ESRF	**Experiment title:** Evaluation of saw-tooth refractive optics for hard x-rays	**Experiment number:** MI-484
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Report:

Introduction

The purpose of the experiment was to evaluate a new type of refractive X-ray lenses for hard X-rays. These lenses have been proven to work with ordinary laboratory sources (B. Cederström *et al.*, Focusing hard X-rays with old LP's, *Nature* 404, p. 951, 2000), but a thorough test requires a synchrotron beam geometry with small divergence and possibility to focus to sub-μm spot sizes. A schematic of the lens is shown in Fig 1.

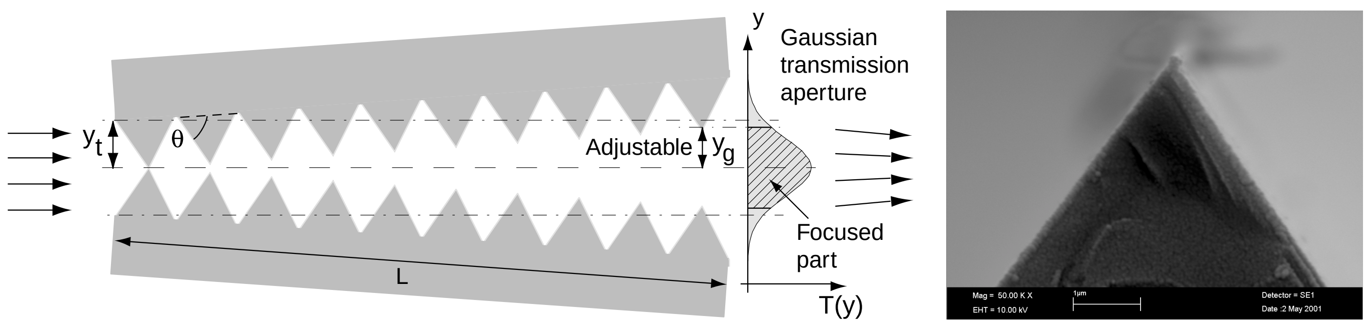

Figure 1: Left: Schematic of the X-ray lens. $y_t = 100$ μm. $L = 60$ mm. In reality there are 430 teeth. **Right:** SEM image of the tip of one tooth. The surface quality is very high and the rms roughness was measured to about 10 nm using white-light interferometry.

The lens is equivalent to a single parabolic lens with radius of curvature $R = y_g y_t / L$ and the focal length is given by $F = R/\delta$, where the index of refraction is $n = 1 - \delta + i\beta$. A unique feature of the lens is that the focal length can be varied by changing the gap between the halves.

Lenses were made by anisotropic etching in KOH in 1 mm thick n-doped Si wafers with (100) orientation. The result of the process was a saw-tooth profile with teeth defined by slow etching (111) planes at 54.7º angles with the wafer surface. The surface roughness was found to be about 10 nm rms and should be negligible. Epoxy lenses were fabricated by molding using the silicon lens as a master. The material used was the two-component epoxy resin Epo-Tek 301-2 with a mean atomic number of approximately 6.

Experimental results

The lenses were put on mechanical stages 40 m from the BM source with a vertical size of 80 μm. After alignment, beam profiles in the focal plane were measured using an edge-scan with a tungsten blade and a Si-diode. Two examples are shown in Fig. 2. For the Si lenses the highest gain was 20 ± 1 (theory: 59) and the smallest focal line width was 1.2 μm (theory: 1.2 μm). For the epoxy lenses the corresponding values were 32 ± 2 (theory: 138) and 0.87 μm (theory: 0.61 μm), respectively. The focal line broadening for the epoxy lens is likely caused by scattering from air bubbles created in the molding process. We believe the lower gain than expected is due to overlap of the two lens halves, resulting in increased absorption.

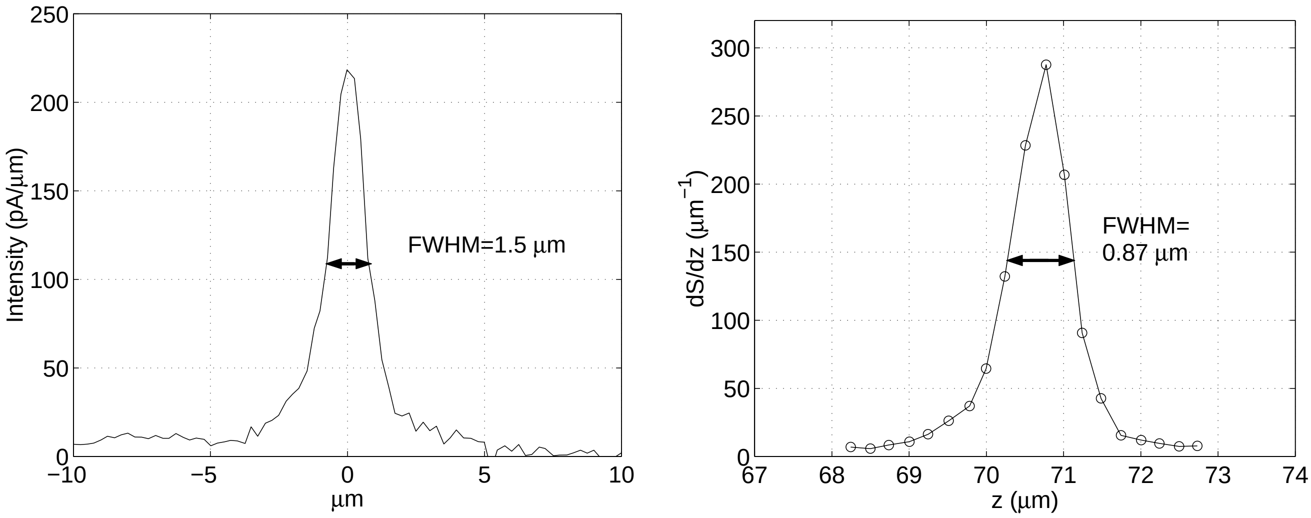

Figure 2: Beam profile in the epoxy lens focal plane. **Left:** Highest gain; $F = 46$ cm, $E = 25$ keV. The intensity gain is 32 ± 2. **Right:** Smallest focal line: FWHM= 0.87 μm, $F = 25$ cm, $E = 18$ keV, gain is 26 ± 2.

Conclusions and future work

These measurements have shown that this type of lenses are suitable for micro-beam production in a 3rd gen. synchrotron facility. Aberration and scattering effects are sufficiently small to allow sub-micron focal spots. An article reporting these results is being prepared for submission to Applied Physics Letters. Next step is to cross two lenses to obtain 2D focusing and squared gain, as well as testing the imaging capabilities. Silicon and epoxy are not optimal lens materials. We believe the simplified geometry will permit fabrication of beryllium lenses, which should provide much larger aperture and intensity gain.