

PARTIALLY COHERENT RADIATION AT X-RAY WAVELENGTHS

D. Attwood, K. Kim, N. Wang, N. Iskander

▶ To cite this version:

D. Attwood, K. Kim, N. Wang, N. Iskander. PARTIALLY COHERENT RADIATION AT X-RAY WAVELENGTHS. Journal de Physique Colloques, 1986, 47 (C6), pp.C6-203-C6-210. 10.1051/jphyscol:1986627. jpa-00225870

HAL Id: jpa-00225870 https://hal.science/jpa-00225870

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

PARTIALLY COHERENT RADIATION AT X-RAY WAVELENGTHS

D. ATTWOOD, K.J. KIM, N. WANG and N. ISKANDER

Center for X-Ray Optics, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, U.S.A.

<u>Résumé</u> - Dans le document, nous discutons les attributs du rayonnement cohérent partiel produit par les lasers de produits par lasers. Nous discutons les propriétés de cohérence spatiale et temporelle, les expériences liées à la microscopie de rayons-X et à la microholographie qui profitent de degrés variés de cohérence. Nous illustrons, pour les valeurs de crête et de moyenne, le rendement radiatif en fonction de la puissance cohérente et de la luminosité spectrale.

<u>Abstract</u> - In this paper we discuss the properties of partially coherent radiation generated by X-ray lasers, undulators, and laser produced plasmas. We discuss spatial and temporal coherence properties, experiments involving X-ray microscopy and microholography which benefit from varying degrees of coherence, and we illustrate radiative performance in terms of both coherent power and spectral brightness, for both peak and average values.

Introduction

In recent years we have seen a significant advance in the ability to generate coherent radiation at ever shorter wavelengths - now extending throughout the ultraviolet and into the x-ray region of the electromagnetic spectrum. These are particularly interesting spectral regions for applications in many scientific and technological disciplines. Because the wavelength is short, the radiation can be used to both "see" and "write" patterns of small feature size. Thus one can form high spatial resolution x-ray microscopes and microprobes and can fabricate yet more powerful integrated circuits. The photon energy is particularly interesting as it coincides with the many atomic and molecular transition resonances which pervade this region of the spectrum. The new accessibility of this region, provided both high brightness sources and requisite x-ray optics are available, will permit the utilization of many exciting techniques. Element specific bio-dynamics, site specific photochemical processing, polarization sensitive scattering studies of chiral structures, element specific studies of surface state formation, and dynamical studies of thin film and lattice structure formation are, to name a few, fields which would benefit from the unique capabilities of elemental sensitivity and high space-time resolution.

Coherence Requirements

An example of an experimental technique which would benefit many of the above cited sciences is that of an x-ray microprobe. As illustrated in figure 1, a Fresnel zone plate might be used to concentrate radiation in a small

focal spot area. The radiation could be used to probe, stimulate or scan any of a variety of chemically, physically or biologically interesting systems. The size of the focal region is dependent upon both the spatial and temporal properties of the incident radiation. For spatially coherent radiation a focal spot diameter (waist) of 2.44r will be obtained with a zone plate of outer zone width Δr . Resolution, as defined by Rayleigh, would be 1.2 Δr . A zone plate of outer zone width of 500 Å would give a focal spot diameter of approximately 1200 Å. To achieve this diffraction limited focusing it is necessary that the zone plate be perfect to a fraction of a wavelength, and that the radiation emanate from an uncertainty limited phase space characterized by $d \cdot \theta \simeq \lambda/2$. If the radiation is characterized by a larger phase space, the resulting focal spot will be proportionally larger and the resolution proportionally degraded. The zone plate microprobe also requires a degree of temporal (longitudinal) coherence, albeit modest. In order to avoid blurring of the focal region by chromatic aberration, the radiation must possess a coherence length (distance over which interference effects are significant) $\mbox{$\xi_c$} = \lambda^2/\Delta \lambda,$ at least as large as the coherence requirements of the zone plate, N $\lambda/2$, where N is the number of Fresnel zones. Generally this is a modest requirement: with N \simeq 500 and $\lambda \simeq$ 30 Å, one requires $l_c \simeq 1 \mu m$.

A somewhat more demanding experiment is that of off-axis x-ray microholography, as illustrated in figure 2. In this case the ZP does not form an image in the recording plane, but rather it gathers the high frequency (large angle) scattered radiation (containing details of the smaller sample features) and directs it back toward the recording medium where it is encoded through interference with a plane or spherical reference wave generated by the nearby diffraction grating. The scattered radiation is thus heterodyned by the reference wave, with a carrier spatial frequency roughly that of the grating, allowing use of a lower resolution but more sensitive recorder (perhaps x-ray film) than would otherwise be possible. Both spatial and temporal coherence requirements are more demanding in the holographic case, requiring spatially coherent illumination over a field wider by some factor, and a temporal coherence length increased by that factor squared, e.g. if the grating extends laterally to a distance of five ZP radii, then the temporal coherence must be increased by a factor of twenty-five. Thus one would require full spatial coherence and a longitudinal coherence of 20 µm.

Radiation Sources

The generation of partially coherent radiation, combined with requisite spatial and temporal filtering, can be achieved in several ways. Figures 3-5 illustrate an atomic laser, a magnetic undulator, and a laser-produced, hot-dense plasma emitting x-rays into 2w steradians. All three can generate radiation at XUV wavelengths, and perhaps it can be said that all are partially coherent - certainly all could be used as the source of radiation in figures 1 and 2. The differences are the degree of coherence, determining the amount of spatial and temporal filtering required for a particular application; the average and peak power produced; and the shortness of the wavelength and its nearness to the atomic and molecular resonances of interest.

Radiative Performance

In figures 6-8 we show generated coherent power and spectral brightness, for both average and peak values, and for a variety of spectral widths (coherence lengths). In the estimates of coherent power, only that portion of the radiation within $d \cdot \theta \simeq \lambda/2$ is accepted, such that full spatial coherence would result. In addition, perfect optics are assumed - no aberrations, 100% efficiency. The need for several illustrations is due to the wide variety of applications one can envision, some requiring minimal coherence, others requiring substantial coherence. Upon inspection one readily sees that each of the radiation sources has its own advantages.

References

- D.L. Matthews et al., Phys. Rev. Letters, <u>54</u>, 110, 1985; M.D. Rosen et al., Phys Rev. Letters, <u>54</u>, 106, 1985.
- D.T. Attwood, K-J. Kim, K. Halbach, and M.R. Howells, "Undulators as a Primary Source of Coherent X-rays", paper presented at the International Conference on Insertion Devices for Synchrotron Sources, October 1985; also published as Lawrence Berkeley Laboratory PUB-20569, 1985.
- 3. Recent (June, 1986) undulator experiments are reported by H. Rarback, Brookhaven National Laboratory, Upton, New York.
- D.W. Phillion, E.M. Campbell et al., to be published; D.T. Attwood, N.M. Ceglio, E.M. Campbell, J.T. Larson, D.M. Matthews, and S.L. Lane, "Compression Measurements in Laser-Driven Implosion Experiments", <u>Laser</u> <u>Interaction and Related Plasma Phenomenon</u>, (Plenum, New York, 1981) eds. H.J. Schwarz, H. Hora, M.J. Lubin, and B. Yaakobi; B. Yaakobi et al., Optics Communications, <u>38</u>, 196, 1981.
- Nasif Iskander and Nadine Wang, Optical Society of America, Topical Conference on Short Wavelength Coherent Radiation, Monterey, CA, April 1986.



Figure 1. An x-ray microprobe based on use of a Fresnel zone plate. Spatially coherent radiation is focused to the smallest possible focal spot, of diameter 2.4Ar. Longitudinal (temporal) coherence equal to N\/2 is required to avoid chromatic defocusing effects, where N is the number of zones. Thus both temporal and spatial coherence are required.



Figure 2. Three dimensional imaging using off-axis holography. As in figure 1, full spatial coherence is required. Temporal coherence requirements increase as the square of the zone plate/diffraction grating aperture.

Laser Radiation and Partial Coherence



Figure 3. Two forms of lasers are illustrated. The first utilizes cavity mirrors, and internal mode selecting (filtering). The second is a high gain, single pass laser, employing no internal filtering, and thus producing radiation of lesser coherence properties.



Figure 4. Undulator radiation produced by a relativistic electron beam traversing a periodic magnet structure. The radiation is partially coherent in nature. Spatial coherence is set by the phase space of the electron beam and the wavelength. Longitudinal coherence is set by the number of undulator periods.



Figure-5.- Narrow line emission from laser produced plasmas can provide intense radiation at multi-keV photon energies, with competitive coherence lengths, but require significant spatial filtering (e.g. has no natural spatial coherence).

JOURNAL DE PHYSIQUE

photons/sec







Figure 6. Average and peak values of spectral brightness in 0.1% and 0.01% bandwidths are plotted for the sources discussed here.

 Existing Sources
 Proposed Sources

······ Harmonics

Peak Spectral Brightness in 0.1% Bandwidth

(7-B)



(7-A)

Figure 7. Average and peak coherent power in a 1 μm coherence length are plotted for the sources discussed here.



Peak Coherent Power in 100 µm Coherence Length





Figure 8.

Peak coherent power in 10 µm and 100 µm coherence lengths is plotted for the sources discussed here.