Nanotomography
Synchrotron radiation course – project

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**Introduction**

Tomography is a method to image three-dimensional objects by illumination from different angles. With this method, several projected images are formed (see Figure 1) which can be evaluated by a computer into the three-dimensional images. The method is frequently used in medical science due to the possibility to image e.g. brains [1], but it is also possible to use tomography for imaging of nanostructured materials.

![Figure 1. One projection plane from the side of a three-dimensional object [2].](image)

There are several reasons to use x-rays as a sample characterization technique, e.g. they are often non-destructive and has a penetration depth of several hundreds of micrometers which makes it possible to characterize rather thick samples [3]. Furthermore, sample preparation is usually not needed which decreases both the time needed to produce samples but also the risk of introducing artifacts during the preparation [4].

The major drawback with x-rays is thus the obtained spatial resolution which might exceed the resolution in many nanostructured materials. With improving x-ray optics, e.g. focusing lenses, the spatial resolution is, of course, improved as well. With the current technology, resolutions in the nanometer range are possible to obtain [5] with an ongoing shrinking limit.
**Experimental**

**X-ray nanoprobe**

The key issue in x-ray nanotomography is, as mentioned, a good resolution. There is also a tendency towards hard x-rays since the soft x-rays are more sensitive to self-absorption in the sample and has a lower signal-to-noise ratio [6]. However, obtaining a good resolution for hard x-rays is much more difficult due to the requirement of much more stable focusing optics [3].

One option concerning focusing optics is the Kirkpatrick-Baez mirrors which is used in the European Synchrotron Radiation Facility in Grenoble [7]. In a Kirkpatrick-Baez mirror system, two spherical mirrors are used orthogonal to each other, i.e. one with horizontal focusing and one with vertical focusing of the x-ray. Advantages with the system include an easy and inexpensive setup that also cancels astigmatism [8]. Another example of focusing optics is the Fresnel zone plate which is used by the Center for Nanoscale Materials [9].

**Setup**

The setup for tomographic measurements is relatively straightforward. A computer controlled stage is used for rotation of the sample, hence providing the ability to create the amount of two-dimensional needed for rendering of the three-dimensional structure. For detection of the x-rays, a CCD detector is used. However, since hard x-rays are not absorbed by CCD detectors a scintillator is placed in front of the CCD detector [10]. The scintillator is luminescent and hence converts the x-ray photons to photons in the visible energy range which can be detected by the CCD.

**Contrast**

The contrast mechanism in tomographic measurements can either be the attenuation (absorption) of the x-rays or their phase shift when passing through the different materials in the sample. If two materials with a large difference in electron density (i.e. large attenuation difference) are to be examined, the preferred method is to use attenuation contrast. Conversely, if materials with similar electron density are to be examined, the different phase shifts of the x-rays must be taken into account [11]. This yields a more complicated measurement since CCD detectors only detect
the intensity, i.e. the amplitude of the wave, and not its phase. It is also possible to use both methods and superimpose the results for a better accuracy.

**Computerized calculations**

Another important aspect of tomography, except a good resolution, is to assemble a large number of two-dimensional images into a three-dimensional structure which is not straightforward. There exist however several softwares with different algorithms for this purpose. The major issue is whether the obtained three-dimensional image is representative for the real sample. However, with today’s increasing development in computer technology the accuracy of the three-dimensional representation is continuously improving.

**Why use synchrotron radiation**

To be able to study materials, the use of synchrotron has some major advantages compared to other radiation sources. First of all, the radiation has a high intensity, meaning that images with a high signal-to-noise ration can be obtained in relatively short times. This is important since a tomography measurement requires several measurements from different angles which take time. Also, the monochromatization of the beam is easily performed which makes it possible to select different x-ray energies for different materials (e.g. close to an absorption edge for a specific element). Finally, in order to obtain a good image quality it is essential with the parallel beams synchrotrons can offer [12].

**Applications**

The applications examinable with synchrotron x-ray nanotomography cover a wide range. Basically this range consists of any kind of applications with nanostructured (not too “nano” though due to the limiting resolution) materials since there is always an ambition towards non-destructive characterization techniques. Such materials include microelectronics, fuel cells or investigations of the porosity in sintered materials.
References


