layer into a silicon substrate has been advertised by Carl Zeiss [7]. Otherwise laminar gratings could be used at reduced efficiency.

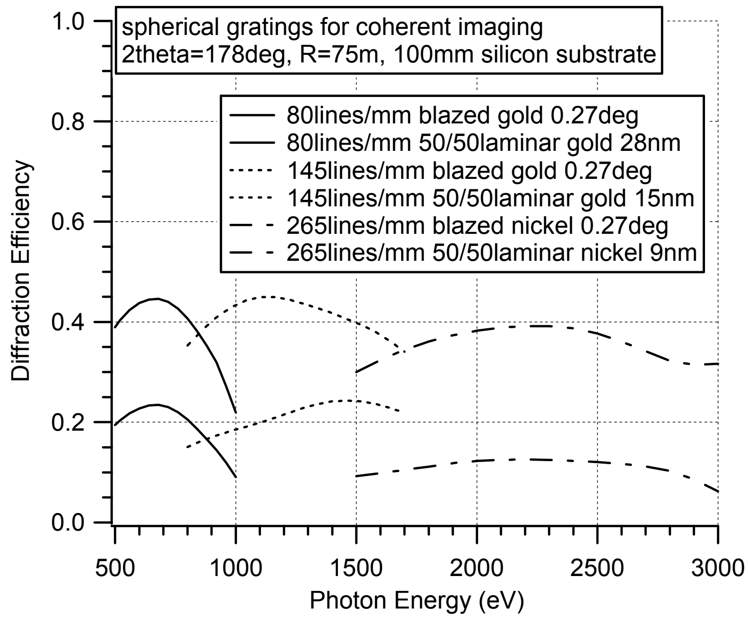

Figure 4. Computed diffraction efficiency for shallow-blaze and laminar gratings. (The blazed gratings have higher efficiency).

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