

The synchrotron-based imaging station for micro-radiography and -tomography at the BAMline (BESSY)

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Abstract. Third generation synchrotron light sources allow one to image micro-structured, multi-component specimens with different contrast modalities and resolutions up to the submicrometer range, thanks to their high brilliance and partial coherence. An imaging setup for micro-tomography and -radiography installed at BESSY as part of its first hard X-ray beamline (BAMline) can now be used for absorption, refraction as well as phase contrast. The experimental station is dedicated to in-house research and applications by external users. Monochromatic synchrotron light between 6 keV and 80 keV is attained via a fully automated double multilayer monochromator. We show the suitability of the setup for several applications from materials research.

1. Introduction

In this article we shall describe the imaging instrumentation of the BAMline at the German storage ring BESSY in Berlin (Berliner Elektronenspeicherring — Gesellschaft für Synchrotronstrahlung m.b.H.). BESSY is a third generation synchrotron light source operating since 1998 (ring energy of 1.7 GeV) [1]. The BAMline is BESSY's first hard X-ray beamline equipped with a superconducting 7 T wavelength shifter insertion device (operated by the Bundesanstalt für Materialforschung und -prüfung (Federal Institute for Materials Research and Testing, BAM), Germany) [2, 3]. The beamline is dedicated to host several experimental methods which include an imaging set-up since 2001 [3].

2. Experimental setup

In Fig. 1 the optical section of the BAMline is displayed. A double multilayer monochromator (DMM) and/or a double crystal monochromator (DCM) can be used to monochromatize the synchrotron light coming from the superconducting 7 T wavelength shifter (7T-WLS) insertion device. A vertical focusing option is available for the DMM and a horizontal focusing option for the DCM. For further beam condition, slits are positioned upstream (aperture/primary – in-vacuum) and downstream of the monochromators (in-vacuum) as well as in the experimental hutch upstream of a differential pumped double foil Kapton window. Several polished metal foils (Al, Be, Cu) placed in front of the DMM are used to absorb low energy X-rays which otherwise would be transmitted by the DMM by total reflection and consequently deteriorate the DMM's monochromaticity. The filters also lower the heat load on the first multilayer mirror. For monochromaticity reasons the layer-structure of the DMM has been optimized to suppress higher harmonic wavelengths (the multilayer coating consists of 150

double layers W/Si leading to an energy bandwidth of 1.7% in the range between 5 keV and 50 keV — experimentally verified at 20 keV with an DCM energy scan downstream of the DMM). Additionally, the beamline can be operated in white beam mode as well.

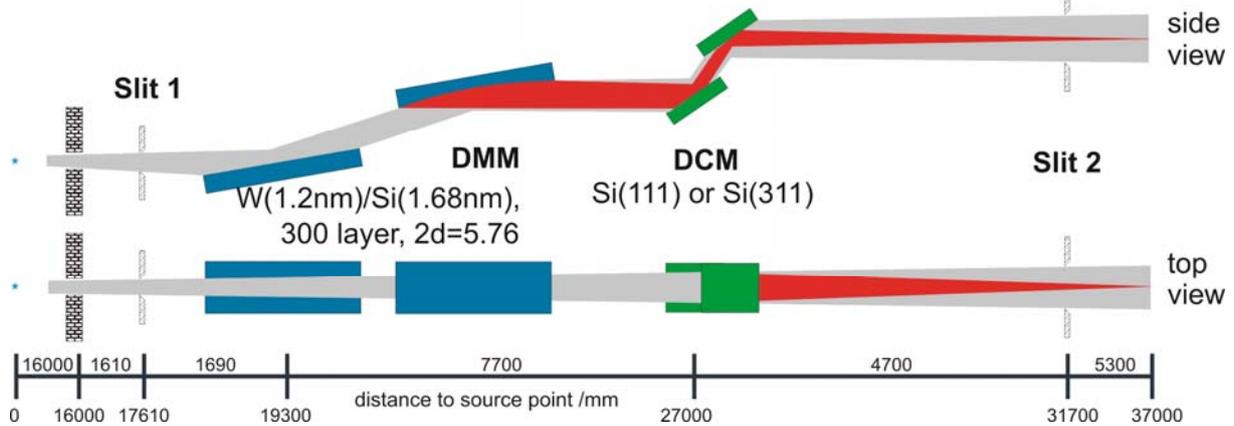


Figure 1. Principle sketch of the BAMline’s X-ray beam path (top: side view, bottom: top view). The radiation originating from the insertion device (7T-WLS) can be monochromatized using a double multilayer monochromator (DMM) and/or a double crystal monochromator (DCM) which includes a vertical focusing option for the DMM and a horizontal for the DCM. The position of the tomography stage is in the experimental hutch at a distance of 35 m from the source [1, 2].

The photon flux measured downstream of the DMM is plotted for different photon energies in Fig. 2. Due to the limited amount of photons available only the DMM is used for micro-tomography. The bending optic of the second multilayer was successfully applied to collimate the beam, resulting in a larger photon flux density and higher acquisition speeds in absorption contrast modes [3].

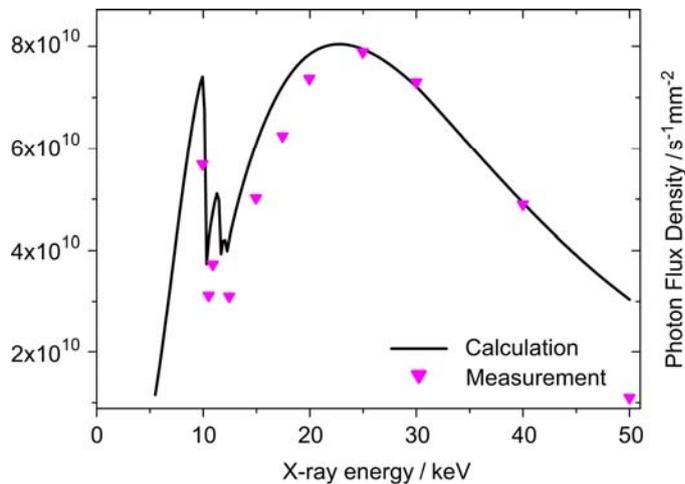


Figure 2. Photon flux density behind the double multilayer monochromator at the BAMline; measured and calculated (using Reflec) with a ring energy of 1.7 GeV, a ring current of 200 mA, a magnetic flux density of 7 T at the wavelength shifter and a distance from the source of 35 m. At 7 keV a flux density of was measured with a focused beam. Around 11 keV typical flux reduction due to the tungsten L absorption edges can be seen (the multilayer coating consists of 150 double layers W/Si) [1, 2].

Indirect X-ray pixel detectors containing thin transparent high-Z scintillators are used in order to record spatially resolved radiographs [4]: an inhouse designed system optimized for larger fields of view (“macroscope”) combining Rodenstock objectives with classical visible light tele-objectives (tandem design). Additionally, a commercially available microscope designed by the French Company OptiquePeter (Lyon) is used for high resolution imaging [3, 5]. As visible light camera a PCO.4000 (Interline Transfer CCD, PCO AG, Germany) is used for micro-tomography and a PCO.1200hs (CMOS) for fast radiography.

3. Applications

In Fig. 3 an example application of the magnesium-aluminum alloy AZ91 is shown. Imaging the real part yields an absorption tomogram with insufficient material contrast (cf. Fig. 3, left). Increasing the sample-to-detector distance results in Fig. 3 (middle) with enhancement of the structural interfaces. Finally we used a method based on contrast transfer functions in order to retrieve the phase maps from a set of four tomographic scans, then compute the holo-tomogram which is shown in Fig. 3 – right. The X-ray energy used for these images was $E = 23 \text{ keV}$, 900 radiographic projections were recorded at each propagation distance and with an effective pixel size of $1.6 \mu\text{m}$ (resolution $< 4 \mu\text{m}$).

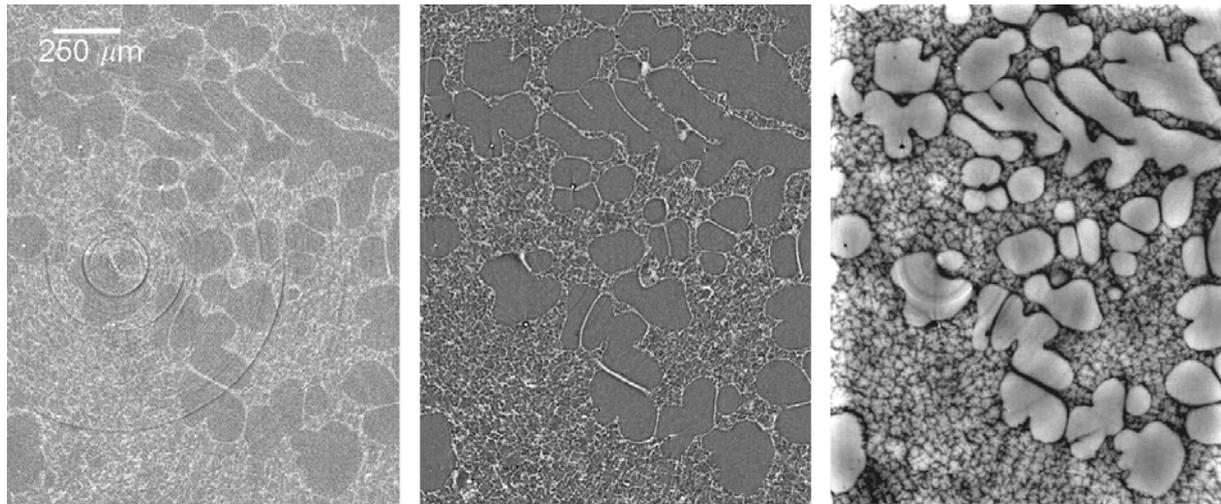


Figure 3. Left: absorption tomogram from a specimen consisting of the alloy AZ91 (magnesium and aluminium, similar attenuation coefficients), middle: same slice but as phase contrast tomography calculated from Fresnel-propagated projection images (edge enhancement), right: holotomography of this slice combining different propagation distances [3].

4. Summery

In this article we have briefly introduced the high resolution synchrotron-based radiography and tomography setup at the BAMline (BESSY), suitable to investigate specimens, in a non-destructive manner, with resolutions up to approximately $1 \mu\text{m}$ (as verified with an Xradia test pattern) and contrast modes measuring the local attenuation coefficient (synchrotron microtomography), the local electron density (holotomography) and inner surfaces and interfaces (refraction enhanced tomography). The high potential of this device is illustrated by investigations of specimens originating from materials research (commercial magnesium–aluminum thixo-alloy AZ91). Optimization approaches such as using a dedicated scintillator concept have been tested successfully, resulting in a higher performance of our setup [3]. Future further improvements include new scintillator development with materials such as LSO:Tb. Other forms of imaging, including white beam and methods with dual energy imaging have shown promising results as well.

5. References

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