

Focusing of Radiation from Capillary Discharge Using the EUV Optics

L. Sveda¹, L. Pina¹, A. Jancarek¹, V. Pickova¹, M. Tamas¹, R. Havlikova¹

¹ *Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, V Holesovickach 2, 180 00 Praha 8, Czech Republic;*

Abstract

Capillary discharge was used as the source of EUV radiation intended for interaction experiments. In order to increase intensity of radiation the EUV optics was designed and coupled to the source. Calculations, EUV optics characteristics and measured focal intensity distribution together with detailed description of the experiment are presented.

Introduction

A capillary discharge X-Ray plasma source has been developed at the Czech Technical University [1]. Experiments with the spectrometer [2] as well as other experiments showed that increasing the flux on the target/detector is needed.

Therefore, the source was equipped with the grazing incidence reflecting X-Ray optics. The goal was to demonstrate the efficiency of the solution and to measure the parameters of the combination of the source and the optics.

Experiment

A schematic view of the experimental setup is plotted in Figure 1. The main properties of the experiment were as follows:

- capillary - created from sapphire, length 56 mm, diameter 3 mm, nitrogen filled with typical pressure ~ 3.5 mbar, voltage 36 kV
- EUV optics - ellipsoidal axially symmetric optics, length 120 mm, diameter 22 mm, gold reflecting surface
- CCD camera - 512×512 pixels, $24 \times 24 \mu\text{m}^2$ each, Peltier cooled
- vacuum chamber - typical pressure 10^{-4} mbar

Two different filters were used in order to reduce the flux on the detector. There was no other special reason for selecting these filters in these first experiments.

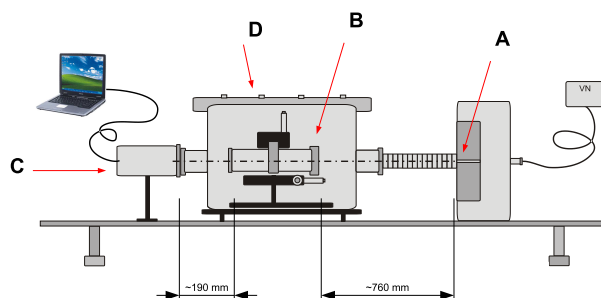


Figure 1: A schematic view of the experimental setup. A - capillary, B - EUV optics, C - scientific X-Ray CCD camera, D - vacuum chamber. Description is given in the text.

Preliminary data processing

A number of detected focal spots for different conditions were measured. The conditions include two different filters, measuring with and without optics and also different number of shots.

Almost all the detected images had the clearly visible focal spot accompanied with the relatively intense and extended background.

The background was modeled for each of the detected focal spots as well as for the radiation detected without any optics and the resulting background intensity is plotted in Figure 3. It showed to be independent on the filter and/or optics actually used, while there is a very nice correlation with the number of shots. This leads to the conclusion, that the background was created mostly by the visible light generated during the shot and reflected from the inner walls of the vacuum chamber. Unfortunately, as a consequence, no direct information about the gain of the optics could be obtained in this experiment.

The images were further processed to obtain the peak profile and intensity. One of the best focal spots measured in the experiment is plotted in Figure 2. The FWHM of the peak is $288 \mu\text{m}$ and $312 \mu\text{m}$ respectively. We have also obtained even smaller focal spots while measuring with the second filter, however, the peak was overexposed and thus discarded from further processing. Nevertheless, this gives us a good confidence that even better results are achievable in further experiments.

Intensity inside the FWHM area was also analysed. The data as a function of a number of shots are plotted in Figure 4. Valid data were gathered for the combination of the filter number one and only one shot per image and further for the filter number two and one and three shots per image. Data obtained for filter number two and larger number of shots are inconsistent with each other. No dependence on the number of shots was detected at this region. This can be caused by a high repetition rate of pulses as well as by some pressure changes. Further study

of the phenomenon is expected.

Peaks measured with filter number one (e.g. 5 μm polypropylene and 0.19 μm Al) were never overexposed and thus were used to estimate the number of detected photons. The transmissivity of the filter [3] and measured source spectrum in 50 – 120 eV range was used. As a result, the number of detected photons inside the FWHM area is $\sim 5 \times 10^4$ per single shot, while the number of photons originally emitted by the source is estimated to $\sim 6 \times 10^{11}$ (per shot, per FWHM area, per given energy range).

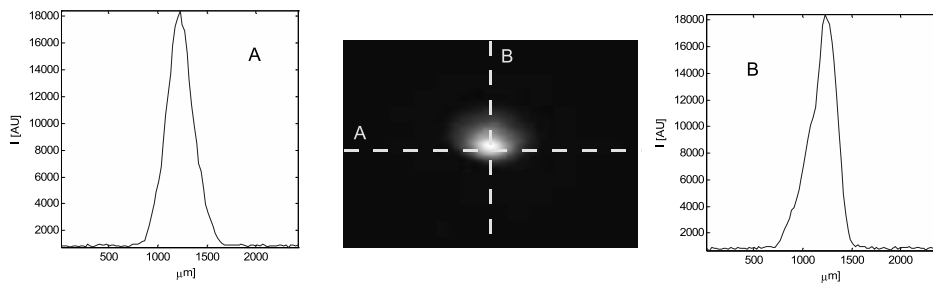


Figure 2: On of the best peaks obtained for a single shot. The FWHM of the peak is 288 μm and 312 μm respectively.

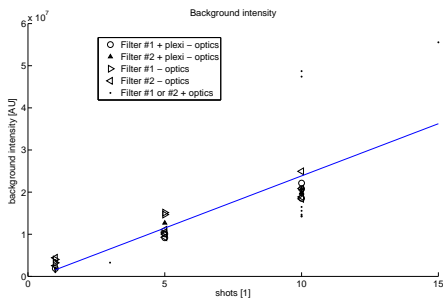


Figure 3: The background intensity for different measurements. It is only a function of the number of shots, as seen from the figure, while it is almost independent on the filter and the optics.

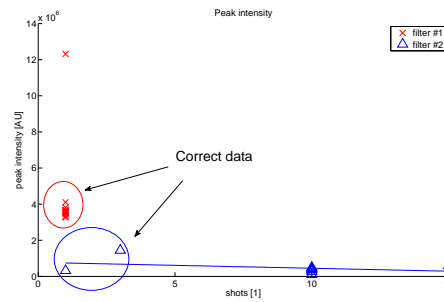


Figure 4: Intensity inside the FWHM area of the peaks as a function of number of shots. Description is given in the text.

Current & Future work

We are currently working on removing the problems encountered during the described measurements. The improvements include:

- better positioning device - a new motorized 5-axis positioning device is being assembled for the vacuum chamber in order to make the manipulation with the optics more simple, reliable and repeatable
- remove the visible light background from the detector - a new combination of filters and shields is being prepared
- better statistics of the shots
- better measurements of the pressure profile inside the device

We expect that future experiments give us more precise information about the true output of the X-Ray source and about the limits on the source dimensions. Increased intensity will be used for further spectroscopy analysis of the source in higher energies.

The system together with the optics and necessary filters and/or monochromators may be used for experiments with the EUV lithography, biological and/or medical experiments and/or as a source for electron emission analysis. Some of the applications are already in the process of problem definition and planning.

Conclusions

The radiation of the capillary discharge source has been focused with the specially designed optics and a sharp focal spot was measured. The experiment provided some preliminary data and verified the whole concept. Improved experiment is currently being assembled using the experience gathered so far.

Acknowledgments

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References

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- [2] P. Vrba et al., Springer Proceedings in Physics, Vol. 115, p 693-699 (2007)
- [3] <http://www-cxro.lbl.gov/>