Project and realization of a microbeam at 2.48 nm

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Abstract

In this article, the geometry of the optical system, the software/hardware control system and the preliminary measures of the monochromatic beam intensity will be reported.
The high X ray conversion efficiency of the Yttrium (Y) used as target in a plasma source, will be important in the realization of an intense monochromatic X-ray beam. In particular, we collect and focus a monochromatic soft X-rays beam at the wavelength of 2.48 nm (500 eV) by multilayer spherical mirror. These mirrors reflect at an angle of incidence close to the normal of the surface.
Moreover, the improvements of the optical system are presented: from the currently with a magnification about 2 in the focal spot to have a magnification less than or equal to 1.
In this way, we obtain a monochromatic microbeam to be used in radiobiological topics and in transmission X-ray microscopy.
A new microbeam system is being implemented at the PLASMA-X laboratory in University of L'Aquila.

Introduction

The X-ray micro-beams are important experimental tools in the field of radiobiology and X ray microscopy due to two significant characteristics: (i) the micrometer size of the focal spot and (ii) the high monochromaticity of the photon energy.
The microbeams play an important role in the study of the biological effects of the ionizing radiation at low doses and low energy photons (100 eV - 1.5 keV).[1]. In particular in the study of mechanisms related to the important phenomenon of the 'bystanding effect' which seems to be linked to cellular apoptosis.[2].
The x ray source of our microbeam is a plasma-laser described in detail in the references [3].
Because of the low average x-ray emitted by the palsma-laser source on a 2 π sr solid angle, we used a multilayer spherical mirror for focusing and monochroming the X-ray beam.
These mirrors have the particularity to reflect the radiation at an incidence angle close to the normal of the mirror surface.
In this mode we can obtain a large collecting area and with a reflectivity of between 30% and 1% with an $\lambda/\otimes\lambda \approx 200$ (depends on the x-ray wavelength). [4]

X-ray microbeam layout at 2.48 nm

a) General

The choice of the 2.48 nm wavelength is determined by the possibility of applying the microbeam in biological imaging and radiobiological themes.

At this wavelength the water (oxygen) is transparent while the biological structures (carbon) are opaque. This aspect permits to obtain: (i) a natural contrast from the water (background) and the biological structures in the x-ray image formation, (ii) to study the "first mechanisms" that connected the photoelectron emission, obtained by photoelectric absorption, with biological effects that are established in the cells.

In figure 1 we show the half intensity path of the X ray radiation at 2.48 nm (500 eV).

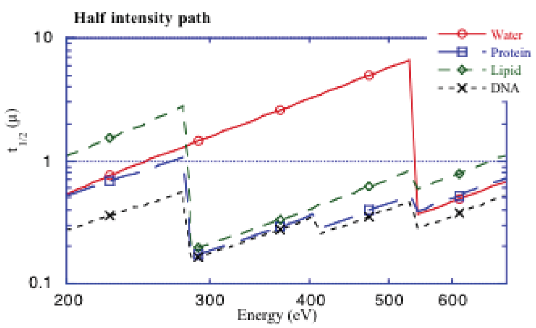

Figure 1 – Half intensity path of the X ray radiation from 200 – 600 eV for different compounds. [6]

The x ray plasma emission depends on the material: in our case the yttrium (Y 39) has a high x-ray conversion efficiency to 2.48 nm and will be used as target in the plasma source. [5]

The monochromatic microbeam at 2.48 nm is obtained using a multilayer spherical mirror, that selects the wavelength of X-rays with an incident angle of 8 degrees from the normal to the surface of the mirror. The mirror has a useful diameter D = 30 mm and a curvature radius R = 265 mm.

To protect the mirror from the debris, produced during the formation of the plasma, we used a window of protection of 50 nm thick silicon nitride.

In Figure 2 we show the pictures of the inside of the interaction chamber (C is the center) where we can see the layout of the spherical mirror (S in figure 2) respect to the target (T in figure 2), both run on rails driven by step-by-step motors controlled by computer. The sensitivity of the whole movement is < 1 μm.

The optical and geometric system is very rigid. A single triangle, SCT, together the biological sample position (F in figure 2) must satisfies the optical equation of the mirrors and the constancy of the incidence angle on the mirror simultaneously.

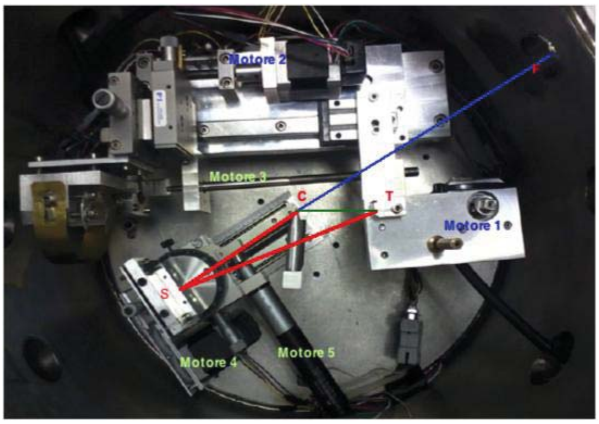

Figure 2 – The x ray interaction chamber. C is the center, S is the mirror, T is the target. The five motors are indicated.

b) Software & Hardware

The software used for management of the system is designed by high level programming language; the hardware is composed of 5 serials controllers, 4 stepper motors and 1 DC motor. The block diagram is visualized in figure 3.

The controller gives a number of features to achieve automation and handling tasks in research and industry in a very cost effective way. Programming is facilitated by the high-level mnemonic command language with macro and compound command functionality.

Macros can be stored in the non-volatile memory for later recall.

Each Motor with encoder is connected to the controller identified by physical address.

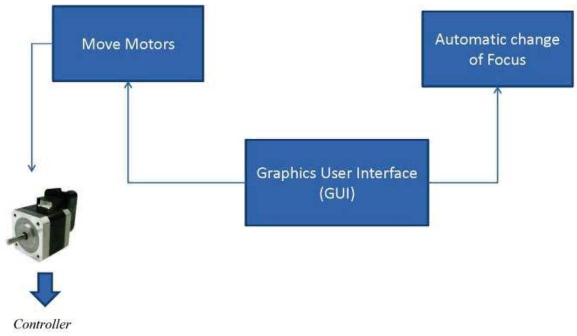

Figure 3 - General block diagram

The motors used in the configuration can be described with the following principal features:

- Accurate positioning;
- Encoder with 3 output channels;
- Stepping control.

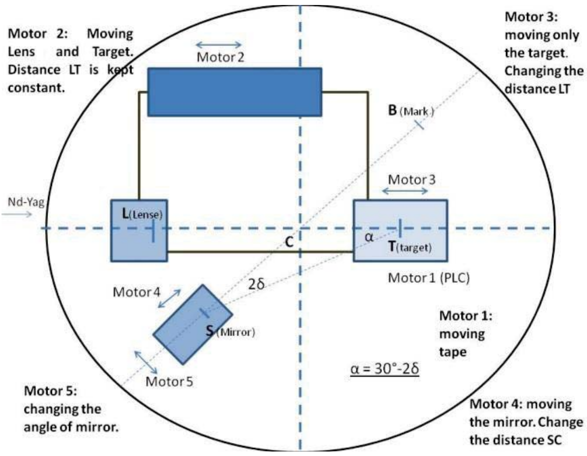

Figure 4 - General setup (hardware)

In according to the figure 4 it is possible to define the movement for each motor:

- Stepper Motor 1: used for moving the tap connected to the PLC system;
- Stepper Motor 2: used for moving lens and target together;
- Stepper Motor 3: used for moving only the lens;
- Stepper Motor 4: used for moving the mirror;
- DC Motor 5: used for rotating the mirror changing the angle.

Main features of the software design can be described as below:

1. Flexible code
2. Simple GUI to re-program
3. Possibility to manage the motors together or in singular

The process of software design (figure 5) consists of developing intermediate levels of abstraction until we reach a compromise: a set of abstractions that satisfy the needs of application programmers and are efficiently implementable (or better yet, already implemented as part of this negotiation process) on the basis of what was available in the first place.

Good design is a negotiation of a process that tries to reconcile the two points, working top-down from the client side and bottom-up from the supplier side.

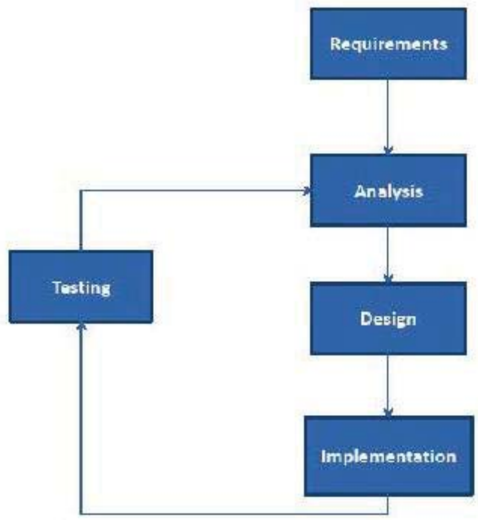

Figure 5 - Process of software design

X-ray microbeam: preliminary measures

The of the presented work is to realize a monochromatic microbeam at 2.48 nm wavelength, which is within the water window energy region. To reflect and select photons with a wavelength of 2.48 nm, a multilayer spherical mirror [4] with a resolution / ≈ 200 and a reflectivity ≈ 1% was used. The multilayer structure includes two packets: 230 periods with a step of 1.256 nm and 220 periods with a step of 1.2475 nm. The material in both packets is W/B4C. The photons were selected with a reflection angle of 8 degrees from the normal of the mirror surface. In figure 6 the reflection curve of the mirror with geometric parameters is shown. The component at 2.48 nm has been focused in the geometry shown in Fig. 7. The mirror plasma distance is 201.5 mm and the image point of the plasma was formed at a distance of 400.2 mm from the mirror. The X-ray detector was placed in the proximity of the focus point of the monochromatic beam. A vanadium microfoil 1 micron thick was placed before the input of a detector to separate the ultraviolet and visible window. The soft X-rays were generated from an yttrium target with a laser beam energy of 3.6 J. The charge collected by the detector was 4 nC which corresponding approximately to 3×10^9 photons of 500 eV energy.

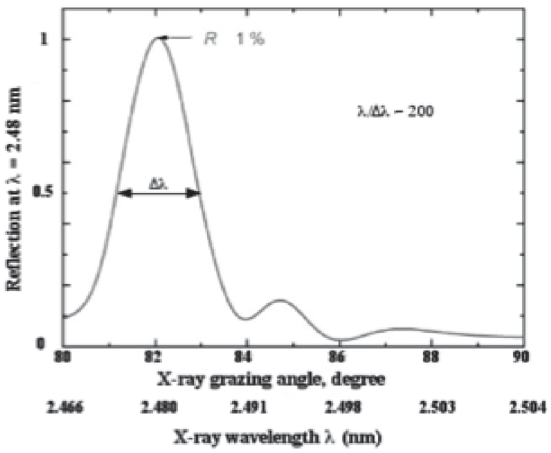

Figure 6. Curve of the reflectivity of the multilayer deposited on the substrate of the spherical mirror.

Considering the magnification 2 of the image of the source the focus of microbeam can be estimated having a density of photons equal to 2×10^5 photons/µm^2. considerable interest for biological applications.

Conclusions

From the microbeam measures, approximately 3x109 photons of 500 eV energy were obtained, wich correspond to a photon density of 2x105 photons/µm2. This results were of significative interest for biological applications. In future we will provide an optimization of optical parameters and an improvement of the X ray emissions using other materials such as rhenium.

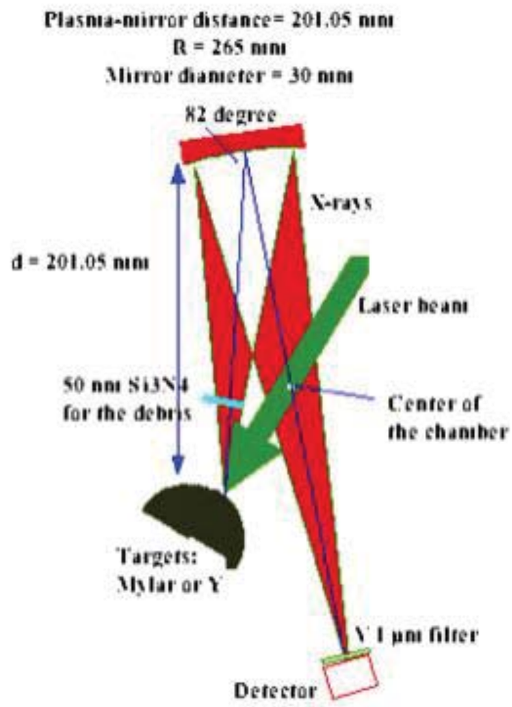

Figure 7. Schematic description of the experimental microbeam arrangement for the measurement of the energy of the X-ray beam reflected from the spherical mirror. The figure shows the optical configuration of the microbeam.

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