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THE ADONE WIGGLER SOFT X-RAY BEAM LINE

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X-ray lithography and X-ray microscopy have important technological and scientific applications. In particular, X-ray lithography is an alternative to optical lithography because it overcomes the fundamental limitations of diffraction allowing the replication of patterns in the submicrometric region: X-ray microscopy fills the gap between the optical and the electron microscopy, giving the possibility to study, with good resolution, thick (1-10 μm), wet and radiation sensitive biological specimens, as well as non-biological opaque samples.

For various reasons[1-3] these applications need photons in the 0.4-10 nm wavelength range (VUV and soft X-ray region) and Synchrotron Radiation (SR) is an ideal source in this range.

This spectral region is well suited also to study and develop X-ray optical devices, as Layered Syntetic Microstructures[4,5] and Zone Plate[8], which can allow the extension of imaging and holography techniques to the soft X-ray region.

To start an experimental activity in these fields we are realizing a soft X-ray beam line which will utilize the SR produced by the Adone wiggler. The beam line has been planned for X-ray lithography[7], but its characteristics are also well suited for X-ray microscopy and X-ray optics.

Since the wiggler magnet is a source more complex than the bending magnet, its characteristics must be carefully considered in determining the beam line features.

Table I reports the main parameters of the Adone wiggler and the r.m.s. divergences and widths of the Adone electron bunch.

TABLE I - Wiggler magnet and Adone electron bunch parameters. σ'_x and σ'_y are respectively the horizontal and vertical r.m.s. beam divergences and σ_x, σ_y the r.m.s. beam widths (from ref.8).

Number of poles	5 full + 2 half poles
Magnet period	0.654 m
Magnetic field	1.85 T
Critical Wavelength	0.45 mm
σ_x (mm)	1.83
σ'_x (mrad)	0.16
σ_y (mm)	0.087
σ'_y (mrad)	0.026

The Adone wiggler is a more intense radiation source respect to the bending, also in the soft X-ray region (Fig. 1). Nevertheless some complications arise from its particular spatial structure. The source vertical

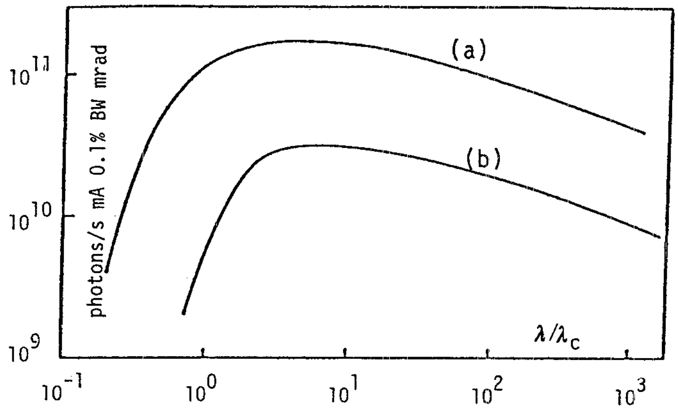

Fig. 1 - Photon flux from the Adone wiggler (a) and from the Adone bending magnet (b).

phase space ellipse in the wiggler centre (Fig. 2) is similar to the bending one, however due to the source depth of field the vertical dimension increases. The r.m.s. of the source vertical divergence and dimension are in our case: σ'_y=0.3 mrad and σ_y=0.3 mm for λ=0.45 nm.

Since at a distance d from the source the r.m.s. of the vertical dimension of the beam is given by $\sigma_{y,d}=\sigma_y+d\sigma'_y$ the beam must be vertically focused to obtain a small vertical beam size far from the source.

Fig. 3 shows the wiggler horizontal phase space. Since the $K=\alpha\gamma$ value is high, the maximum orbit deflection α is strong and the oscillation amplitude is not negligible giving rise to a double source structure.

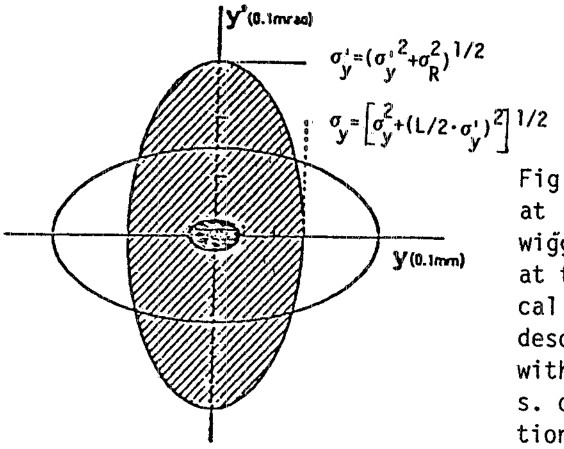

Fig. 2 - Vertical phase space ellipses at $\lambda = \lambda_c$ of the photon source at the wiggler center (stripped ellipse) and at the image point, after the cylindrical mirror. The Adone electron beam is described by the small central ellipse with r.m.s. σ_y and σ'_y. σ_R is the r.m.s. of the natural synchrotron radiation divergence.

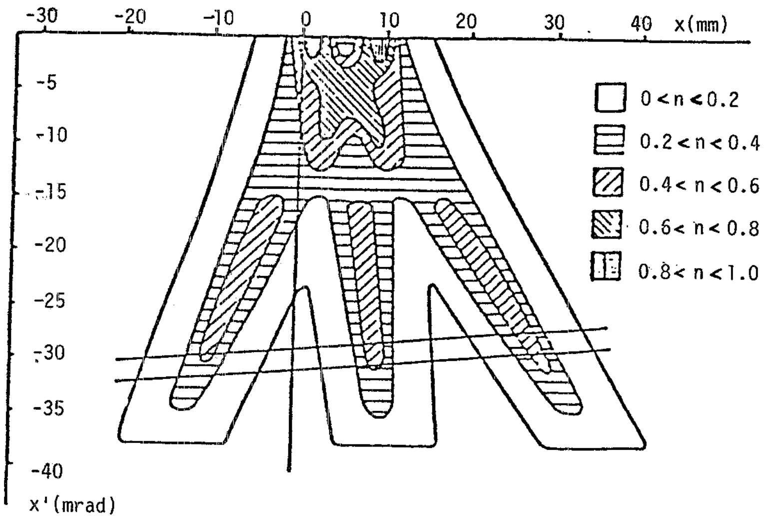

Fig. 3 - Horizontal phase space distribution for the Adone wiggler (from ref.8): n is the ratio between local and maximum brilliance. The horizontal acceptance of the cylindrical mirror is shown.

This particular situation allows to see the source up to an angle of about 2° in the horizontal plane, however the source uniformity in this plane must be carefully checked.

Fig. 4 shows a sketch of the soft X-ray beam line; the beam lines dedicated to spectroscopy are shown too.

The main elements of the line are:

a) a cylindrical gold coated fused quartz mirror, vertically focusing and horizontally deflecting, with a radius of curvature R=0.43 m;
b) a pair of flat gold coated fused quartz mirrors, for the vertical scan of the beam.

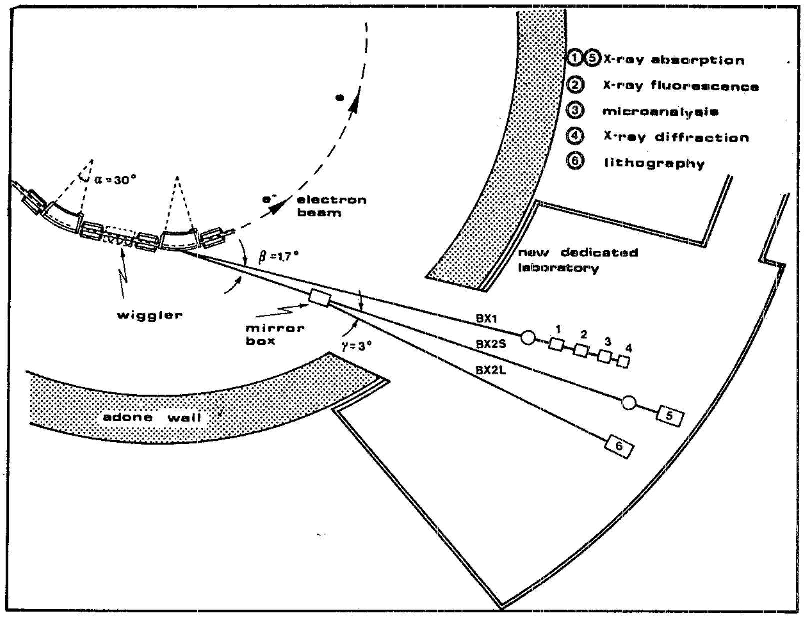

Fig. 4 - Adone wiggler beam lines.

The first mirror, located 12.5 m far from the source, is 1 m long, flat in the horizontal plane, with a 1.5° grazing angle and collects 2 mrad of radiation. It cuts off wavelengths shorter than 0.46 nm.

This mirror focuses vertically to reduce the length of the pair of flat mirrors and to obtain a more uniform flux on the sample in the vertical direction. A small beam size at the sample can also be usefull for application in which a good spatial coherence without strong intensity loss is required[9,10].

As can be argued from Fig. 2, the vertical dimension of the beam with the mirror is about 20 time less than without.

The flat mirrors will be utilized, during X-ray lithography experiments, to obtain, moving the beam in the vertical direction, the complete exposition of large area resist.

Since X-ray lithography needs an intensity distribution uniform within 2% on the photoresist surface, the horizontal uniformity of the beam has been evaluated.

The beam line makes an angle of 30 mrad with the wiggler axis and so the horizontal acceptance of the mirror is centered at this angle in the horizontal phase space (Fig. 3).

To check the beam uniformity in the horizontal plane, we measured the integrated flux after 2 mm thick Al window, in the horizontal angular range 27-33 mrad. Our results show that in this range the beam is uniform at least within 10%.

A rough integration made in the phase space in the same angular range, along strips 1 mrad wide, shows that the variation of the flux in the horizontal plane is of the order of 3%.

These results show that the beam uniformity should match quite well the X-ray lithography requirements.

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