# Optimization of X-ray grating interferometry

## *and results on a 160 kVp lab source*


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## Introduction

Grating interferometry [1] can perform phase-contrast imaging on conventional X-ray sources [2]. This technique is sensitive to attenuation, refraction and scattering of the radiation. Analytical formulas are derived for the smallest detectable refraction angle and for the polychromatic visibility of the interference pattern as a function of the design parameters. Imaging at energies above 100 keV is particularly relevant for medical computed tomography and material science. Two Talbot-Lau interferometers were realized with a design energy of 100 keV and 120 keV.

## Sensitivity of Talbot-Lau interferometers

The sensitivity of a Talbot-Lau interferometer, or the smallest detectable angle of refraction[3] is

$$\sigma_\alpha \propto \frac{p_2}{d}\frac{1}{v\sqrt{N}}$$

where $p_2$ is the period of the absorption grating $G_2$, $d$ is the distance between $G_1$ and $G_2$, $v$ is the visibility and $N$ is the number of photons on the detector.
This suggests using an increased distance $d$ with setups at higher Talbot orders, but this would also decrease the flux $N$. A sensitivity dependent on the exposure time $t$ and the total setup length $s$ can be written as

$$\frac{p_2}{d} = \frac{p_0 + p_2}{s}$$
$$N \propto \frac{t}{s^2}$$
$$\sigma_\alpha \propto \frac{p_0 + p_2}{v\sqrt{t}}$$

Therefore, the best sensitivity is achieved for smallest $p_0$ and $p_2$. Since the period is generally limited by the fabrication technique, where the requirements for the two absorption gratings are the same, a symmetric setup with $p_0 = p_2$ is the best combination.

## Polychromatic visibility

The visibility for the case of a polychromatic source can also be derived analytically[4]. For each energy $\mathcal{E}$ and a Talbot order $m \in \{1, 3, 5, \ldots\}$, the visibility is

$$v(\mathcal{E}) = \frac{2}{\pi}\left|\sin^\eta\left(\pi\frac{\mathcal{E}_0}{\mathcal{E}}\right)\sin\left(m\pi\frac{\mathcal{E}_0}{\mathcal{E}}\right)\right|$$

With $\mathcal{E}_0$ the design energy, and $\eta = 2$ for a $\pi$-shifting beam splitter, and $\eta = 1$ for a $\pi/2$ shift. The total visibility can be calculated if the spectrum $\rho(\mathcal{E})$ is known

$$v = \int v(\mathcal{E})\rho(\mathcal{E})\,\mathrm{d}\mathcal{E}$$

This can be used to show the difference between a $\pi$ and a $\pi/2$ shift in the $G_1$ grating. The result is that the $\pi/2$ has a marginally better spectral acceptance only at the first Talbot order, and is worse otherwise.

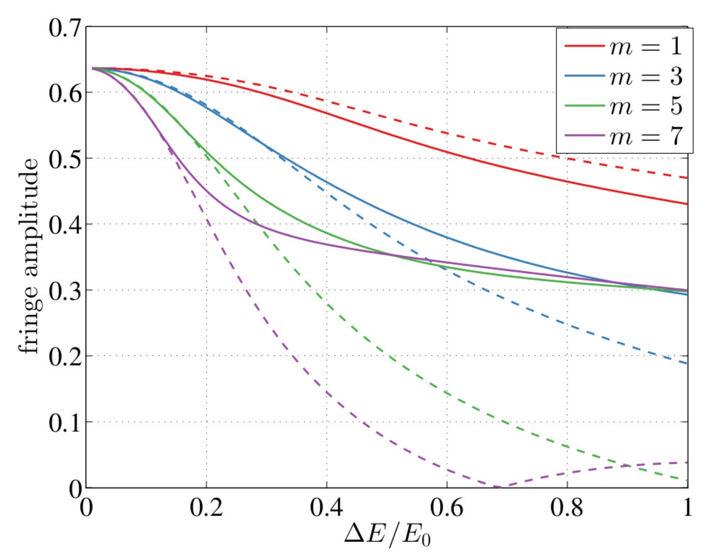


Figure 1: Fringe visibility for a polychromatic beam of a point source as a function of the normalized energy bandwidth $\Delta E/E_0$ of a gaussian spectrum for different talbot orders $m$ and for $\eta = 1$ (dashed lines) corresponding to a $\pi/2$ shift in the phase grating structures, compared to a $\pi$-shifting phase grating (solid lines).

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## Grating design

The fabrication of gratings for X-ray energies above 100 keV is a severe technical challenge. The requirement of an extreme aspect ratio is overcome here with the idea of edge-on illumination. The parameters for the two interferometers were chosen according to the above principles: they are operated at the first Talbot order $m = 1$, $d = p/8\lambda_0$ on a symmetric arrangement with $\pi$-shifting beam splitters. The gratings were manufactured by Microworks GmbH, Germany. The absorption gratings have a thickness of 800 µm. All gratings have a pitch $p$ of 2.8 µm. The interferometers are operated at the first Lohmann distance

| | | |
|---|---|---|
| **design energy** | 100 keV | 120 keV |
| **intergrating distance** | 15.8 cm | 18.9 cm |
| **total length** | 54 cm | 61 cm |
| **beam splitter** | gold | nickel |

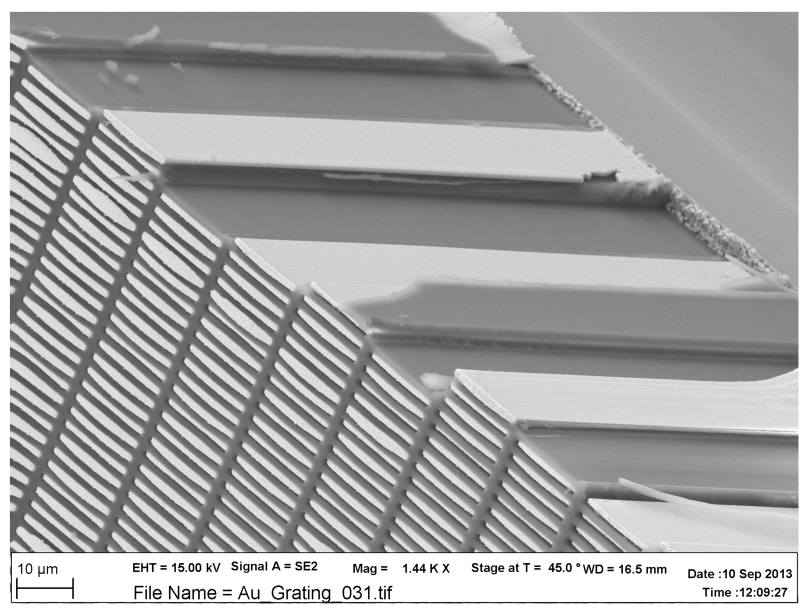

Figure 2: scanning electron microscope image of the grating structures.

## Experimental results

The setups have a rather low average visibility (∼ 6 %) caused by the low quality of the gratings. The first images show the three complementary contrasts retrieved from the phase-stepping procedure [5].

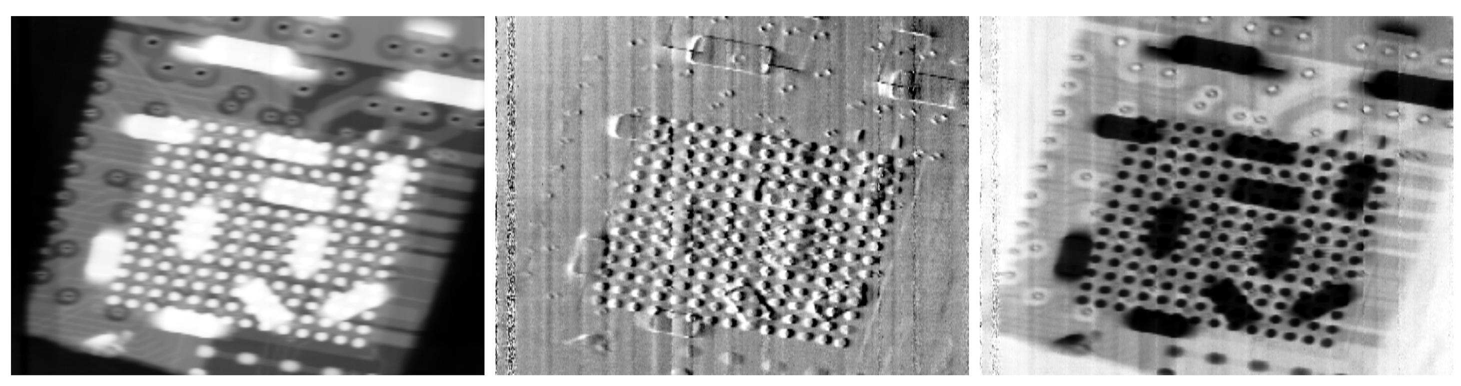

Figure 3: Absorption, differential phase and dark-field image of a metal chip scanned in 100 µm steps. Field of view 2 cm × 2 cm. 100 keV setup.

The exposure time has to be very long (24 phase steps × 15 s per line) in order to reduce the noise given by the low visibility.

## References


[1] C. David, B. Nöhammer, H. Solak, and E. Ziegler, "Differential x-ray phase contrast imaging using a shearing interferometer," *Applied Physics Letters*, vol. 81, no. 17, pp. 3287–3289, 2002.

[2] F. Pfeiffer, T. Weitkamp, O. Bunk, and C. David, "Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources," *Nature Physics*, vol. 2, pp. 258–261, Mar. 2006.

[3] P. Modregger, B. Pinzer, T. Thüring, S. Rutishauser, C. David, and M. Stampanoni, "Sensitivity of X-ray grating interferometry," *Optics Express*, vol. 19, pp. 18324–18338, Sept. 2011.

[4] T. Thüring and M. Stampanoni, "Performance and optimization of x-ray grating interferometry," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 372, no. 2010, 2014.

[5] T. Weitkamp, A. Diaz, C. David, F. Pfeiffer, M. Stampanoni, P. Cloetens, and E. Ziegler, "X-ray phase imaging with a grating interferometer," *Optics Express*, vol. 13, no. 16, pp. 6296–6304, 2005.