Coherence preservation and beam flatness of a single-bounce multilayer monochromator (beamline ID19 – ESRF)

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Abstract

Larger spectral bandwidth and higher photon flux density are the major advantages of multilayer monochromators over crystal-based devices. Especially for synchrotron-based hard X-ray microimaging applications the increased photon flux density is important in order to achieve high contrast and resolution in space and/or time. However, the modifications on the beam profile induced by reflection on a multilayer are a drawback which can seriously harm the performance of such a monochromator. A recent study (Rack et al., J. Synchrotron Radiat. 17 (2010) 496) has shown that the modifications in terms of beam flatness and coherence preservation can be influenced via the material composition of the multilayer coating. The present article extends this knowledge by studying further material compositions used on a daily basis for hard X-ray monochromatization at the beamline ID19 of the European Synchrotron Radiation Facility.

Keywords: multilayer mirrors, X-rays, X-ray optics, coherence, X-ray monochromators, X-ray imaging, X-ray phase contrast, synchrotron radiation

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1. Introduction

The inhomogeneities in the beam profile due to reflection on a multilayer mirror are a challenge for microimaging applications. Typical examples of flat-field images taken downstream of a double-multilayer monochromator (DMM) are shown in Fig. 1. These stripe patterns cause various artifacts, lead to different signal-to-noise ratios in the images acquired and prevent exploiting the full dynamic range of the X-ray detector. Furthermore, reflection on a multilayer mirror can influence the coherence properties of the beam which are important for, e. g., phase-sensitive imaging techniques such as holotomography [1].

A recent study has shown that the beam quality in terms of flatness as well as coherence properties after reflection on a multilayer mirror can be influenced by its material composition [2]. While these results are based on test samples (coatings deposited on superpolished 25-mm Si substrates), this article introduces characterisations of mirrors with 300 mm surface length, installed in a fixed, water-cooled assembly at the 150-m beamline ID19 of the European Synchrotron Radiation Facility (ESRF) [3]. Hence, they represent mirrors used during daily operation at an imaging beamline. Furthermore, material compositions not available within the previous study could be tested, see the following section.

2. Multilayers

The multilayer compositions studied are listed in Table 1. The coatings had been deposited on superpolished Si substrates (General Optics, Gooch & Housego) with dimensions of 300 mm × 45 mm × 30 mm. One of the mirrors investigated hosts three multilayer stripes (1× W/B_4C, 2× Ru/B_4C), deposited using the former deposition system in the ESRF multilayer laboratory (corresponding names of the samples are marked with an additional ”1”) [4]. For a second one, two stripes (Ru/B_4C and W/B_4C) were deposited using the new machine installed in the ESRF multilayer laboratory [5].

Example results of the metrology characterization done before and after deposition at the ESRF metrology laboratory can be found in Fig. 2 [6]. The micro-roughness of the first substrate at the position of each of the two Ru/B_4C stripes in its final stage is below 1.0 Å rms (averaged, 50x magnification, rms = root mean square). The slope errors are for both 0.3 µrad rms with the shape errors being 3.6 and 6.3 nm rms. The micro-roughness of the second substrate before deposition was found to be in the range of 0.60 Å rms (averaged, 50x magnification) at the position of the W/B_4C stripe. By applying the coating this value was increased to 2.5 Å rms. The slope error was 1.0 µrad rms (for the full 280 mm active surface length including some edge effects) / 0.3 µrad rms (for a reduced active surface length of 250 mm, avoiding the edge effects) before and after the deposition at the position of the stripes. The shape errors measured are 7.9 / 5.3 nm rms before and 6.4 / 7.0 nm rms after deposition (Ru/B_4C / W/B_4C, respectively).

Table 1: List of samples and (nominal) specifications. N is the number of bi-layers, d the corresponding period thickness, for all samples holds the thickness ratio $\Gamma = 0.5$. Ru/B_4C - 2 and W/B_4C were produced with the new deposition machine of the ESRF multilayer laboratory [5], Ru/B_4C - 1 with the former one [4].

Materials	N	d (nm)	$\triangle E/E$
Ru/B_4C - 1	65	4.0	$\approx 2.8\%$
Ru/B_4C - 1	40	6.0	$\approx 5.7\%$
Ru/B_4C - 2	60	4.0	$\approx 3.2\%$
W/B_4C	80	2.5	$\approx 2.3\%$

3. Results

A comparison between two multilayers mirrors consisting of the same material composition (Ru/B_4C - 1), deposited by the former deposition system of the ESRF multilayer laboratory on the very same substrate can be found in Fig. 3. The only difference between the two mirrors is the period thickness d (4 nm vs. 6 nm). Images were acquired at the beamline ID19 (ESRF) with 18 keV X-ray photon energy. Similar to previously reported results, the d-spacing shows only a negligible influence on the stripe pattern in the beam profile [2].

The results concerning the coherence preservation can be found in Fig. 4. The left column shows the beam profile after reflection by three different multilayer mirrors as well as after passing a double-crystal monochromator (DCM). Again, acquired at ID19 (ESRF) with 18 keV photon energy. The right column displays results of the measurements on the coherence properties of the reflected beam by means of fractional Talbot imaging: the visibility of a phase grating is measured for different distances between grating and detector [1], [7], [8], [9], [10]. Further details about the experimental settings are published elsewhere [2]. Briefly noted, all multilayer mirrors introduce a very strong stripe pattern but preserve the coherence properties of the beam similar as the DCM. The material composition seems to have nearly no influence, neither on the beam profile nor on the coherence preservation. Differences between the stripe patterns after reflection on Ru/B_4C - 1 and Ru/B_4C - 2 might be related to different filling modes of the storage ring when the images were taken.

4. Summary & Discussion

Our previous study based on multilayer coatings deposited on superpolished 25-mm Si substrates revealed a strong influence of the material composition on the beam profile as well as on the coherence properties of the reflected beam [2]. The d-spacing as well as the number of bi-layers grown had no or only negligible influence [2].

The recent results acquired with multilayer mirrors of larger dimensions, permanently installed at an imaging beamline confirmed these findings only partially. While the new measurements confirm the experience that the d-spacing has no noticeable influence on the presence or shape of fringes, the multilayer structures of different materials compositions also showed very little differences.

Based on findings from the previous study [2] multilayer mirrors with larger dimensions were realised for a DMM installed now at the TopoTomo beamline of the ANKA light source (Karlsruhe, Germany) [11]. As predicted, after passing this DMM the beam shows a very smooth profile, which is related to the source properties and the position of the DMM with respect to the source and the experiment, cf. Fig. 5 [12]. We conclude that neither the larger dimensions of the mirrors nor its permanent installation explain the differences between the results published and those introduced within this article. We also exclude differences in substrate quality, since the 25-mm substrates used in [2] were of extremely high quality and showed no quality variation within the lot.

Hence, for the future more rigorous investigations on the influence of the growth parameters as well as differences between the different multilayer laboratories are required. **The latter will allow as well to classify the reproducibility of the performance of a multilayer composition.** Consequently, this will be the next step of our research activities.

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Figures

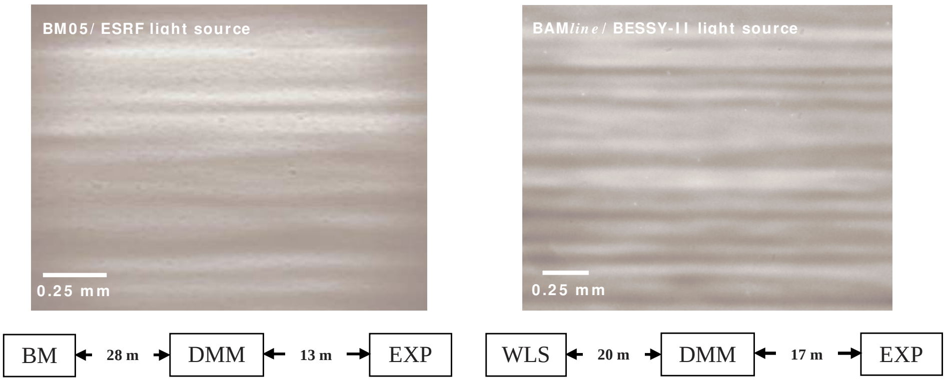

Figure 1: [1.5-column-span] Examples of stripe modulations in the flat-field background due to reflection by multilayer mirrors (not the samples studied in this article). The left image is taken at the bending magnet (BM) beamline BM05 of the European Synchrotron Radiation Facility (France) at 20 keV, with the multilayer coating consisting of Ru/B_4C (70 bi-layers, d-spacing = 4.0 nm) [13]. The right image was acquired at the wavelength-shifter (WLS) insertion device BAM*line* of the BESSY-II light source (Germany) using 18 keV photon energy. The multilayer coating consists of 150 bi-layers W/Si (d-spacing = 2.88 nm) [14]. At both experimental stations a double multilayer monochromator (DMM) is used.

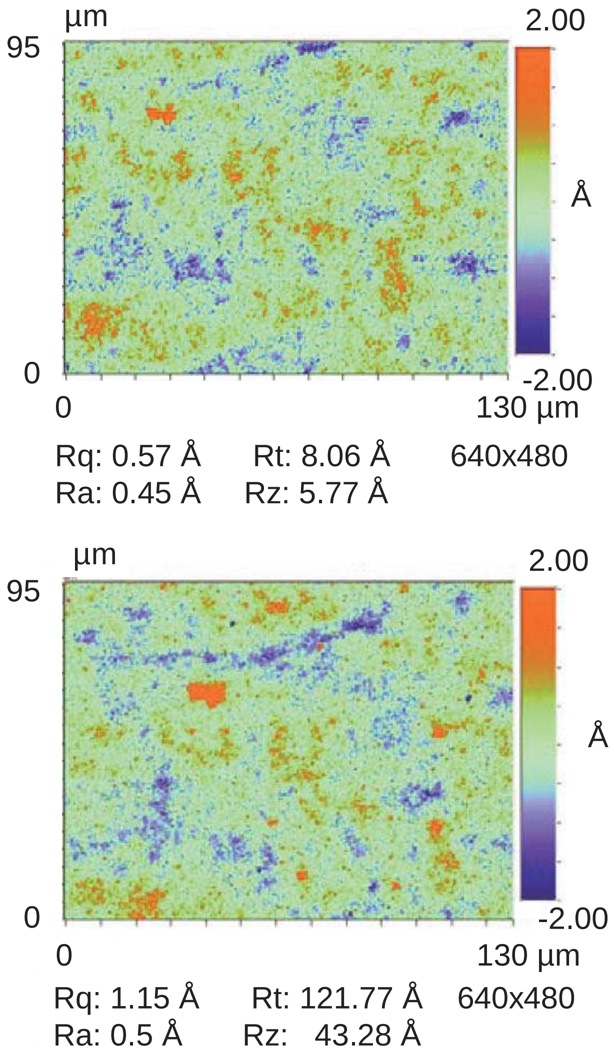

Figure 2: [1-column-span, color only online] Micro-roughness of the 2-stripe substrate (measured with a Wyko NT9300 at the ESRF metrology laboratory, 50x magnification, Rq is the rms value, Ra the arithmetic average, Rt is the peak-to-valley measure, Rz is the average of the 10 highest peak-to-valley) at the position of the Ru/B_4C stripe in its initial state (top) and final state with the coating applied (bottom) [6].

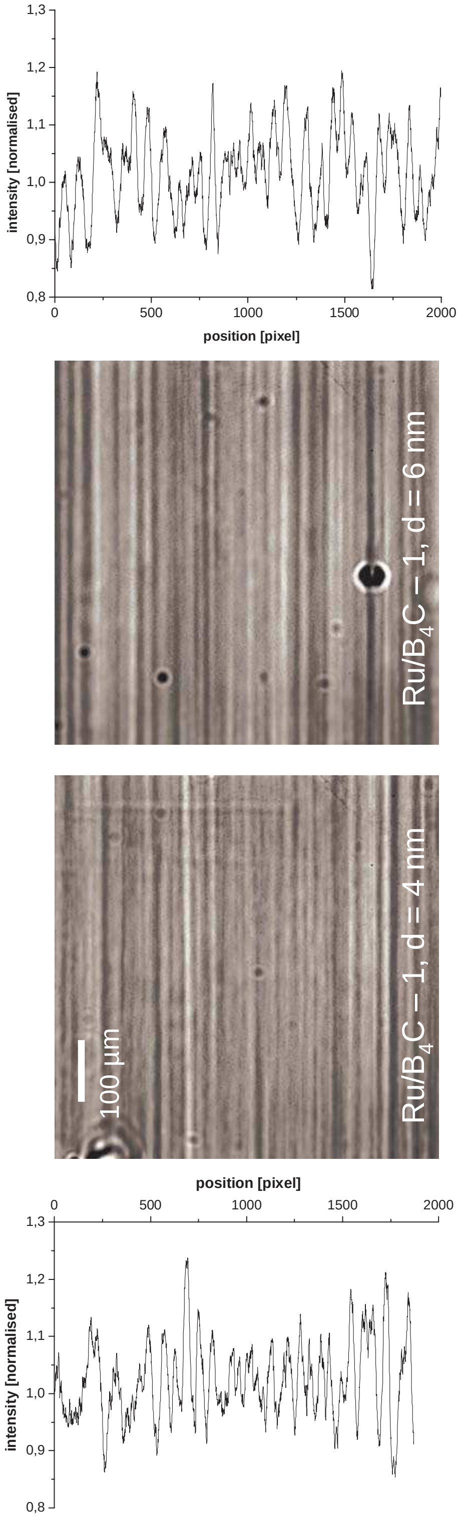

Figure 3: [2-column-span] Flat-field images taken at beamline ID19 (18 keV X-ray photon energy, 0.3 µm effective pixel size) with plots of a selected intensity profile for each picture [3]. Similar to previously reported results, the d-spacing has a negligible influence on the stripe pattern induced by reflection on one of the multilayers [2].

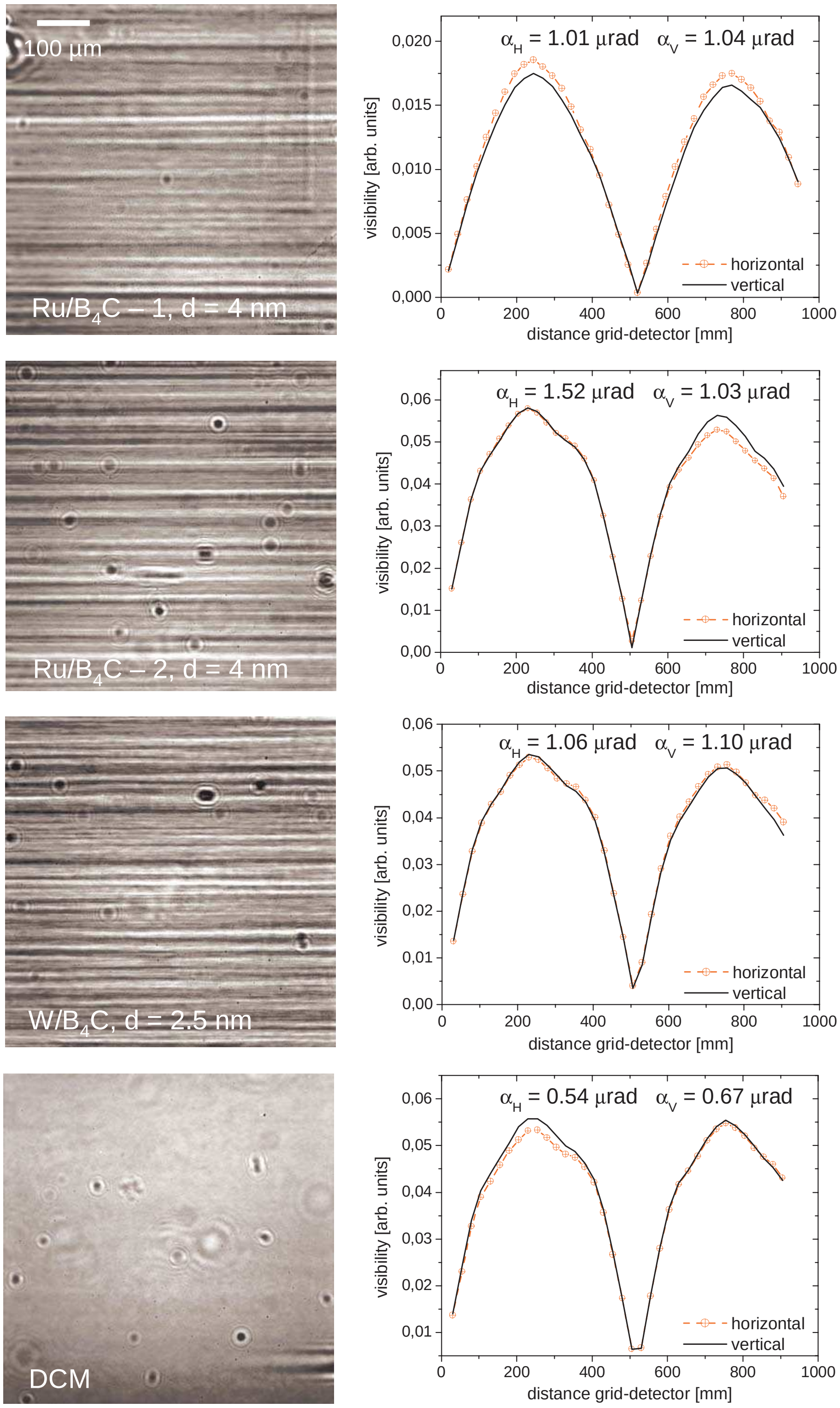

Figure 4: [1.5-column-span, color only online] The left column shows flat-field images taken with the beam reflected by different multilayer mirrors as well as downstream of a DCM (18 keV X-ray photon energy, acquired at ID19, ESRF) [3], [2], [15]. The right column displays the corresponding coherence measurements by means of Talbot imaging [2], [9], [10]. The angular source size α is calculated from the two Talbot planes given [16].

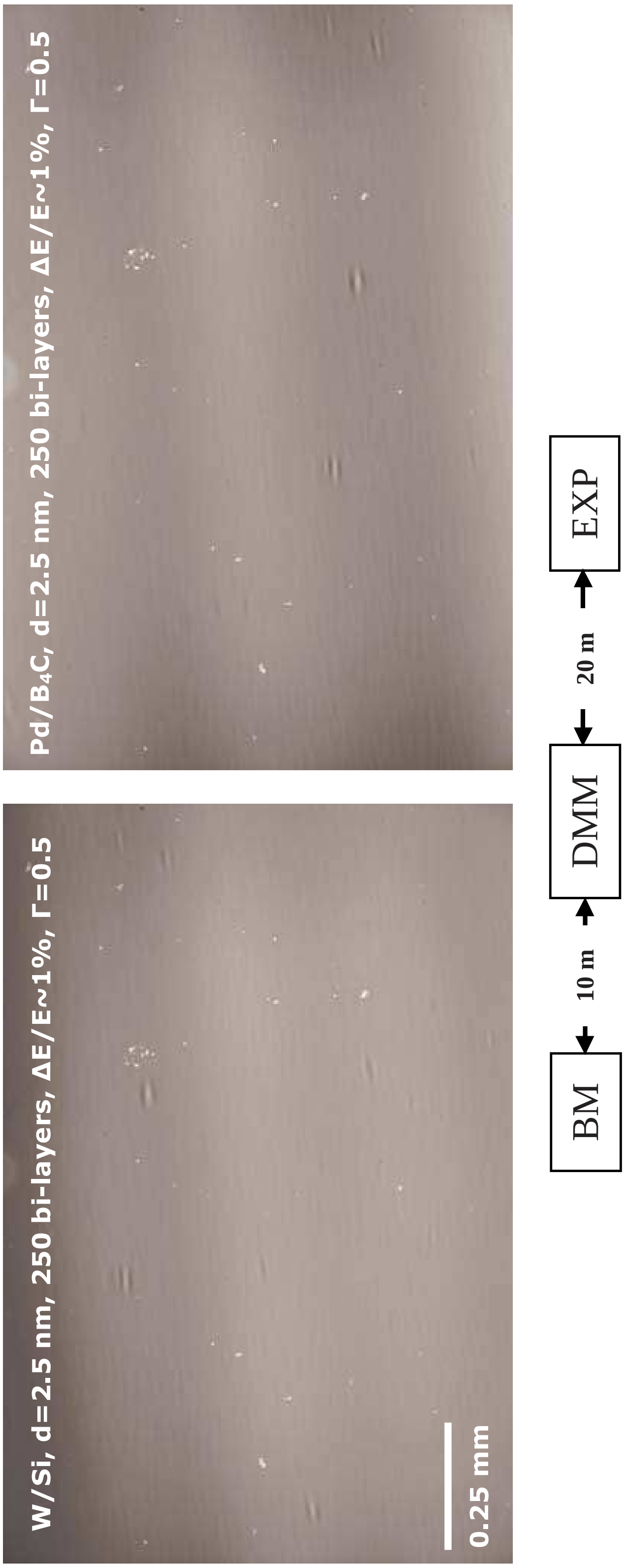

Figure 5: [1.5-column-span] Flat-field images taken with 18 keV photon energy downstream of the double-multilayer monochromotor at the TopoTomo beamline of the ANKA light source (Karlsruhe, Germany) [11], [12].