Microtomography on Biomaterials using the HARWI-2 Beamline at DESY

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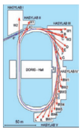
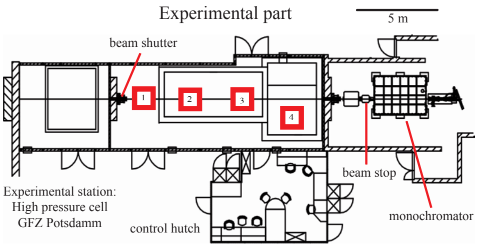
INTRODUCTION



The beamline HARWI-2 operated by the GKSS-Research Center in cooperation with Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany is designed for materials science experiments using hard synchrotron radiaton. Recently, the fixed-exit monochromator was installed, which is optimized for diffraction and imaging applications. The monochromator provides a highly intense and monochromatic X-ray beam in the energy range between 15 and 200 keV [1]. The large range of photon energies, the spatial resolution down to 3 µm and the related density resolution are the benefits for microtomographic applications. The advantages of the beamline are demonstrated for the synchrotron radiation based micro computed tomography (SRµCT) in absorption contrast mode on the field of biomaterials.

HARWI-2 BEAMLINE



Experimental stations operated by GKSS:

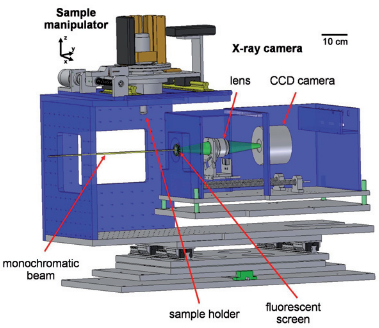
1 temporary setups
3 diffraction enhanced imaging
2 tomography
4 high energy diffractometer

Sketch of the HARWI-2 beamline showing the beamline optics, experimental stations, and control hutch.

Modernization of HARWI:

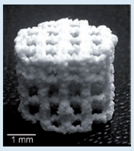
- high energy X-rays
- optimised for strain measurements, texture analysis and microtomography
- high flux
- new fixed-exit monochromator
- double Laue/Laue-Bragg for the energy range of 20 - 100 keV and 60 – 200 keV

Absorption contrast µCT at two different stations		BW2	HARWI-2
photon energy:		7 - 24 keV	15 - 200 keV
sample size:			
	height	3.5 mm	8 mm
	width	10 mm	70 mm
spatial resolution:		2 µm	3 µm



Schematic of the microtomography apparatus in absorption contrast mode. The incident monochromatic X-ray beam penetrates the sample and hits the fluorescent screen, where it is converted into visible light, which then is projected onto the CCD camera.

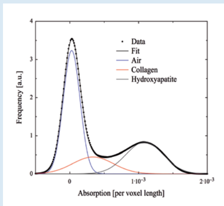
µCT OF SCAFFOLDS FOR BONE REPLACEMENT

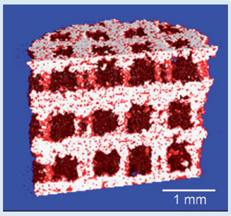


An optical image of the surface of a 3D-printed and collagen-coated scaffold intended for use as bone replacement. These scaffolds are individually designed according to the information determined by a CT scan of the bone.

The use of natural coating materials such as collagen improves significantly the stability of the scaffolds. The homogeneity of the collagen coating has been analysed using SRµCT in absorption contrast mode at the beamline HARWI-2 at a photon energy of 30 keV [2].

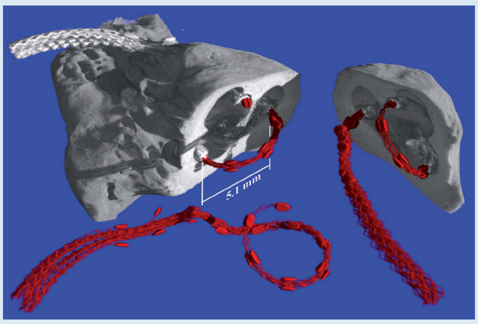
The histogram of the tomography data shows two peaks representing air and material, which can be easily separated and fitted using three Gaussians associated with air (blue), coating (red), and ceramics (gray).





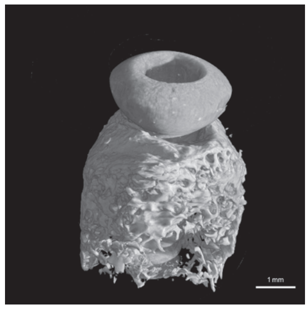
The virtual cut of the scaffold is colored according to the fitted histogram: air – black, coating – red, and HA – white. The collagen coating is homogenously distributed on the surface filling the open micro-pores of the HA, while the macro-pores remain open.

µCT OF HUMAN COCHLEAR

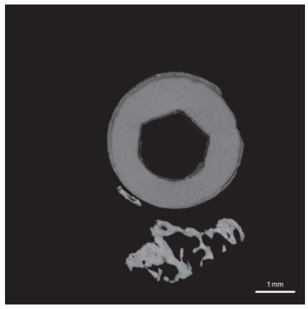


The cochlear implant consists of 12 electrodes and was inserted into the inner ear of a patient with a sensory neural hearing loss. The non-destructive visualization of the integration of the implant inside the inner ear using SRµCT is almost free of any artefacts, which are often unavoidable using histological techniques [3].

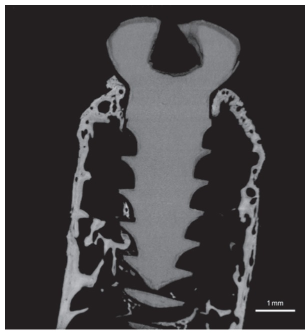
µCT OF BONE SCREWS



The corrosion behaviour of cortical bone screws was analyzed using SRµCT at a photon energy of 30 keV. The screws, machined from magnesium alloy AZ31 extruded rods, were implanted into hip-bones of sheep and removed three months later.



While the screw head exhibited severe surface corrosion on the convex areas of the screw head (see 3D figure and axial cut above), just minor corrosion attack was observed on the area of the machined hexagonal screw drive. The threads of the screw displayed a quite homogeneous corrosion layer (see frontal cut below) [4].



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CONCLUSIONS

The SRµCT at HARWI-2 due to its superior density resolution allows for visualizing non-destructively the 3D distribution of collagen coating on bone grafts. The detailed analysis of the human cochlear implant also takes advantage of the microtomography for visualizing non-destructively the bone structures of the inner ear, the position of the electrode array and for characterizing the integration of cochlear implants almost free of any artefacts. The SRµCT enables to describe the in-vivo corrosion of cortical magnesium AZ31 screws in sheep bone and thereby overcomes artefacts associated with the preparation of magnesium materials soluble in water and body fluids.

Due to the wide energy range and the superior contrast the SRµCT at HARWI-2 provides a non-destructive high quality 3D visualization of a large range of different materials. Even samples with a dimension of several centimetres can be analyzed with a very low amount of artefacts.