Studies on Metallic X-Ray Capillary Waveguides


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The X-ray capillary optics is now widely studied version of devices designed for X-ray guiding and squeezing. The X-rays travelling through capillaries are reflected in small angles if they should be reflected inside capillaries [1,2]. The most popular capillaries are made of glass. The next goal in the field was to construct the metallic capillaries, that give the opportunities to guide the higher energy X-ray photons, to use somewhat higher critical angles of reflection and to shape the capillary profile under better control. The application of metallic capillaries should be especially advantageous for one-bounce uses. The first successful attempt of production was made by Hirsch [3]. The original version of preparation of X-ray capillaries was invented in Chemistry Department of Lublin Catholic University [4]. In the over one-year-long experimental work, the electroforming method of manufacturing of capillaries with the metallic cover (Au) inside walls was worked out. At first, the hard steel-made cathode wire (~200 µm thick) was coated with copper layer in controlled electrolytic process. It gave the precisely shaped parabolic core part. The shape of the core part was controlled with the electron microscope and, independently, by laser micrometer. The shape was kept in the ±1 µm limit in relation to the designed shape on a distance of several centimeters along the main axis (see Fig. 1a). As the next, a thin layer of gold was coated in electroless way. The formation a thick copper layer by the electrochemical operation finished the work. It formed the body part of the capillary. Then, the copper part of the core was etched with the chemicals. In general, we produced paraboloidal capillaries of length ~65 mm, with the inlet diameters ~350 µm and the outlet diameters ~200 µm.

The roughness (rms) of the core part was controlled by the use of atomic force microscope. It was kept in the limits of 3.5-6 nm and was in the low limit of allowed levels (see Fig. 1b). The roughness was dependant on the area of the scanned field. In many cases, this dependence was of roughly fractal character.

The openings of capillaries were investigated by a series of optical experiments. The He-Ne laser light (633 nm, beam divergence 0.8 mrad) was propagated through the capillary. The escaping beam was registered by the use of a CCD camera (Panasonic). The outgoing image is presented in Fig. 1c. In some experiments, the output beam was registered in a linear scan method by passing the inlet of 10 µm wide optical waveguide before the front of the capillary outlet. The collected light was guided to the photodetector and registered. The result is shown in Fig. 2a, presenting the moderately high degree of the internal symmetry in the capillary interior.

Some capillaries from the first manufacturing series were checked in HASYLAB, line L, during a session 30.08-2.09.2005. The X-ray photons of 17 keV energy were used in the experiments. Due to the preliminary character of those capillaries, we established that the quality of the internal hole of the capillaries was this time insufficient. The image of the direct beam (probably without internal reflections) was registered and is shown in Fig. 2b. It testifies about the highly symmetric shape of the opening. Nevertheless, the internal roughness probably deviated from the assumed value of ~5 nm. In addition, the etching process was probably nonsufficient and left some remains of copper, highly increasing surface roughness of the side walls.

Now, the production of capillaries is much improved and the next series of capillaries should be checked at beamline L.

This work was supported by the European Community - Research Infrastructure Action under the FP6 "Structuring the European Research Area" Programme (through the Integrated Infrastructure Initiative "Integrating Activity on Synchrotron and Free Electron Laser Science").
Fig. 1. (a) The profile of the core part used in the production of a capillary as measured with the laser micrometer MITUTOYO, LSM-500H (all dimensions in micrometers). (b) AFM image of the core part of capillary: 10*10 µm dimensions; The rms parameter estimated as 5.33 nm. (c) Image of transmitted laser beam, optical beam, wavelength 633 nm, registration by the use of CCD camera. Spot size: ~ 30 µm.

Fig. 2. Result of the linear scan of the capillary output, registered with the optical waveguide of 10 µm diameter (black line), as compared with the registration of the raw laser radiation (blue line). (This capillary has not been tested in HASYLAB). (b) Image of the X-ray output from the metallic capillary, measured with CCD camera placed in the semi-focus of the capillary. X-ray energy = 17 keV. Measured at beamline L at HASYLAB. Dimensions of the spot: ~ 200 µm.

References