Nuclear Instruments and Methods in Physics Research B xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Transmission diffractive patterns of large microchannel plates at soft X-ray energies

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A R T I C L E I N F O

Article history:
Received 13 November 2016
Received in revised form 17 February 2017
Accepted 27 February 2017
Available online xxxx

Keywords:
X-ray
X-ray optics
Capillary
Channeling phenomena
X-ray emission and fluorescence

A B S T R A C T

In this contribution we compare experimental and theoretical diffractive patterns of Micro Channel Plates (MCPs) in transmission. We evaluate the transmission efficiency of different optical devices at different energies of the primary X-ray radiation in the normal incidence geometry. Data were collected performing angular scans of both the MCP device and of the detector in the range of a few degrees. We analyzed MCPs of 33 mm and 20 mm diameter and ~300 μm thickness, having circular micro-channels of 3.4 μm directed normal to the MCP surface. Quite symmetric patterns of increasing complexity from high to low photon energy have been collected. Their shape and intensity are in reasonable agreement with preliminary simulations.

1. Introduction

X-ray based techniques offer plenty of applications in materials science, chemistry, medicine, life science and environmental science thanks to the unique properties of this radiation such as penetration capability and sensitivity to structural and chemical parameters. However, the continuous growth of nanoscience and nanotechnology applications demands new tools with extreme spatial resolution down to the nanometer domain and both elemental and chemical sensitivity. X-rays are particularly suitable to investigate nano-objects and nanostructures due to the short wavelength, penetrating power, and the possibility to probe samples in their natural environment. However, to make this possible from the submicron range down to the nanometer domain, important advancements in X-ray focusing optics utilizing refraction, reflection and diffraction properties are necessary. Actually, the development of new optical devices providing X-ray beams of both size and divergence compatible with the most powerful 3rd generation sources, and suitable to control coherence properties as required by the use of a Free Electron Laser source, is mandatory.

Focusing X-ray optics are widely used in X-ray imaging. Polycapillary X-ray optics represent an attractive option as focusing elements in magnifying imaging systems for both conventional and synchrotron radiation sources [1–4]. They can condense and focus a divergent X-ray beam into a small spot for X-ray microanalysis. Moreover, a polycapillary collimating optics can form a divergent X-ray beam into a quasi-parallel beam for X-ray diffraction. Both focusing and collimating polycapillary optics accept only X-ray photons emitted within a finite region, and so they can be used to a selective collection of the divergent radiation, as an

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http://dx.doi.org/10.1016/j.nimb.2017.02.075
0168-583X/

Please cite this article in press as: M.I. Mazuritskiy et al., Transmission diffractive patterns of large microchannel plates at soft X-ray energies, Nucl. Instr. Meth. B (2017), http://dx.doi.org/10.1016/j.nimb.2017.02.075

example for micro-analysis. In the last two decades the properties of X-ray beams shaped by polycapillary optics have been deeply investigated, including the control or the enhancement of the coherent contribution by means of capillary systems [3,5–11]. The technology of polycapillary optics is rather complex and represents a multistep glass drawing process. However, there are similar optics, which can be used to collect X-rays in a wide energy range from a relatively large source angle, but relatively simple to fabricate. In particular, MicroChannel Plates (MCPs) used for focusing radiation are quite large and effective low weight optics. In the literature [12–16] a discussion on the geometrical approach of focusing with MCPs based on the total external reflection of X-rays from the internal surface of the microchannel walls is available. In these manuscripts a simple theoretical analysis and a Monte Carlo ray-tracing of X-ray focusing properties of MCPs, based on single reflection regime together with some preliminary experimental results are available. These works demonstrate also that different capillary arrays can collimate radiation due to the high ratio between the cylindrical channel length and diameter.

More recently, MCPs have been used in low power instruments for different scientific applications [17,18]. They combine unique properties like high transmission, high spatial resolution and high temporal resolution, being suitable for many applications such as: imaging spectroscopy, electron spectroscopy and microscopy, mass spectrometry, astronomy, molecular and atomic collision studies, cluster physics, etc. High sensitivity optical, UV and EUV and X-ray spectrometers based on MCPs can be also assembled with appropriate filtering and dispersive elements. In this contribution we will consider the micro-channels of the MCP as waveguides and we will describe the propagation of X-rays through a MCP using the permittivity function and the interaction of the radiation with the inner surface of micro-channels.

2. Materials and methods

The MCPs characterized have arrays of 10^4–10^7 miniature hole micro-channels oriented parallel each other, regularly separated and with a hexagonal symmetry in the transverse cross-section. The channel matrix of these plates is fabricated using a SiO_2-PbO glass and channel axes are normal to the top surface. An image of a Micro Channel Plate and of its internal layout is showed in Fig. 1.

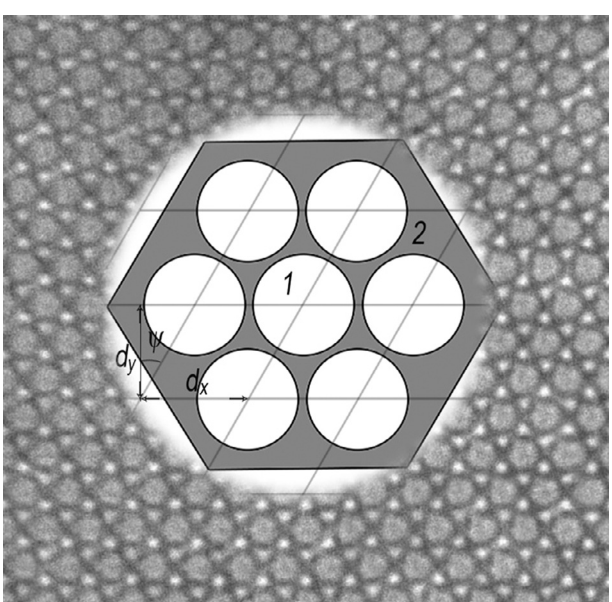

Fig. 1. Image of a MCP and its shape and symmetry: 1 – hole micro-channels; 2 – Si-Pb glass.

We present and discuss here the angular and energy distributions of the X-ray radiation of two different MCPs: white and black. Both have a thickness of ~0.27 mm, channels with the same diameter (3.4 μm), the same pitch size (4.2 μm) and the same length to diameter ratio (~80). Black MCPs are devices that underwent to a specific heat treatment.

To characterize these devices at different energies we performed experiments at two facilities, using two different instruments: a) the Reflectometer, a versatile 10 axes UHV-reflectometer, available now as a permanent end-station at the Optics Beamline at the BESSY II synchrotron radiation facility [19,20] and b) the IRMA (Instrument pour la Reflectivite' MAgnetique) HV chamber, available on request at the Circular Polarization beamline (CiPo) of the Elettra synchrotron radiation facility [21]. The Reflectometer end-station of the XUV-Optics Beamline at the BESSY synchrotron radiation facility has a four-circle goniometer operating in vacuum. Two axes are dedicated to sample scans and two to detector scans. The vacuum vessel has a diameter of 1 m and it can host large MCP samples. The maximum diameter of MCPs is limited by the distance of the horizontal plane of the holder from the center of the beam, which is ~20 mm in the Reflectometer. Additional information and the layout of the UHV-Reflectometer are discussed in Refs. [19,20].

CiPo at Elettra can provide a beam of variable polarization (circular or linear) over a very broad range of photon energies. The photon beam is produced by an electromagnetic elliptical wiggler and is dispersed by means of two collinear monochromators: a Normal Incidence Monochromator (NIM) and a Spherical Grating Monochromator (SGM). For the experiments we used the SGM monochromator that provides a beam in the soft X-ray range from ~40 to 900 eV. The IRMA reflectometer, designed for resonant X-ray scattering studies under vacuum, is a two-circle goniometer installed inside an UHV vessel. More details can be found in Ref. [21]. The experimental layout, similar to the BESSY geometry, has the MCP mounted in the vertical plane with the possibility of two independent angular scans, i.e., the angular rotation of the sample in the horizontal plane and the rotation of the Hamamatsu detector ($4 \times 4\ mm^2$ with ahead a 200 μm slit) in the vertical plane.

3. Results

In both experimental runs at BESSY and Elettra we measured radiation transmitted by MCPs. At BESSY we used a primary monochromatic radiation with a squared profile ($0.1 \times 0.1\ mm^2$) in the extended energy range from ~90 eV to ~1800 eV to illuminate our MCP devices. The divergence of the beam is 3.6 mrad × 0.5 mrad (H × V) [19]. The transmitted monochromatic radiation was detected by a photodiode with a pinhole aperture of 2 μsr located inside the Reflectometer chamber at the distance of 310 mm from the sample. In particular, we have measured the soft X-ray transmission in the energy range around the Si L and K edges (90–1800 eV) to characterize the fine structures of the angular distribution of the radiation at the exit of MCPs (see Fig. 2).

A transmission efficiency of ~60% was evaluated for flat MCPs with 3.4 μm diameter channels at both 90 and 1800 eV, by dividing the intensity of the radiation before and after the MCP. The diffraction properties of this flat MCP at 90 and 1800 eV are compared in Fig. 2. We clearly recognize the hexagonal diffraction structure for 90 eV (Fig. 2a), while only a single central maximum is detected at 1800 eV (Fig. 2b).

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