High-Resolution Differential Phase Contrast Imaging Using Microfocus X-Ray Sources

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We combined grating-based phase contrast imaging with projection magnification using a high-brilliance microfocus x-ray source. This geometry offers increased detection efficiency even at higher energies for quantitative high-resolution phase contrast imaging. By systematic methodical investigations, it is shown, how the primary measurement signal is affected by the magnification factor. Furthermore, the influences of different physical parameters, as the size or the energy spectrum of the x-ray source, on the measurement results are discussed using numerical simulations. Based on these investigations, the phase shift can be determined quantitatively with high precision. Finally, experimental results demonstrate feasible applications like quality inspection of refractive x-ray lenses and high-resolution phase contrast tomography.

Keywords: X-ray, Phase retrieval, Interferometer

1. Introduction

X-ray absorption imaging is an important tool for medical and technical applications. However, for the imaging of weakly absorbing or thin structures, the applicability of the method is limited, since the absorption contrast is low. Phase sensitive x-ray imaging can overcome these shortcomings. It has the potential for a significantly increased contrast, because it uses the phase shift as an imaging signal [1]. For phase contrast imaging, propagation based methods [2] are often applied in combination with laboratory x-ray sources.

Using recently developed grating based methods [3], the differential phase contrast (first derivative of the phase shift) is measured. This is an advantage in comparison to propagation based methods, where the data contain essentially the second derivative of the phase shift, which makes the evaluation of noisy data difficult.

The authors combined grating-based phase contrast imaging with projection magnification using a high brilliance microfocus x-ray source. In contrast to propagation based methods, scintillators and detector systems with moderate spatial resolution can be used in our case. This is a second advantage in comparison to propagation based methods, because low resolution detectors can offer increased detection efficiency at higher energies.

2. Experiments

An outline of the setup is shown in Fig. 1. The phase grating g_1 has lines showing negligible x-ray attenuation but a phase shift of π. It acts as a beam splitter and divides the incoming beam essentially into the +1st and −1st diffraction orders. Downstream of g_1, the diffracted beams interfere and form a periodic interference pattern in planes parallel to g_1. Modifications of the incident wave front due to an object in the beam path

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lead to a change of the first order diffraction angle. Thereby, the position of the interference fringes is shifted by [4]:

$$s = d \cdot \frac{\lambda}{2\pi} \frac{\partial \phi}{\partial x}, \qquad (1)$$

where d is the distance between the phase and the absorption grating, λ is the wavelength, and $\partial\phi/\partial x$ is the differential phase shift at the phase grating plane. Consequently, a measurement of the position change of the interference fringes yields the differential phase shift caused by the object. In order to determine the location of the fringes of the interference pattern, it is scanned with the analyzer grating g_2, which consists of highly absorbing lines and has a period which matches that of the interference pattern. This is done by recording a series of images at different relative positions of the two gratings.

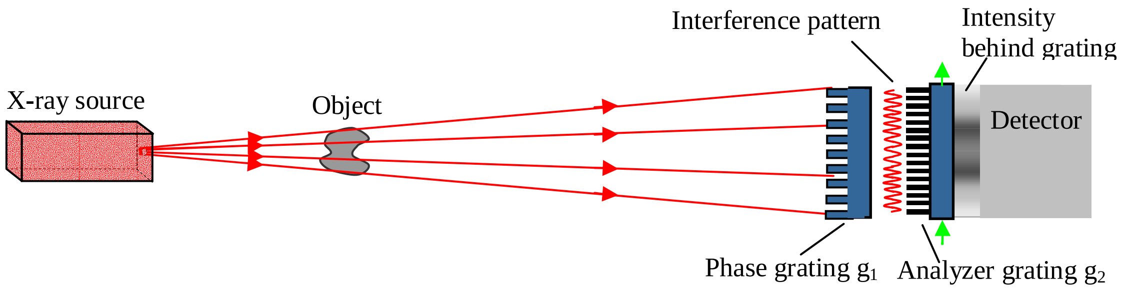

Fig. 1: Setup for high-resolution differential phase contrast imaging with a cone beam geometry.

Methodical experiments [4] show that the position change s of the interference fringes varies with the magnification factor. In order to demonstrate the capabilities of the method, a phase tomography of a wasp was acquired [4]. A rendered visualization of the refractive index decrement δ is presented in Fig. 2. A magnification factor of 3.5 was chosen which yields a resolution of approx. 28 µm at the sample position for the detector resolution of approx. 100 µm.

As a technical application, quality evaluation measurements of refractive x-ray lenses were presented [5]. In order that the lens focuses the x-rays onto the focal point, the beam deflection angle must be linearly proportional to the distance from the optical axis of the lens. The method described gives a direct measure of the beam deflection angle and can therefore be used for quality inspection of x-ray lenses.

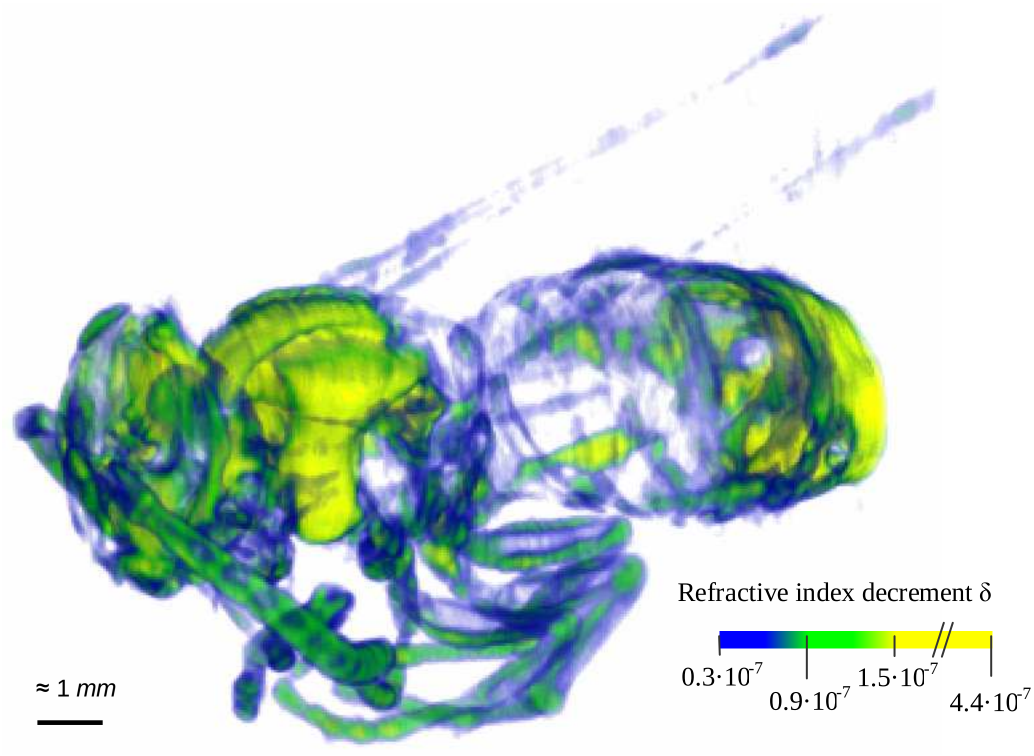

Fig. 2: Phase tomography of a wasp: Colour coded quantitative representation of the refractive index decrement δ for an effective energy of approx. 23.6 keV.

3. Simulations

The intensity distribution of the interference pattern downstream of g_1 was determined in different planes parallel to g_1 [6]. The wavefront propagation is based on the Rayleigh Sommerfeld integral. Certain simplifications (paraxial approximation, Fresnel diffraction, c.f. Ref. 6) were used. The simulations show that a wide energy interval contributes to the measurement and that thus the method can be well combined with polychromatic laboratory x-ray sources. Furthermore, it is shown how the fringe shift *s* is formed for a polychromatic energy spectrum and that a measurement, performed using a polychromatic x-ray source, can be evaluated quantitatively by assigning an effective energy. Finally, the effects of an extended x-ray focal spot (transversal coherence) are discussed.

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