Soft X-ray Microbean Layout Using a Plasma Source

L. Palladino(1),(2)

(1)*Physics Department of L'Aquila University*

libero.palladino@aquila.infn.it

(2)*INFN, Laboratorio Nazionale del Gran Sasso, Assergi (AQ)*

Abstract

In this article we present the analysis of a microbeam project in the soft X-ray energy region using a plasma source, which operates in the PLASMA-X laboratory of the Physics Department of L'Aquila University. In this work, we discuss the reasons that led to the design of the apparatus. Will describe the main features of the project.

INTRODUCTION

Many types of sources and X-ray focusing devices have been developed to obtain a micrometric spot [1]. In this contest, top-table soft X-ray for application in radiobiology and biological imaging are very interesting. With this aim we have constructed an X-ray plasma source while the achievement of an optical system based on the zone plates as optical elements, in the soft X-ray region (200 eV – 800 eV), is in progress. The X-rays ranging from ≈ 200 eV up to ≈ 800 eV are used in several biomedical and X-ray microscopy applications [2,3]. With this experimental set-up we will want realize a soft X-ray microbeam and an image system of irradiated biological sample.

EXPERIMENTAL APPARATUS

The X-ray emission of a plasma-source is based on the production of plasma obtained focalizing a laser beam on a specific target. This source is characterized for an instantaneous spectral high brightness, for a punctiform dimension (some tens microns, focal laser spot) and for a pulse temporal structure with the same duration of the laser in the whole spectral region. In our case, we use a high power Nd:YAG/Glass laser system whit pulse energy up to 8 J max @ 1064 nm and 6 ns pulse duration. The laser beam is focalized by an aspherical triplet lens on a target and the plasma and X-ray photons are emitted in 2π sr solid angle [4]. A schematic layout of the interaction chamber is shown in figure 1, where, we note that it is possible to place the target system in different positions respect to the middle of the vacuum chamber (C in figure 1). This configuration makes it possible the employed optical mirror or crystals to select the photon energy in a particular energy interval. In figure 1, it is indicated the relative position of the plasma-target and the copper mirror. It permits that the Cu mirror reflects the incident X-ray radiation with a grazing angle θ. In figure 1, together the interaction chamber, we show the X-ray optical beam layout. The set-up is based on the utilisation

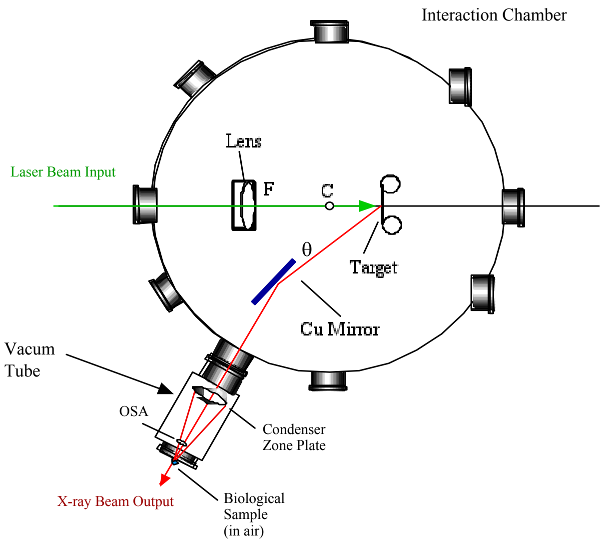

Fig. 1. Schematic layout of the interaction chamber. We note that it is possible to place the target system in different positions respect to the middle of the vacuum chamber (C in figure 1). It is indicated the relative position of the plasma-target and the copper mirror. q is the grazing angle of the incident X-ray radiation on copper mirror. We show the X-ray optical beam-line layout. The set-up is based on the utilisation a condenser zone plate (CZP). The sample is placed in air at 500. µm from the SiN exit window 100 nm tick.

a condenser zone plate (CZP) and collimator system (OSA). The biological sample is placed in air at 500 µm from the SiN exit window 100 nm tick. This window separates the vacuum chamber from the outside.

X-ray energy interval selection

To select the photons in this energy region a copper mirror at fixed grazing incidence and helium gas at different pressure are used.

In fact, in figure 2 and 3 are shown respectively the copper reflectivity, at different grazing angle θ, and He transmission, for different pressure and for 5 cm constant distance [5].

We obtain that optimal grazing angle for stop

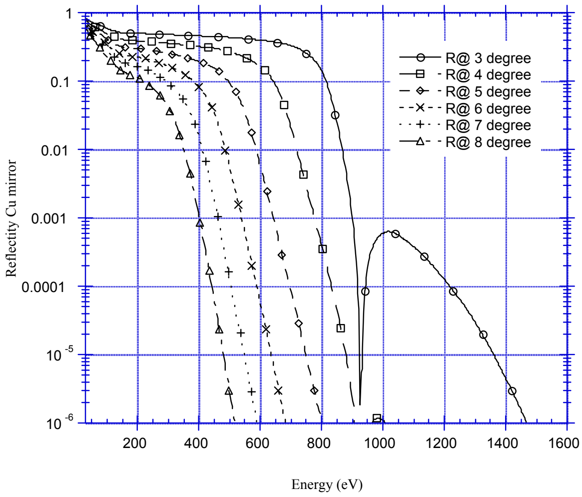

Fig. 2. The copper reflectivity at different grazing angle θ.

the X-ray greater than ≈ 900 eV is θ = 5 - 4 degree and the He absorbs at energy lower than ≈ 200 eV,

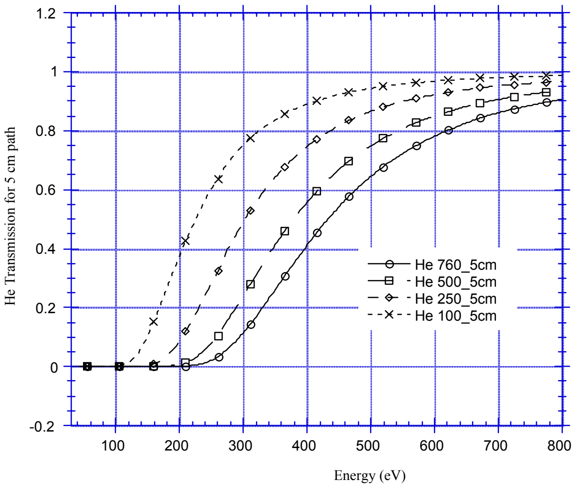

Fig. 3. He transmission, for different pressure and for 5 cm constant distance.

at 1 atm pressure and 5 cm distance. The total output transmission of the Cu reflectivity and He transmission, together a SiN 100 nm window, is shown in figure 4. We observe that at a better partial energy resolution of the X-rays corresponds a total transmission lower.

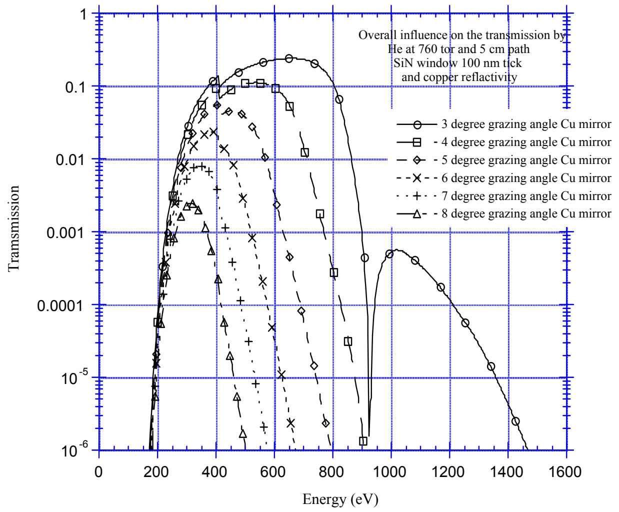

Fig. 4. The total output transmission of the Cu reflectivity and He transmission, together a SiN 100 nm window, is shown. We obtain that optimal grazing angle for stop the X-ray greater than ≈ 900 eV is θ= 5 - 4 degree and the He absorbs at energy lower than ≈ 200 eV, at 1 atm pressure and 5 cm distance.

To choice the better conditions presented in figure 4, we have designed and built a mirror-holder, in this case a copper mirror, with accuracy in the rotation angle of 1/10 of degree (see figure 5). It is placed in the interaction chamber (see figure 1) in radial position.

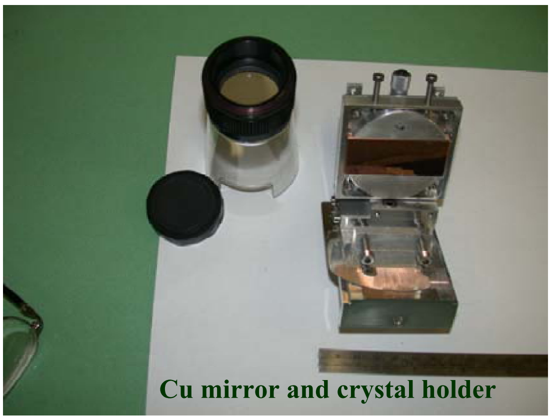

Fig. 5. Photo of the mirror-holder, in this case we see a copper mirror, with accuracy in the rotation angle of 1/10 of degree. For dimensions see the ruler.

X-ray optical system

The condenser zone plates are optical elements which selects and focalizes, at different positions on the CZP optical axis, $f_{m,\lambda}$, the wavelength, λ, components through interferential process for the m order. To eliminate the zero order X-ray component (direct beam), at middle of the CZP is present a central stop, which absorbs the incident radiation completely. This relation

$$f_{m,\lambda} = \frac{(r_{ZP}^2 - r_0^2)}{m \cdot N \cdot \lambda} \tag{1}$$

links the CZP focal length, $f_{m,\lambda}$, to the zone plate radius, r^2_{ZP} , the central stop radius, r^2_0, and the zone number, N, fixed the interference order m and the wavelength, λ. In figure 6, we show the position of the zone plate focal for the first, second and third order at fixed wavelength. To select a wavelength first order (or superior order) or a specific wavelength of our interest, it is necessary to introduce a collimator, which intercept the radiation not useful. Another important optical parameter is the depth of focus. It is defined, for a fixed focal length and wavelength as

$$\Delta z = \pm \frac{1}{2} \frac{\lambda}{(NA)^2} \tag{2}$$

where NA is the numerical aperture of the zone

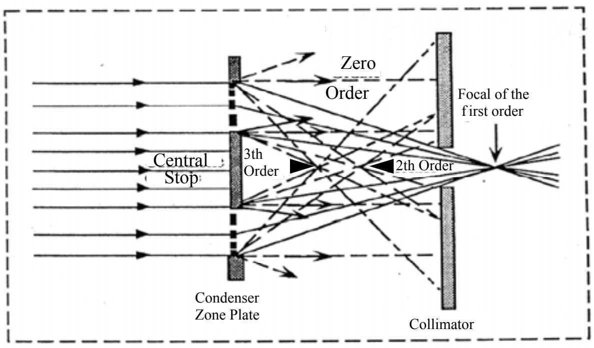

Fig. 6. Zone plate - collimator system. It is indicated the position of the zone plate focal for the first, second and third order (indicate by a black triangle) at fixed wavelength.

plate lens. The depth of focus limits the region of a tick sample is in the focus and submits at quite constant irradiation and indicates the dimension of the permitted displacement, from the ideal focal plane, for which the beam intensity on optical axis is reduced by only ±20%.

In our case, we have the possibility to use a gold CZP, made by Heidenhain, with a diameter 1010 µm, a zone number 506, an outer zone dimension 500 nm and a central spot radius 22.5 µm. The gold wires are freestanding and are 0.5 µm thick.

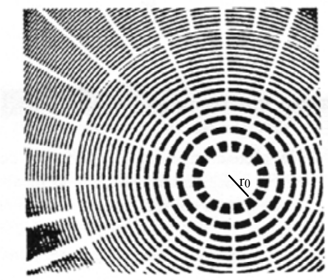

Fig. 7. TEM image (x100) of a part of the gold zone plate. 1010 µm diameter and 22.5 µm r_0.

In figure 7, we show a TEM image of our zone plate where are reported the principal CZP features (x100). In figure 8 and 9 we show the focal length and the depth focus of the gold-CZP in relation to the wavelength of X-ray radiation. The CZP

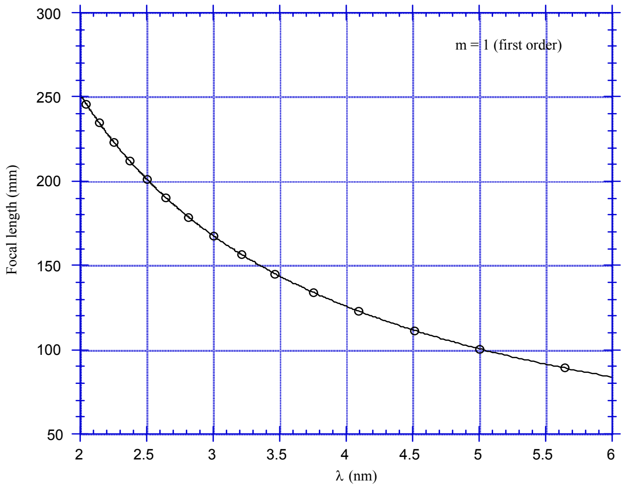

Fig. 8. The gold-CZP focal length versus the wavelength of X-ray radiation.

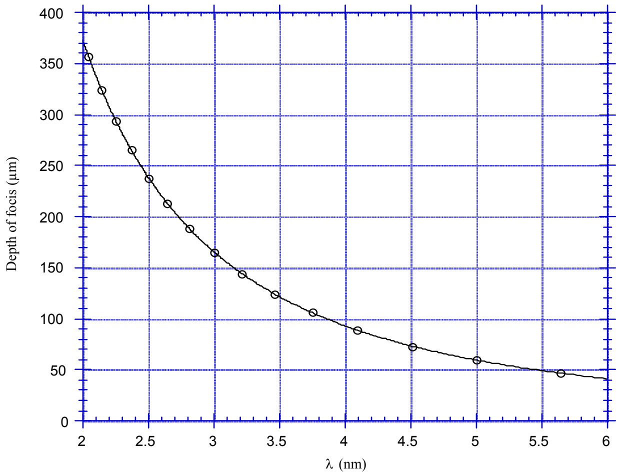

Fig. 9. The gold-CZP depth of focus versus the wavelength of X-ray radiation. The CZP has a average depth focus of ±150 µm.

has a average depth focus of ±150 µm in 2.5 – 4 nm wavelength interval.

Then the CZP is convenient for tick samples. The dimension of the focal spot depends on Airy distribution in the focal plane and in our case we obtain, by calculations [6], 0.6 µm in diffraction limit conditions and punctiform source. In general, to find the real dimension of the focal spot, it is necessary to add, in quadratic mode, the size of Airy pattern to the dimension of the source, obtained by the geometrical lens law, in the focal spot. In our source the source diameter is 65 µm.

CONCLUSION

In conclusion, from radiation and optical features of the beam line it is possible to obtain a soft X-ray microbeam for radiobiological applications. The optical features, as the average depth focus of ±150 µm, are good for the general thickness of the biological samples. In fact for a sample with a thickness greater than of the depth focus, the material outside that region would be not irradiated. The zone plate resolution of 0.5 µm is sufficient to analyze the biological structures. The dimension of the focal spot depends by the geometrical position of the source and the sample respect to the lens and then by the relative de/magnification.

ACKNOWLEDGMENT

We would like to thank Prof. E. Coccia Director of Gran Sasso National Laboratories of INFN and Prof. S. Santucci Director of The Physics Department of L'Aquila University for supporting us. This work is financially supported by INFN, LASEX experiment.

REFERENCES

[1] G. Schettino et al. - The ultrasoft X-ray microbeam: a sub-cellular probe of radiation response. 4th International Workshop: MicrobeamProbes of Cellular Radiation Resoponse - Dublin 1999.

[2] Gerritsen H. C., Van Brug H., Bijkerk F. and Van Der Wiel M. J.:J. Appi. Phys., 59, 2337 (1986).

[3] T.Limongi, L.Palladino, E.Bernieri, G.Tomassetti,L.Reale, F.Flora, P.Cesare, C.Ercole, P.Aimola and A.M.Ragnelli A.M.: J. Phys. IV France 345-348, 104 (2003).

[4] L.Palladino, T.Limongi, G.Gualtieri, R.Gimenez De Lorenzo and P.Zuppella:Radiation Effects & Defects in Solids Vol. 163, N.4-6, April-June 2008, 505-512.

[5] Calculated from: X-Ray Data Booklet - Center for X-ray Optics and Advanced Light Source - Lawrence Berkeley National Laboratory.

[6] Born & Wolf - Principles of Optics - sixth edition - Pergamon Press.