X-Ray Radiation Channeling through Micro-Channel Plates: spectroscopy with a Synchrotron Radiation Beam

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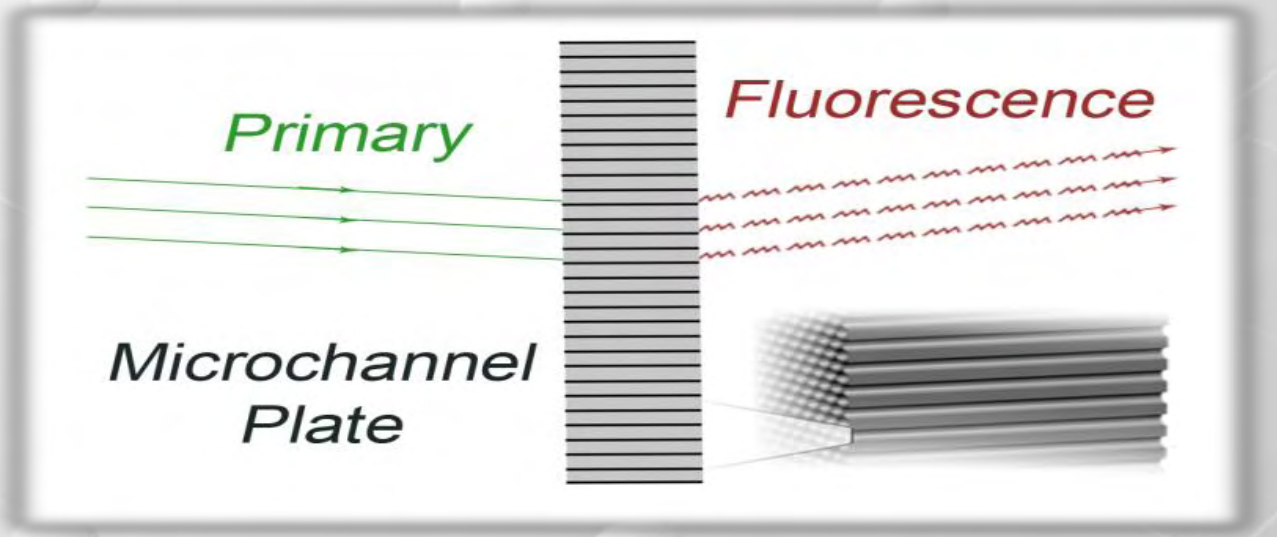

Aknowledgments

- HZM/BESSY
(projects #20120188 and #141100626)
- DA/INF[illegible]ht
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- A. Soldatov
- A. Gaupp
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Layout

* Introduction
* MCP optics
* Experimental data
* Conclusions
* Perspectives and future work

Polycapillary X-Ray Optics

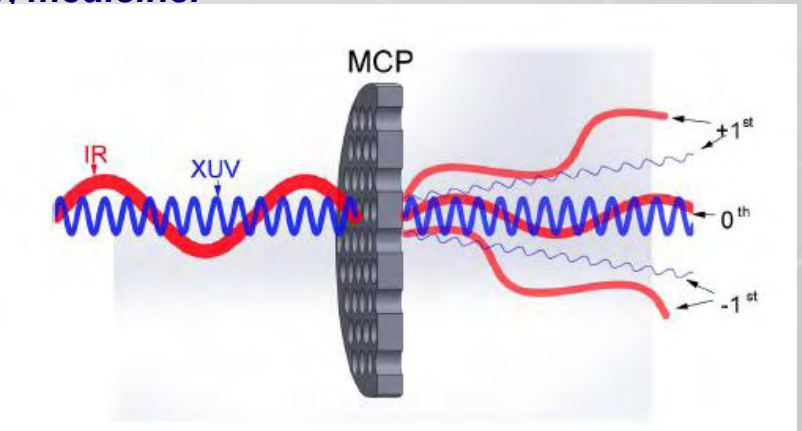
X-ray polycapillary optics consist of arrays of a large number of small hollow glass tubes assembled with a certain shape. These optics collect X-rays emitted by a X-ray source within a large solid angle producing at the exit a focused beam or a parallel beam. Hollow cylindrical Multi Channel Plates (MCP) are microcapillaries that may work also as waveguides for x-ray radiation.

Analytical instruments based on polycapillary X-ray optics are widely used in compact, low power x-ray devices used in-line in many different fields of science and technology, both in academic laboratories and industrial institutions.

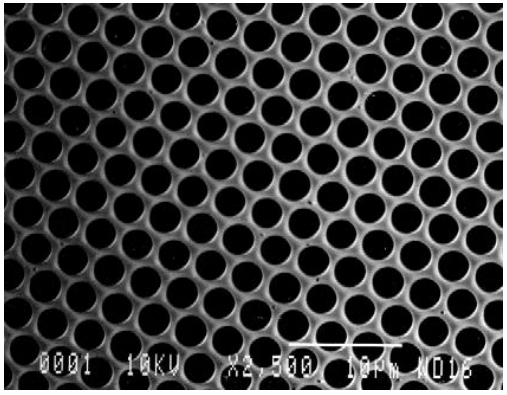
Nevertheless, the investigation and the understanding of features present in the transmission spectra of x-rays through micro-channel structures is limited and new focusing devices suitable to work at shorter and/or longer wavelengths is a hot topic. New devices and methods may offer practical applications in physics, chemistry, biology. medicine.

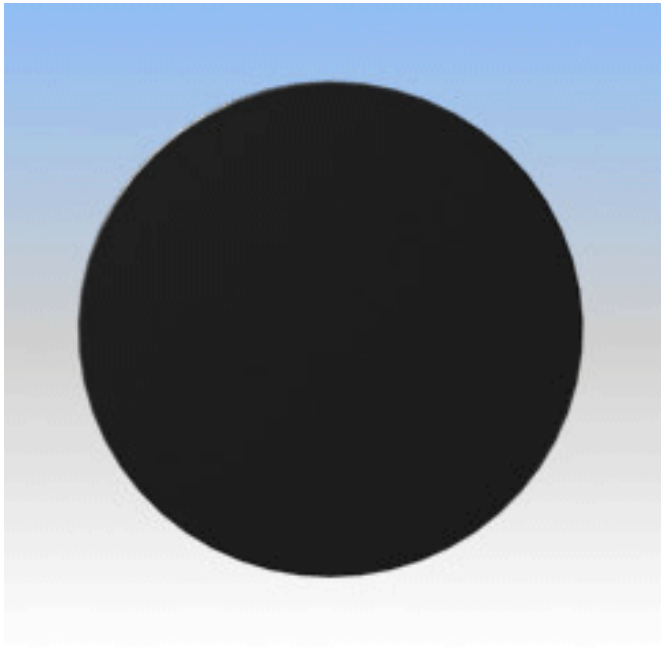
M. I. Mazuritskiy et al., Wave propagation of induced radiation in microcapillary holes of a glass microchannel plate, J. Opt. Soc. Am. B 31, 2182 (2014)

Qi Zhang et al., Suppression of driving laser in high harmonic generation with a microchannel plate, Opt. Lett. 39, 3670 (2014)



Micro-Channel Plates (MCP)





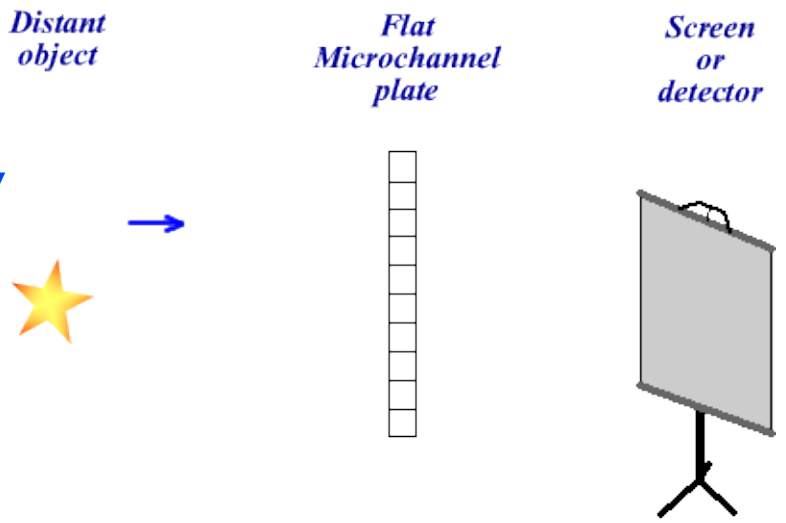
MCP samples have been manufactured from SiO_2 glass substrates by the BASPIC company (Russia).
For these experiments we used ~0.3 mm thick MCP's with a transversal hexagonal shaped cross-section.
The MCP's are characterized by regular holey cylindrical channels (pore) with a diameter of 3.4 μm and with a pitch size of 4.2 μm

Goal

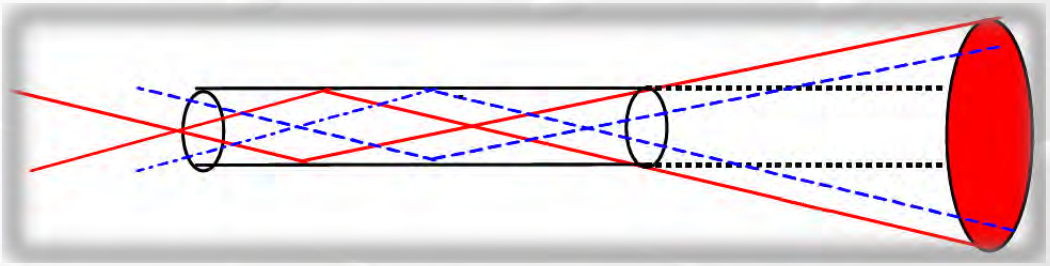
Present and discuss new experimental data on the transmission of X-ray radiation trough silicon glass based micro-channel plates (MCPs).

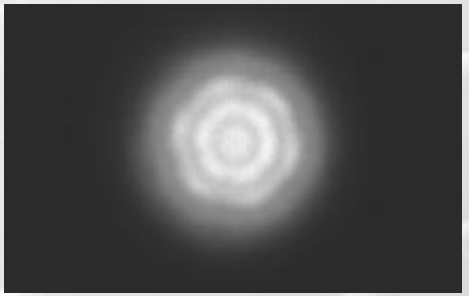
Characterize the transmitted radiation and in particular the fluorescence radiation excited inside the micro-channels and their transport along these hollow silicon-glass micro-capillary structures.

Discriminate the origin of the fine structure in the angular distribution of the transmitted radiation and in the spectra observed at the exit of MCPs due to the excitation of the incident monochromatic radiation.



Channeling of Excited Fluorescence Radiation

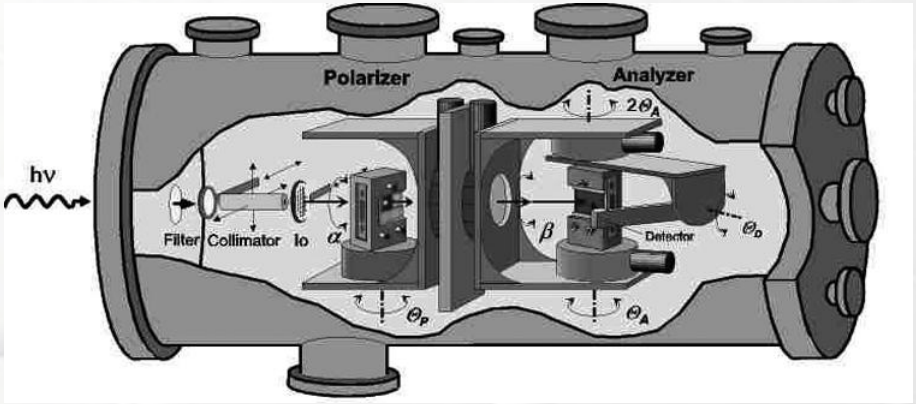


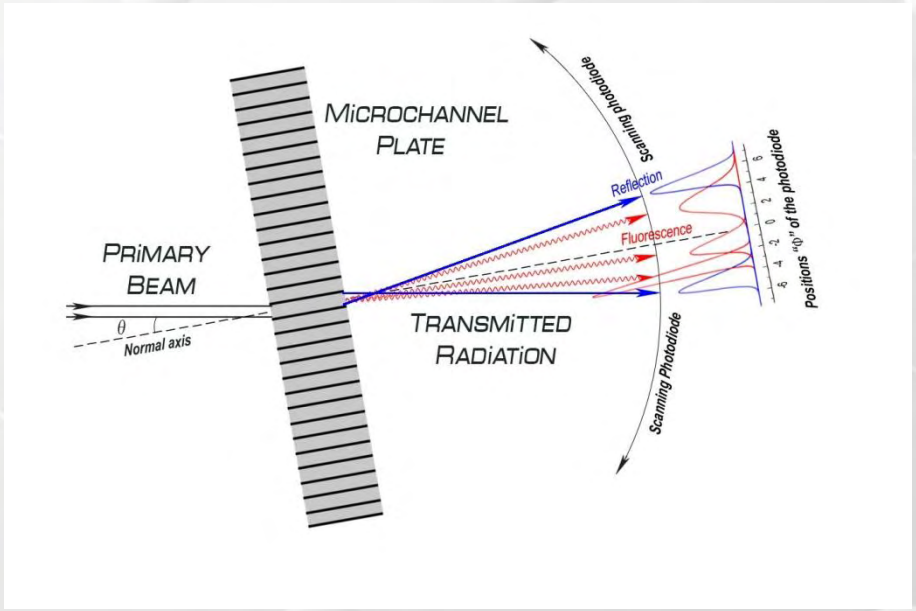


The physics of conventional capillary optics is founded on the total external reflection of X-rays and a mode regime of transport of the primary radiation. If the energy of the incident (primary) radiation is close to the energy of the electronic transition from an inner electron shell to unoccupied free states, many resonance phenomena can be observed in the energy spectra collected near an atomic absorption edge.

The fine structure observed in the spectra after the main edge contains peaks and valleys and corresponds to reflection or absorption spectra. In particular, we studied the inelastic scattering/refraction contributions in the anomalous dispersion region at the energies of the Si-L edge and of the O-K edge (from ~90 to ~600 eV).

The BESSY II Polarimeter end-station layout





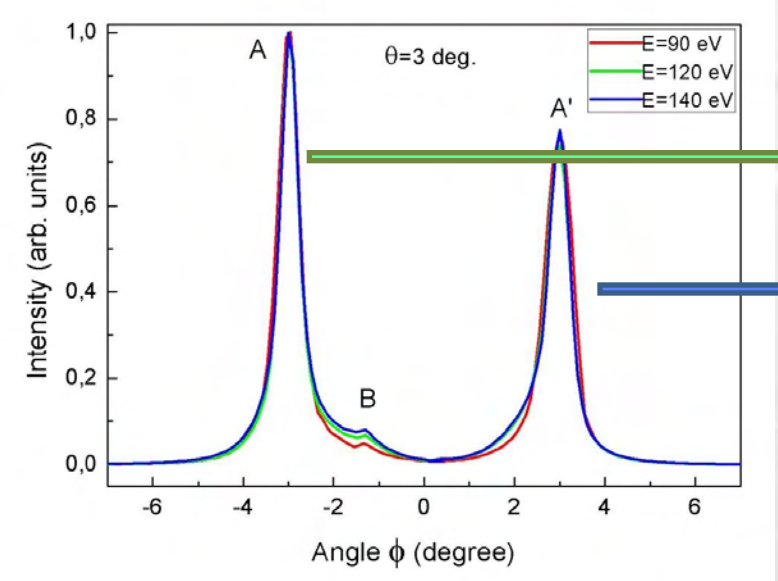
Experiments were performed on the end-station of the Polarimeter available at the BESSY II synchrotron radiation facility in Berlin.

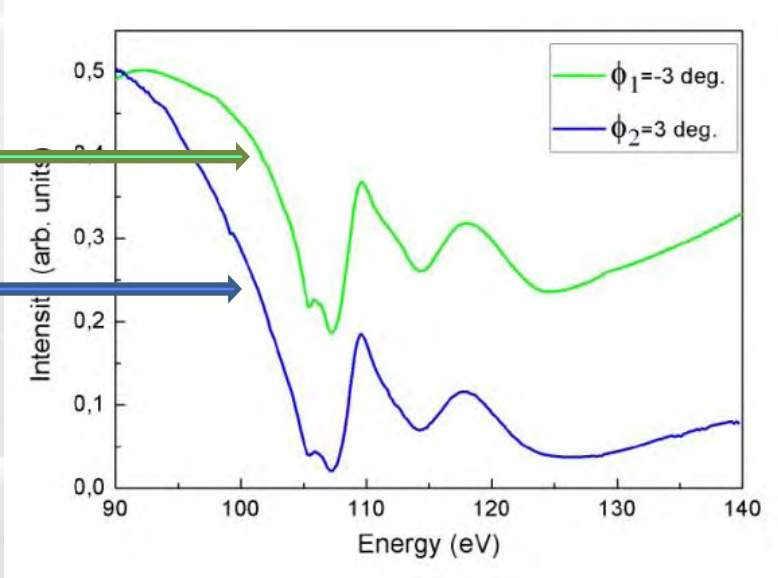
A primary monochromatic beam with a divergence <5 mrad was illuminating the MCP surface. The radiation propagating inside micro-channels was collected with a photodiode sets on the other side of the MCP.

In the transmission geometry, the grazing angle θ between the primary beam and the MCP microchannel walls was set rotating the device around the axis perpendicular to the plane of the figure. We collected spectra with the photodiode sets at different angles (Φ).

For each value of the grazing angle θ, the direction "normal" to the surface has been considered the relative "zero" of the corresponding angular scan.

Radiation at the exit of a MCP: Si L–edge



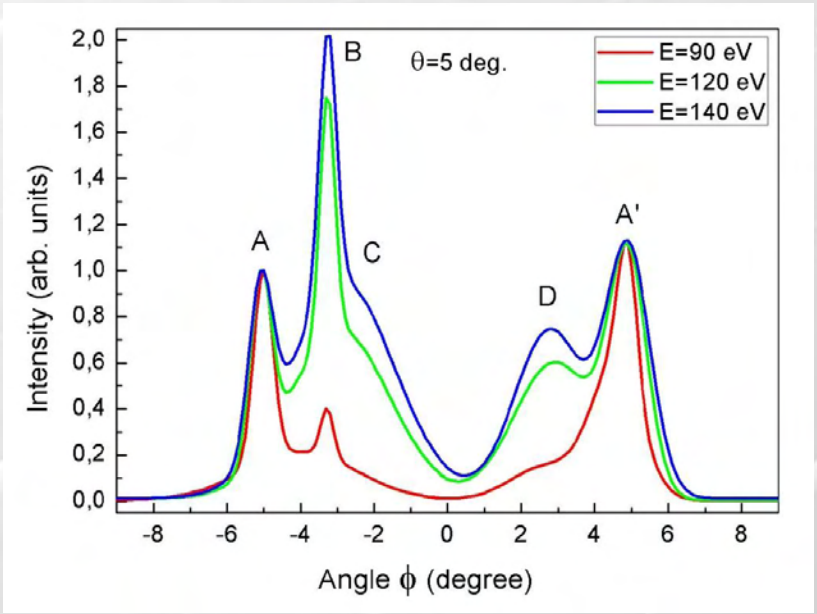


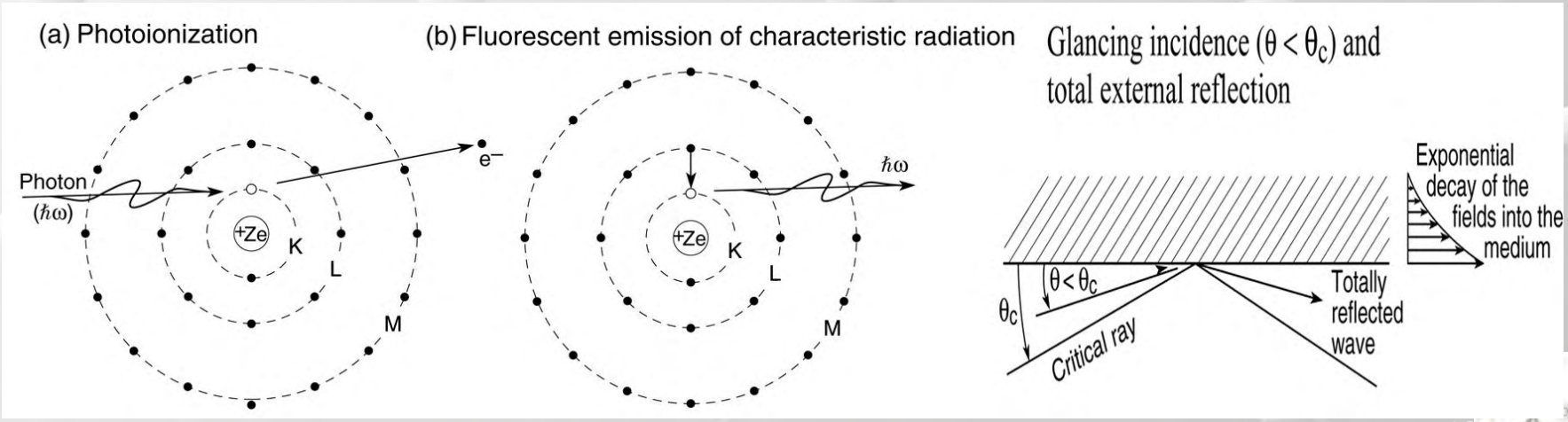
In the above figures we show the angular distributions of the intensity of the radiation transmitted at the exit of a MCP for different energies and incident angles of the incident (primary) radiation. Two maxima are clearly observed in the left panel: A (-3°) and A' (3°) and in the right one: A (-5°) and A' (5°), all due to multiple reflections of the primary radiation inside the microchannels.

With the Polarimeter layout we had the possibility to fix the angular position of the photodiode for each maxima. As an example we show the energy spectra collected at the exit of the MCP at -3° and at 3° both for an incidence angle of the primary radiation of θ=3° and in the energy range around the Si L-edge. The fine structures of both spectra are very similar to the reflection spectra of a silicon glass.

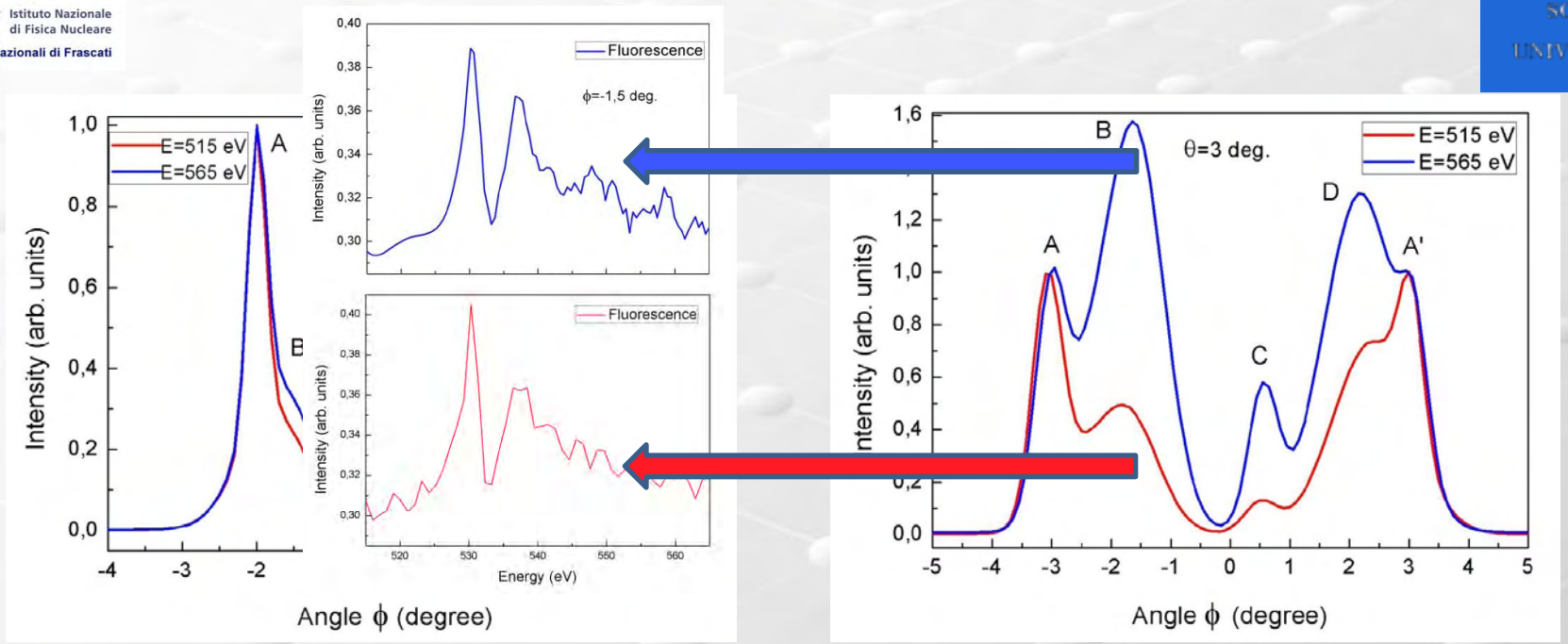
Fluorescence radiation at the exit of a MCP: Si L – edge

If the photon energy of the incident radiation is close to the energy of an inner electron shell, resonance phenomena can be observed in the X-ray spectra near the atomic absorption edges. We investigated the angular distribution of the fluorescence radiation traveling inside MCP microchannels in the energy range around the Si $L_{2,3}$ edges. In this case, in a narrow range the angular distributions of the radiation show other maxima and features: B, C and D, corresponding to the fluorescence radiation detectable only at large values of the grazing angle between the primary beam and MCP microchannel walls.





Radiation at the exit of a MCP: O K – edge



When the primary radiation energy is close to the O K- absorption edge again is possible to collect the fluorescence radiation at the exit of a MCP. The total external reflection angle (θ_c) at the energy of the O K edge (~540 eV) is ~3˚ . The two figures above show the angular distributions collected just below and above the O K-edge, i.e., at the energies of 515 eV and 565 eV below and above θ_c.

Depending on the θ angle, when the incident energy is above the O K-edge the fluorescence at the exit of a MCP shows two or three features: B, C and D. Moreover, fine structures in the energy spectra collected at the exit of a MCP contain additional information regarding the nature of the radiation (see figures in the center). Similarly to the case at the Si L-edge spectra, for any angular position of the photodiode in the range -θ<Φ<θ the fluorescence radiation at the exit of a MCP is detected in a narrow angular range.

Conclusions

We measured the angular distributions of the intensity radiation at the energies of Si L – and O K – edges using MCPs with microchannels with a diameter of ~3 μm.

The angular distributions of the intensity of the radiation show in a narrow angular range several maxima (e.g., B, C and D) corresponding to fluorescence radiation propagating inside MCP´s.

The fluorescence radiation has been detected only for quite large values of the grazing angle θ between the primary beam and MCP microchannel walls, e.g., ~5° at the Si L – edge and ~2° at the O K – edge.

We collected the fluorescence radiation for energy of the primary radiation close to the energy of the Si L – and O K- edges. For an incident energy below the corresponding absorption edge no fluorescent radiation was detected at the exit of a MCP.

Fine structures of reflection and fluorescence radiation spectra collected at the exit of MCPs contain additional information on the nature and the way the radiation propagates inside these policapillary systems.

Perspectives

To proceed in the characterization of MCPs we submitted a new proposal at BESSY II:
"Angular distribution and XANES spectroscopy of channeling x-ray fluorescence at the exit of glass micro-channel plates"
Next experimental runs are foreseen next year.

We are also going to test MCP's as focusing optics in laboratory instruments using conventional radiation sources.

3) M.I. Mazuritskiy, et al.
'X-ray radiation channeling through micro-channel plates: spectroscopy with a synchrotron radiation beam' - to be subm. (2014)

2) M.I. Mazuritskiy, et al.
'Wave propagation of induced radiation in microcapillary holes of a glass microchannel plate'
J. Opt. Soc. Am. B 31, 2182-2187 (2014)

1) M.I. Mazuritskiy, et al.
'X-ray spectroscopy of fluorescence radiation channeling in μ-capillary holed glass plates'
Nucl. Instr. & Meth. B 309, 240-243 (2013)

Thanks for the attention

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