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A phase retrieval method for X-ray microscopy based on a $\pi/2$-biased X-ray zone-plate pair

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ABSTRACT

A method for X-ray imaging and phase retrieval of a sample is proposed, wherein a zone-plate pair with a bias of $\pi/2$ is used to take only twice differential-interference-contrast images of the sample via reverse projection. The images of the sample and its reverse projection have the same absorption but opposite differential phase shift signals, which are post-processed to quantitatively retrieve the phase shift and the absorption of the sample. Theoretical analysis and numerical simulations indicate that the spatial resolution of the retrieved results could attain the Rayleigh limit of a single zone plate in the zone-plate pair.

1. Introduction

The capability of nondestructive visualization of the internal structures of matter with a high resolution makes X-ray imaging an indispensable tool in various areas such as material science and biomedical research. The spatial resolution of traditional transmission X-ray microscopy based on absorption has reached a nanometer scale with the development of focusing optics [1]. However, this absorption-based method would lead a poor contrast when imaging low-Z materials since the absorption of X-rays is roughly proportional to the biquadratic of the atomic number Z [2]. Utilizing an X-ray wavelength closing to the absorption edges of a material would improve the contrast, but it does not work for a low-Z material as the absorption edges lie in the longer wavelength range and moreover, the probable radiation damage to the material is still an unsolved problem.

The X-ray phase imaging is a promising technique to overcome the shortcomings in the absorption-based imaging. When X-rays pass through low-Z materials, the generated phase shift is typically two to three orders of magnitude larger than the absorbance or the modulus of the natural logarithm of the transmittance [3]. By utilizing the variation of the phase shift, which is more sensitive than that of the absorbance, contrast enhanced imaging is realized. Several methods have been proposed to realize a high-resolution X-ray phase imaging, such as Zernike's X-ray microscopy [4,5], ptychography [6,7], grating-interferometer-type imaging [8,9], and differential-interference contrast (DIC) microscopy [10,11]. The Zernike's X-ray microscopy uses a phase-shifting ring to introduce a phase shift into the undiffracted part of an incident beam which interferes with the diffracted part, whereas the quantitative phase retrieval from the imaging is unfavorable [3]. Ptychographic imaging is capable of retrieving the phase shift of the sample but requires spatial coherent illumination and multiple imaging [7]. Grating-interferometer-type X-ray imaging can also retrieve the phase shift, but the spatial resolution is limited by the grating periods to be on the order of microns [8,9]. Progress has been made in improving the resolution up to nanometers by combining a grating and a zone plate [12,13], but a number of steps for a phase-stepping scan are necessary to eliminate the higher order diffractions introduced by the grating [12,13].

On the other hand, high resolution DIC imaging in the X-ray range was demonstrated in experiments by Wilhein et al. [10], wherein two zone plates were stacked to be a zone-plate pair (ZPP) which creates double wavefronts to form differential interferences on the image and thus increase the image contrast. Later, Nakamura and Chang proposed a method [14,15] to retrieve the phase shift and absorption of a sample from the DIC imaging. By displacing the zone positions of four ZPPs, the bias of these ZPPs are adjusted and then from their different DIC images the phase information of a sample can be retrieved. This process of retrieving is relatively complicated as it needs four times of DIC imaging by four ZPPs with different biases, respectively.

In this paper, we present an alternative method for high-resolution X-ray imaging and phase retrieval of a sample, wherein only one ZPP with a bias of $\pi/2$ is needed to take only twice DIC images of the sample via reverse projection (RP). The RP was initially used in grating-interferometer imaging with a parallel beam illumination to obtain a

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