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Imaging the Nanostructure of Teeth

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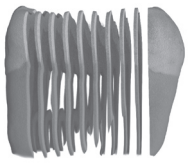
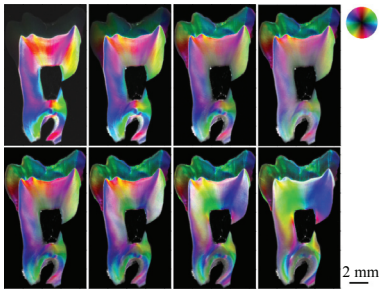
INTRODUCTION



To fully understand the properties of human tissue, information on all length scales, from the macroscopic level down to the molecular range, is needed. Therefore, imaging techniques which grant acces to all the lengthscales are needed. On one hand there is a wealth of well established imaging techniques which offer relatively low spatial resolution and a large field of view such as computed tomography or visible light microscopy, and on the other hand the high resolution imaging techniques, for example electron microscopy, generally offer only a restricted field of view. Small angle X-ray scattering (SAXS) in scanning mode offers the means to gather information on the size, shape, abundance and orientation of nanostructures in human tissue with micrometer resolution. For example, information about the nano-scale organization of human teeth is available only for restricted areas. Such data is not sufficient to explain the mechanical properties of a macroscopic structure as the human tooth with anisotropies on the nanometer scale over its complete volume.

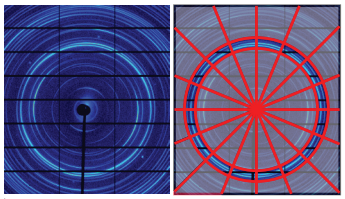
TEETH

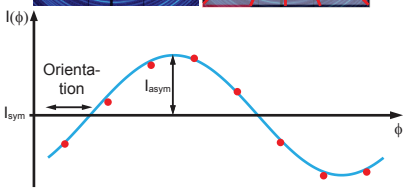
The figure below shows the processed scattering signal of a 400 µm thin tooth slice. The shown nano-structure-range are 5 to 7 nm, 12 to 23 nm, 34 to 46 nm, 46 to 64 nm, 71 to 92 nm, 106 to 120 nm, 138 to 162 nm and 183 to 212 nm from top left to bottom right. The scans were performed at a photon energy of 18.6 keV and 50 µm step width in x and y direction. The colors are chosen according to the orientations of the scattering signal, see color wheel, their brightness relates to the nanostructure abundance. The nanostructures in the dentin are nearly perpendicular to the dentin-enamel junction, whereas the ones of enamel are almost parallel to the dentin-enamel junction.



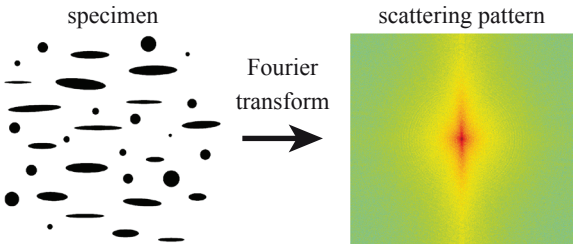
DATA TREATMENT

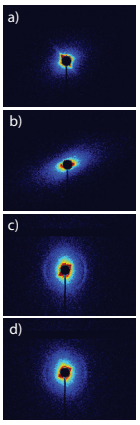
The scattering patterns are divided in 16 segments. The intensity at a predefined radius range, which corresponds to a certain lengthscale in real space, is integrated in each segmentt and plotted as a function of the segment angular position. The datapoints are aproximated by a cosine curve. Information as the abundance, orientation and degree of orientation of the nanostructures in this range can then be easily extracted.

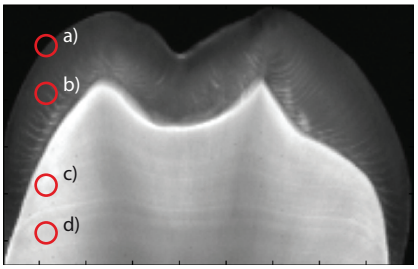




SCANNING SAXS



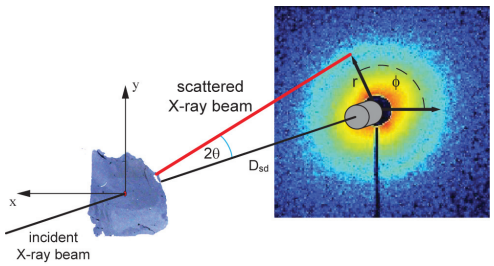


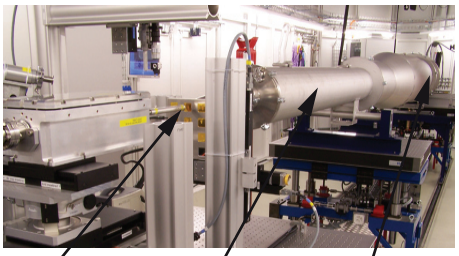


A micrometer-sized x-Ray beam is focussed on the specimen. The scattering pattern is the Fourier transform of the electron density in the illuminated area. This pattern contains information on the distribution, size, shape and orientation on the nano-structures (see figure on the left). The X-ray beam is raster-scanned across the specimen in micrometer-sized steps, and a scattering pattern is recorded at each point (see figure on bottom). With an acquisition rate of 15 frames per second, macroscopic areas in the cm^2 range can be imaged in under an hour. To achieve such high frame rates, special requirements have to be met. First, a sufficiently high photon flux is needed to obtain significant statistics in tenths of milliseconds. Second, a detection unit with fast acquisition and readout times is necessary. The PILATUS detector available at the cSAXS beamline (SLS, PSI, Villigen, Switzerland) has the ability of single photon counting and full frame readout times below 15 ms, thus making scanning SAXS possible. As each frame is coprised of roughly 2.5 million pixels, a huge ammount of data is generated in short time. Dedicated software tools are needed to process the data in reasonable time.

cSAXS BEAMLINE

At the cSAXS beamline, small angle X-ray scattering SAXS measurements are performed in scanning mode. The X-ray beam is focussed to a spot size of 5 x 20 µm² at the location of the specimen, which can be raster-scanned through the beam in micrometer-sized steps. To detect the X-rays scattered at angles between 1 and 0.02 degrees, the PILATUS detector is placed at 7.2 m distance from the specimen. An evacuated flight tube is placed between specimen and detector to reduce noise from air scattering.





CONCLUSION AND ACKNOWLEDGEMENT

Scanning SAXS offers the means to uncover a wealth of information on nanostructures of human tissues over macroscopic areas with micrometer real space resolution. However, identification of specific structures from 2D scattering patterns is a challenging task. For the interpretation of the data, close collaboration withmedical doctors is needed, as physicists lack the anatomical knowledge available to the former. Thus, the synergy of these two fields will lead to a deeper understanding of the human bewing on the nano-range.

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