Study of multilayer-reflected beam profiles and their coherence properties using beamlines ID19 (ESRF) and 32-ID (APS)

A. Rack[1], L. Assoufid[2], R. Dietsch[3], T. Weitkamp[4], S. Bauer Trabelsi[5], T. Rack[6], F. Siewert[7], M. Krämer[3], Th. Holz[3], I. Zanette[1], W.-K. Lee[2], P. Cloetens[1], and E. Ziegler[1]

[1]*European Synchrotron Radiation Facility, BP220, Grenoble, France, email: arack@snafu.de*
[2]*Advanced Photon Source, Argonne National Laboratory, Argonne, USA*
[3]*AXO DRESDEN GmbH, Dresden, Germany*
[4]*Synchrotron Soleil, Gif-sur-Yvette, France*
[5]*K.I.T. / ANKA light source, Karlsruhe, Germany*
[6]*Charité, Berlin, Germany*
[7]*Helmholtz Zentrum Berlin/BESSY-II, Berlin, Germany*

Abstract. The use of multilayer mirrors is an interesting alternative for reflective X-ray monochromatization with respect to reflection from crystal optics. The increased photon flux density due to the multilayers' larger bandwidth is of crucial importance for, e.g, full-field X-ray imaging applications. Drawbacks are the introduced modifications of the reflected beam profile as well as a certain loss of coherence, summarized as wavefront degradation. Our recent work has shown that the modification of the beam profile can vary with, e.g., the material composition of the coating applied. In order to verify our findings, a beamline round-robin has been initiated, comparing the wavefront profiles after reflection by selected multilayers at beamlines 32-ID (Advanced Photon Source) and ID19 (European Synchrotron Radiation Facility) with our initial results acquired at BM05 (ESRF) [1].

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INTRODUCTION

Compared with crystal lattice reflection, the use of Bragg reflection on a multilayer mirror as a monochromator for hard X-rays has the advantage of a higher photon flux density because of the larger spectral bandpass. The main disadvantage lies in the strong modifications on the reflected beam profile, a major issue for micro-imaging applications where multilayer-based monochromators are frequently employed to deliver high photon flux density [1, 2].

Due to the lack of a formalism relating the performance of multilayer mirrors to their structural quality, we have started to study the performance of different multilayer mirrors in terms of the profile of the reflected beam as well as its coherence properties. Among the parameters varied were the multilayer period ("d-spacing"), the material composition and the number of bi-layers grown. Recently, the study was extended by characterizing multilayer mirrors produced by different deposition facilities [3].

In this article, the reflected beam profiles and coherence properties of commercially available multilayer mirrors characterized at the beamlines ID19 (European Synchrotron Radiation Facility, ESRF) and 32-ID (Advanced Photon Source, APS) will be shown [4, 5]. The aim of this round-robin is to verify our previous results: Even though the intensity of beam profile modifications changes due to the different beamline geometries, the relative differences between the multilayer structures remain the same. This means, the effects are solely inherent to the multilayers and can be applied at various experimental set-ups.

MULTILAYER MIRRORS

Commercial one-sided superpolished silicon single crystals (General Optics, Gooch & Housego) were applied as substrates for the two multilayers presented here. The substrate diameter was 25.40 mm with a thickness of 6.35 mm and surface roughness of around Sq = 0.10-0.15 nm. The multilayer structures (Mo/Si and Pd/B_4C, 220 bi-layers) were deposited on these substrates by means of magnetron sputtering (the period thickness was nominal: 2.5 nm). Further details are published in [1].

EXPERIMENT

A similar protocol which was recently successfully used to characterize the wavefront preservation capabilities of reflecting X-ray optics was applied to study the coherence properties and beam profile after reflection on the multilayers under study [1, 6, 7]: for both beamlines employed, 32-ID as well as ID19, monochromatic radiation of 18 keV photon energy was obtained by filtering the insertion device (undulator) spectrum by a Si-based double-crystal monochromator (32-ID/ID19: 275 µm × 40 µm / 125 µm × 25 µm (horizontal × vertical) effective source size (the ESRF operated in the so-called “4-bunch mode” during the experiment), 30-m / 140 -m source-to-monochromator distance, and 40-m / 7-m distance monochromator-to-multilayer). Approximately 18 cm downstream of the multilayer, a Si phase grating (6-µm pitch) is placed [8]. By measuring the visibility of the grating at different distances downstream of the multilayer with a high-resolution imaging detector, the coherence properties of the beam can be quantitatively and qualitatively compared [9]. Approximately 3 m (32-ID) / 6 m (ID19) downstream of the multilayer mirror, a second high-resolution imaging detector is placed in order to capture the beam profile after a longer propagation distance. The latter gives an idea about how the mirror would perform when being permanently installed, i.e. as part of a multilayer monochromator [2, 10, 11].

RESULTS

The results of the wavefront preservation characterization performed at 32-ID are shown in Fig. 1 below. As frequently observed, the reflection by a multilayer mirror introduces a characteristic stripe pattern in the beam profile, with respect to the beam profile as recorded when only the crystal monochromator is used. The intensity profile is superimposed with the Gaussian intensity profile of the incoming beam. Imperfect flat-field corrections, which previously have been observed are causing the visibility curve for the Mo/Si mirror to be rather rough [1]. The reflection leads as well to a significant loss of vertical visibility, and hence, a degradation of the coherence properties of the beam. Similar to our previously reported measurements, the stripe modulations are less pronounced for this specific Pd/B_4C mirror with respect to the Mo/Si mirror from the same lot [1].

The results of the measurements as performed on ID19 are shown in Fig. 2 on the next page. Due to the different beamline geometries, the profile of the synchrotron beam as reflected by one of the two mirrors is significantly different: the stripe modulation (peak-to-valley) is much more pronounced than for the 32-ID case. Due to the varying source size when operating in “4-bunch mode”, the peak visibilities at the two given Talbot distances differ significantly between the scan done with the beam reflected by the Mo/Si mirror with respect to the scan with the Pd/B_4C

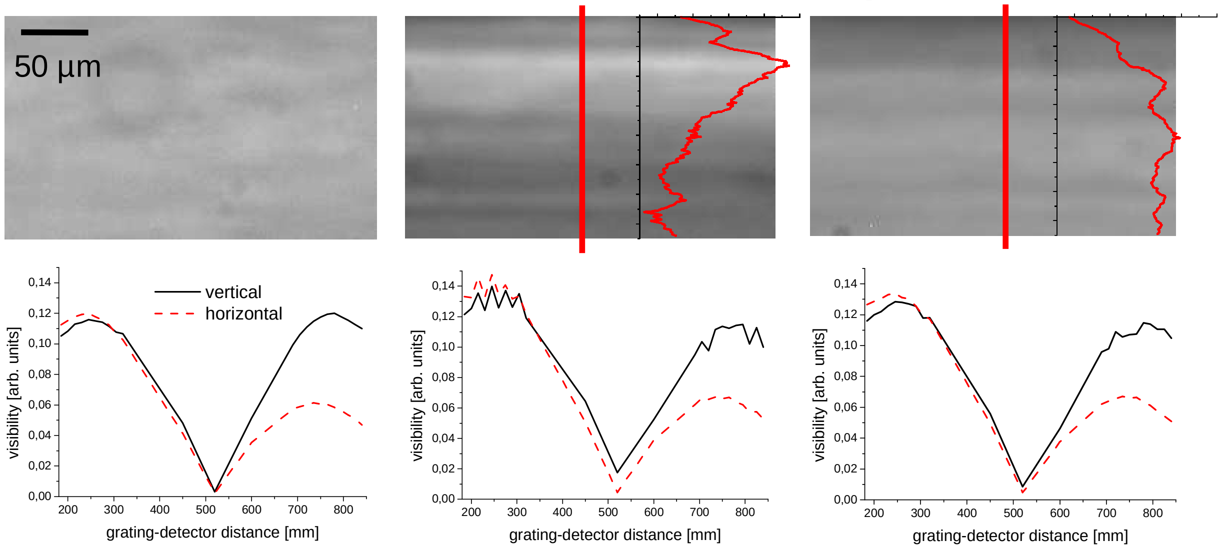

FIGURE 1. Top: beam profiles acquired at 32-ID (APS). Left: with only the crystal monochromator in the beam. Center: after additional reflection on the Mo/Si multilayer. Right: after reflection on the Pd/B_4C multilayer. Exemplarily chosen profile plots are shown as well. The bottom plots show the corresponding results of the coherence measurements (Note the roughness of the curve for the Mo/Si mirror, related to imperfect flat-field corrections).

mirror. The ratio between the visibilities at the two Talbot distances is rather similar for both multilayer mirrors.

DISCUSSION

The results of our study presented in [1] (based on results acquired at the ESRF beamlines BM05 (beam profiles) and ID19 (coherence)) have been verified by the experiments at 32-ID (APS) and ID19 (ESRF). The different coherence properties of the reflected beam determined at 32-ID can be associated with the rather simple mounting compared to the ESRF experiment. Future experiments will focus on round robins, new materials and the influence of the substrate [12].

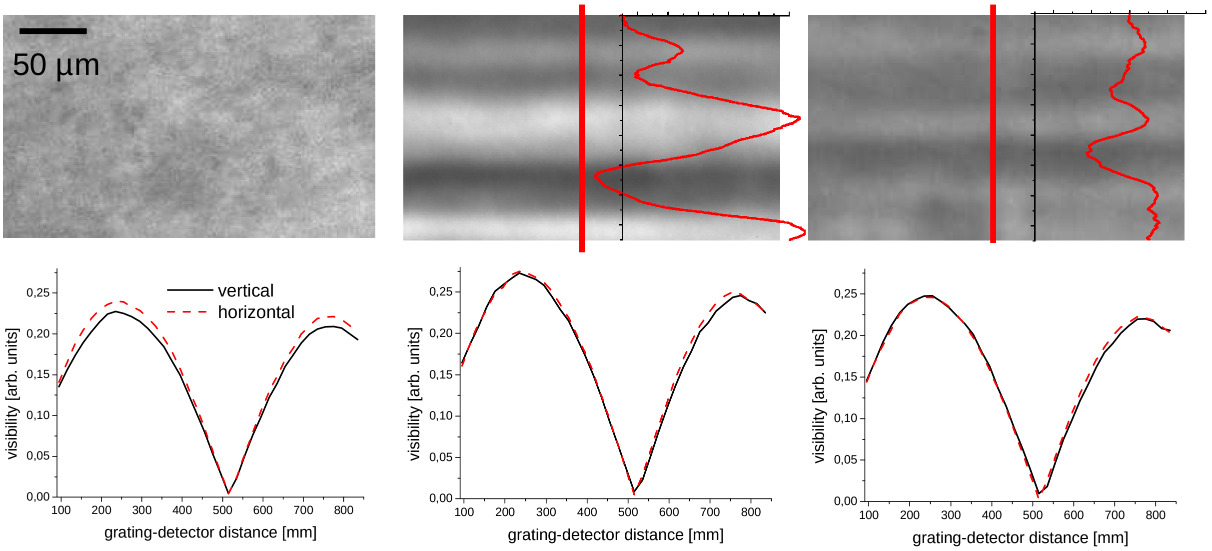

FIGURE 2. Top: beam profiles acquired at ID19 (ESRF), left: with only the crystal monochromator in the beam, center: after additional reflection on the Mo/Si multilayer, right: after reflection on the Pd/B_4C multilayer. Exemplarily chosen profile plots are included as well. The bottom shows the corresponding results of the coherence measurements.

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REFERENCES

1. A. Rack, T. Weitkamp, M. Riotte, D. Grigoriev, T. Rack, L. Helfen, T. Baumbach, R. Dietsch, T. Holz, M. Krämer, F. Siewert, M. Meduňa, P. Cloetens, E. Ziegler, *J. Synchrotron Radiat.* **17**, 496-510 (2010).
2. A. Rack, H. Riesemeier, P. Vagovič, T. Weitkamp, F. Siewert, R. Dietsch, W. Diete, S. Bauer Trabelsi, T. Waterstradt, T. Baumbach, *AIP Conf. Proc. (SRI09)* vol. **1234**, 734-737 (2010).
3. A. Rack, T. Weitkamp, I. Zanette, Ch. Morawe, A. Vivo Rommeveaux, P. Tafforeau, P. Cloetens, E. Ziegler, T. Rack, A. Cecilia, P. Vagovič, E. Harmann, R. Dietsch, H. Riesemeier, *Nucl. Instr. & Meth. Phys. Res. A* **649**, 123-127 (2011).
4. T. Weitkamp, P. Tafforeau, E. Boller, P. Cloetens, J.-P. Valade, P. Bernard, F. Peyrin, W. Ludwig, L. Helfen, J. Baruchel, *AIP Conf. Proc. (ICXOM2009)* vol. **1221**, 33-38 (2010).
5. Q. Shen, W.-K. Lee, K. Fezzaa, Y. S. Chu, F. De Carlo, P. Jemian, J. Ilavsky, M. Erdmann, G. G. Long, *Nucl. Instr. & Meth. Phys. Res. A* **582**, 77-79 (2007).
6. A. Rack, L. Assoufid, W.-K. Lee, B. Shi, C. Liu, C. Morawe, R. Kluender, R. Conley, N. Bouet, *Opt. Engin.*, submitted (2011).
7. R. Kluender, F. Masiello, P. van Vaerenbergh, J. Härtwig, *phys. status solidi A* **206**, 1842–1845 (2009).
8. C. David and D. Hambach, *Microelectron. Eng.* **46**, 219-222 (1999).
9. P. Cloetens, J. P. Guigay, C. De Martino, J. Baruchel, M. Schlenker, *Opt. Lett.* **22**, 1059-1061 (1997).
10. A. Rack, S. Zabler, B. R. Müller, H. Riesemeier, G. Weidemann, A. Lange, J. Goebbels, M. Hentschel, W. Görner, *Nucl.Instr. Meth. Phys. Res. A* **586**, 327-344 (2008).
11. A. Rack, T. Weitkamp, S. Bauer Trabelsi, P. Modregger, A. Cecilia, T. dos Santos Rolo, T. Rack, D. Haas, R. Simon, R. Heldele, M. Schulz, B. Mayzel, A. N. Danilewsky, T. Waterstradt, W. Diete, H. Riesemeier, B. R. Müller, T. Baumbach, *Nucl. Instr. & Meth. Phys. Res. B* **267**, 1978-1988 (2009).
12. E. Spiller, *Soft X-Ray Optics*, SPIE Press, Bellingham, WA (1994).