Talbot Carpets for X-Ray Phase-Contrast Imaging

A. Yaroshenko, G. Potdevin, M. Bech, A. Malecki and F. Pfeiffer

1Department of Physics and Institute of Medical Engineering, Technische Universität München, James-Franck-Strasse 1, 85748 Garching, Germany

2Medical Radiation Physics, Lund University, Barngatan 2B, 22185 Lund, Sweden

X-ray phase-contrast and dark-field imaging have recently attracted a lot of interest as two imaging modalities that can, among other, significantly enhance the soft tissue contrast in biomedical applications and yield complementary information to the conventional absorption-based x-ray imaging [1, 2, 3]. Recently, particular focus of the research has been directed to developing a compact laboratory setup at clinically relevant x-ray energies.

In order to access the new imaging modalities, a three binary gratings Talbot-Lau interferometer is introduced into the x-ray beam. The first (transmission) grating, placed close to the x-ray emission point, introduces coherence to the beam. The second grating is a phase grating and yields an interference pattern that is analyzed by a third (transmission) grating. The analyzer grating is placed typically at a Lohmann distance behind the phase grating to obtain the highest visibility. For a typical binary $\pi/2$ phase shifting grating the shortest Lohmann distance is given by $\frac{1}{4}Z_t$ [4, 5], where $Z_t = \frac{2p^2}{\lambda}$ is the full Talbot distance, determined by the x-ray wavelength $\lambda$ and the phase grating period $p$. For a grating with a $\pi$ phase shift, the shortest Lohmann distance is given by $\frac{1}{16}Z_t$ [4, 5]. However, binary $\pi$ phase shifting structures introduce an interference pattern with a doubled spatial frequency. Therefore, in case of a $\pi$ phase grating, an analyzer grating with half the period of the phase grating is needed in order to resolve the interference pattern. Production of high aspect-ratio analyzer gratings is limited by manufacturing possibilities. Construction of a compact x-ray phase-contrast and dark-field imaging setup for clinically relevant energies, using a binary phase grating is currently only feasible, if very small, 1-2 $\mu$m period gratings were available with structure heights of several hundred $\mu$m.

Simulations predict that the distance between the phase and the analyzer grating can be significantly reduced if phase gratings with triangular shaped structures instead of binary ones are used in the interferometer. For validation x-ray interference carpets were directly measured at Petra III, Beamline P10. A nickel binary phase grating with height 10 $\mu$m and period 5 $\mu$m was placed in a 19.2 keV beam, with a resulting phase shift of $3\pi/2$. A detector with an effective pixel size of 360 nm was placed on a motorized stage and moved upstream, acquiring images at 158 equidistant positions up to the full Talbot distance of 78 cm. Subsequently, the grating was tilted by 14 degrees, so that an effective triangular shape of the phase shifting structures was achieved and the intensity measurements were repeated.

The obtained intensity carpets are presented in figure 1 for both cases of grating orientations along with the resulting visibilities. The visibility was calculated from the measured intensity carpets, by convoluting the measurements with an ideal analyzer grating with the same period as the phase grating. It can be clearly seen that similarly high peak visibilities could be achieved in both cases of a binary and a triangular phase grating. However, the distance from the phase grating with triangular structures to the first visibility peak is significantly shorter than for the binary grating.

The obtained result is very interesting for the design of a compact setup for x-ray phase-contrast and dark-field imaging. The reduction of the distance, needed between the phase and the analyzer grating means that the requirements for the aspect-ratio for the analyzer and the source grating can be significantly reduced. Therefore, future studies should focus on implementing phase gratings with triangular-shaped phase shifting structures into setups with laboratory sources. The presented results are a significant part of a manuscript submitted for publication.
Figure 1: Top row: directly measured intensity carpets for (a) a binary grating and (b) a binary grating, tilted to a triangular shape. Bottom row: visibilities calculated from the measured carpet for (c) binary and (d) a triangular phase grating, assuming an ideal analyzer grating.

References