X-RAY TOMOGRAPHY: FORM MICRO TO NANO

Victor ASADCHIKOV, Alexey BUZMAKOV, Denis ZOLOTOV

SHUBNIKOV INSTITUTE OF CRYSTALLOGRAPHY RAS, Moscow, Russia

X-ray tomography gives us the opportunity of non-destructive investigation of opaque objects. The possibility to obtain three-dimensional inner structure of a set of shadow projections makes this an indispensable technique in various branches of industry, including defectoscopy, as well as biology and medicine. Hard X-ray bremsstrahlung (with a maximum intensity at a wavelength of ~0.2 Å) with a broad spectral distribution is widely used for these purposes. It should be noted that the use of a very hard polychromatic radiation is undeniably justified in the defectoscopy of inorganic materials. The reason to apply such radiation in medical tomographs is the following. It weakly interacts with biological objects and, hence, is relatively safe. However, for the same reason, the contrast between different types of biological tissues is relatively low. It should also be noted that the linear attenuation coefficient μ for these tissues cannot be reconstructed because waves of different lengths in the broad spectrum of probe radiation are attenuated differently. However, in the study of inorganic objects with sizes of the order of a millimeter or large-sized organic (in particular, biological) objects, the use of hard X-ray radiation with a broad energy spectrum is, in our opinion, insufficiently informative in the majority of cases. The use of a softer monochromatized radiation in the wavelength range 0.5–2.5 Å, which approximately corresponds to energies in the range from 25 to 5 keV, seems more effective.

What are the disadvantages of the broad spectrum? The point is that the radiation spectrum changes after this radiation is transmitted through an object; in this case, the softer the radiation, the stronger it is absorbed by the object. When the internal structure of the object is unknown (it is this structure that we have attempted to determine in our investigation), the change in the radiation spectrum after transmission through this structure is also unknown. Even the use of a hypothetical detector that makes it possible to determine not only the coordinate of each photon transmitted through the sample but also its energy leads to the necessity of solving the problem of double convolution with respect to energies and trajectory; that is,

$$I = \int S_{in}(E)\exp\left[-\int \mu(x,y,z,E)ds\right]dE,$$

where S_{in} is the spectrum of incident radiation depending of it energy E and ds is the elementary unit of the curve along which the radiation propagates.

Therefore, the use of monochromatic radiation is preferred because it allows one to reduce the problem to the form

$$I = I_0 \exp\left[-\int \mu(x,y,z)ds\right],$$

where $\mu(x, y, z)$ – is linear absorption coefficient, I- registered intensity, I_0 – intensity of the primary beam. So, the use of monochromatized irradiation is more informative, but the question is, how to choose suitable wavelength.

We justify in the present work the choice of the optimum x-ray wavelength for the study of different types of materials. It is shown, that wavelengths of the range 0.5–2.5 Å are optimal to investigate the biological objects with sizes from 1 mm to 10 cm [1]. The results obtained in the study structure of biological and mineral samples with a resolution of 6 - 13 μm are given.

We show the possibility to apply magnifying x-ray optical elements in order to increase the resolution up to 1 μm [2].The results of the microtomography experiments with such resolution are given. We constructed several different microtomographs with the given in the following table parameters:

№	Field of view	Spatial resolution	X-ray detector type	X-ray magnifying elements
1	0.1×100 mm	150 µm	1-D X-ray detector	-
2	10×10 mm	13 µm	CCD-detector 1024×1152 px	-
3	1×1 mm	6 µm	CCD-detector 2048×2048 px	Capillary air bubble lens
4	0.6×0.6 mm	1-2 µm	CCD-detector 2048×2048 px	Crossed asymmetric cut single crystals

The way to increase the resolution up to the submicron level is use magnifying X-ray zone-plates system [3] or the schemes with the projection magnification [4].

References:

1. V. E. Asadchikov, A. V. Buzmakov, D. A. Zolotov, R. A. Senin and A. S. Geranin. Laboratory X_Ray Microtomographs with the Use of Monochromatic Radiation // ISSN 1063_7745, Crystallography Reports, 2010, Vol. 55, No. 1, pp. 158–167. © Pleiades Publishing, Inc., 2010.
2. R.A. Senin, A.V. Buzmakov, A.V. Konovko, I.S. Smirnov, A.S. Geranin and V.E. Asadchikov «Gain in spatial resolution of X-ray laboratory microtomographs with enlarging X-ray optical elements.» // Journal of Physics: Conference Series 186 (2009) 012035
3. http://www.xradia.com/
4. http://www.skyscan.be/home.htm