Institute of Physics Publishing Journal of Physics: Conference Series **21** (2005) 207–210
doi:10.1088/1742-6596/21/1/034 Second International Conference on Photo-induced Phase Transitions

Bent Crystal X-Ray Mirrors for Time-Resolved Experiments with Femtosecond Laser-Produced X-ray Pulses

M Nicoul[1], U Shymanovich[1], S Kähle[1], T Caughey[2], D Sampat[2], K Sokolowski-Tinten[3] and D von der Linde[1]

[1] Institut für Experimentelle Physik, Universität Duisburg-Essen, Universitätsstr. 5, 45117 Essen, Germany
[2] INRAD, 181 Legrand Avenue, Northvale, NJ 07647, USA
[3] Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

nicoul@iep.physik.uni-essen.de

Abstract. In the last few years, bent crystal X-ray mirrors have played an important role in time-resolved X-ray diffraction experiments when X-ray pulses from femtosecond laser-produced plasmas were used [1-4]. Improvements in manufacturing techniques have significantly increased the quality of this type of mirror.

1. Introduction

Femtosecond laser-produced plasmas represent simple, table-top sources of multi-keV X-ray pulses with subpicosecond duration. By focusing an intense femtosecond laser pulse onto the surface of a solid or a liquid, a microplasma is formed which emits incoherent X-rays into a large solid angle. The radiation spectrum contains mainly characteristic line emission (i.e. K_α) at wavelengths determined by the target material. To obtain an X-ray flux high enough to carry out diffraction experiments, efficient collection and focusing of the emitted radiation is required. This can be accomplished, for example, with the help of toroidally bent crystals which allow a monochromatic point-to-point imaging of the plasma source. This report discusses the development and the performance of two different kinds of germanium X-ray mirrors for Ti-K_α (4.51 keV) and Cu-K_α (8.05 keV) radiation.

2. Experimental

The experiments were carried out with laser pulses from a terawatt CPA (chirped pulse amplification) titanium sapphire laser (λ = 800 nm). The laser system produces pulses of 120 fs duration with pulse energies of up to 150 mJ at a repetition rate of 10 Hz. Using a lens with 20 cm focal length the laser beam is focused onto a moving wire. A microplasma is generated and a burst of incoherent X-rays is emitted into the full solid angle with line emission at 4.51 keV for titanium K_α ($\lambda_{Ti\text{-}K\alpha}$ = 0.275 nm), and 8.05 keV for copper K_α ($\lambda_{Cu\text{-}K\alpha}$ = 0.154 nm).

To detect these characteristic X-rays, we used detectors adapted to the specific photon energy: for the Ti-K_α emission a back-illuminated CCD camera, and for Cu-K_α emission a phosphor based intensified CCD camera.

3. Focusing of multi-keV X-rays

If one wishes to use such an incoherent, point-like X-ray source for experiments, a X-ray mirror with high reflectivity and a large acceptance angle for the efficient collection and focusing of X-ray photons is required. Bent crystals are excellent candidates as they allow one to make use of the strong Bragg reflection of X-rays from the lattice planes of crystals [5].

Bent crystals are prepared in the following way: a slab of high purity, single-crystal germanium is grown and oriented to better than 0.1° and then polished flat. Using standard grinding and polishing techniques, the crystal is thinned to less than 100 μm in thickness. Before attaching the crystal to the toroidal substrate, the orientation is checked, and a X-ray reflection topography is used to verify that the crystal planes are uniformly oriented. The thin germanium crystal platelet is then bonded onto a toroidally shaped glass substrate. The wave front distortions are optically checked using 632 nm radiation from a HeNe laser. For the Ti-K_α and the Cu-K_α point source we use a Ge (400) and a Ge (444) toroidally bent crystal, respectively. The horizontal and the vertical radius of curvature of the toroidal mirror must satisfy $R_V/R_H = \sin^2(\Theta_B)$, where Θ_B is the Bragg angle (see figure 1). Using a Rowland circle geometry, one-to-one imaging of the point source is obtained.

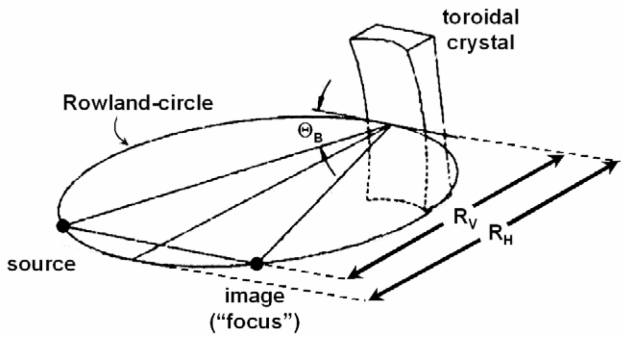

Figure 1. Typical arrangement of a toroidally bent crystal in a Rowland geometry.

We have carefully examined the surface quality and the size of the focus. The topography pictures measured with the detector placed between the mirror and the focus plane are shown in figure 2.

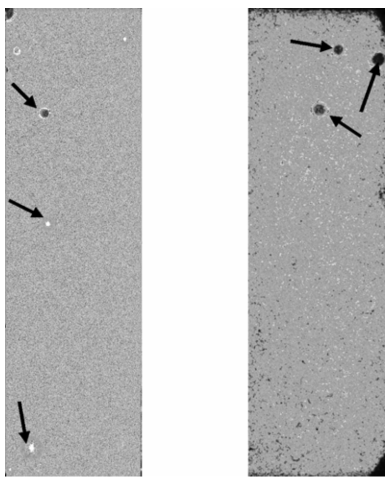

Figure 2. Topography picture for Ti-K_α mirror (left) and Cu-K_α mirror (right). The arrows mark some of the point-like imperfections of the mirrors.

Corresponding distributions of the X-ray emission measured with the CCD-camera in the focal plane are shown in figure 3.

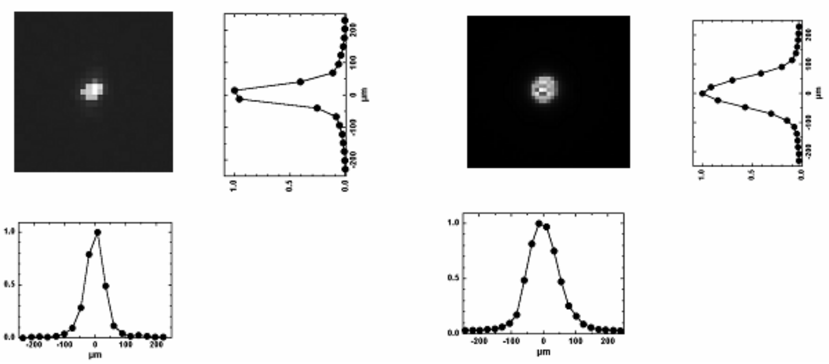

Figure 3. Focus and distribution for Ti-K_α mirror (left) and Cu-K_α mirror (right).

Both for Ti-K_α and Cu-K_α two different mirrors were available. The measured results of the four mirrors are given in Table 1.

Table 1. Measured properties of germanium toroidal mirrors.

Radiation	Ti-K_α		Cu-K_α	
	Mirror 1	Mirror 2	Mirror 1	Mirror 2
Size	12.5 x 40 mm			
Orientation	100		111	
Bragg-reflection	400		444	
Bragg-angle	76.4°		70.6°	
R_H	499.3 mm	498.6 mm	496.51 mm	496.63 mm
R_V	474.3 mm	473.7 mm	441.82 mm	441.75 mm
R_V/R_H	.94993	.95006	.88985	.88950
$Sin^2(\Theta_B)$	.94471		.88967	
Thickness	90 mm		90 mm	
Surface fig (PV @632 nm)	0.1 λ	0.15 λ	0.17 λ	0.09 λ
Orientation error	<10”		<10”	
Focus size (FWHM) [a]	90 x 70 μm^2	60 x 70 μm^2	90 x 90 μm^2	110 x 110 μm^2

[a] The measured focus size represents a convolution of the imaging properties of the optics and the source size. However, a 100 μm focal size is small enough to carry out experiments.

4. Conclusion

We have checked the surface quality and focus of four toroidal mirrors manufactured by INRAD for Ti-K_α or Cu-K_α wavelength. The investigated mirrors have excellent surface quality allowing the X-rays to be diffracted homogeneously over the entire surface and focused into a spot of less than 100 μm diameter (FWHM).

References

[1] Rischel C, Rousse A, Uschmann I, Albouy P A, Geindre J P, Audebert P, Gauthier J C, Förster E, Martin J L and Antonetti A 1997 Femtosecond time-resolved X-ray diffraction from laser-heated organic films *Nature* **390** 490

[2] Rousse A *et al.* 2001 Non-thermal melting in semiconductors measured at femtosecond resolution *Nature* **410** 65

[3] Sokolowski-Tinten K, Blome C, Dietrich C, Tarasevitch A, Horn von Hoegen M, von der Linde D, Cavalleri A, Squier J and Kammler M 2001 Femtosecond X-ray measurement of ultrafast melting and large acoustic transients *Phys. Rev. Lett.* **87** 225701

[4] Sokolowski-Tinten K *et al.* 2003 Femtosecond X-ray measurement of coherent lattice vibrations near the Lindemann stability limit *Nature* **422** 287

[5] Missalla T, Uschmann I, Förster E, Jenke G and von der Linde D 1999 Monochromatic focusing of subpicosecond X-ray pulses in keV range *Rev. Sci. Ins.* **70** 1288.