Microfabrication of gratings for X-ray Imaging

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Introduction

Conventional X-ray radiography relies on the differences in absorption of the constituent of a sample. For biological tissues, polymers or other organic materials, the absorption is so weak that high contrast imaging is very difficult to achieve.

Using the phase shift of X-rays passing through a sample, the image contrast can be significantly enhanced as shown by C. David et al. [1]. The experimental setup being built at our partner institute (Teknologisk Institut) consists in 3 gratings (g₀, g₁ and g₂) as shown below. The analyzer grating g₂ as well as the grating g₀ raise the most severe fabrication challenges. As opposed to g₁ which is made of silicon, g₂ and g₀ require heavy absorbing material. Often they are fabricated using electrophoresis of gold in a pre-fabricated silicon mould. Although expensive, gold is an ideal absorber for X-rays and can easily be electroplated. However, to achieve an absorber grating with this conventional method, several fabrication steps must be achieved, hence, increasing the complexity of the overall fabrication process [1][2].

Objectives

A compact and affordable tool to perform non-destructive X-ray analysis will be beneficial in the near future. Our objectives is to obtain a good quality grating while focusing on the following points:

- Reproducibility of the fabrication process for industrial large scale fabrication
- Reducing the fabrication complexity by decreasing the number of process steps
- Evaluating the possibilities to pattern cheaper absorbing materials

Grating fabrication using Si mould and Au electroplating

1. Photolithography on Si
2. DRIE of Si using optimized Bosch Process
3. Gold evaporation of gold seed layer
4. Removal of FC layer and resist using Lift-off + Oxygen plasma
5. Gold evaporation back-side contact
6. Electroplating

X-ray image of a fish (C. David et al.) (a) in conventional absorption (b) in phase contrast using photon energy 7.5 keV [1]

Tungsten alternative using laser material ablation

Tungsten (W), also known as Wolfram, has the atomic number 74. When compared to gold, W exhibits similar X-ray energy absorption and is significantly cheaper than gold. Thus, W is an inexpensive alternative grating material. Using laser ablation in air, we have patterned a 7x7mm grating with a 27 ± 1µm line width in a 50µm thick W foil. The grating was characterized using X-ray tomography.

Schematic of single grating phase contrast setup with pattern of the detector. The phase contrast images of a sample can be found from measuring the horizontal (Δx) or vertical (Δy) shift of the projected X-ray pattern when inserting a sample.

First test of X-ray phase contrast imaging at DTU Physics

UV wavelength: 355nm
Tungsten thickness: 50µm
Beam passes: 220
Mark speed: 200 mm/s
Fluence: 1.2 J/cm²
Line width: 3.1 ± 0.5µm
Micrograph:
Number of pulses: 15000
Fluence: 25 J/cm²
Hole Ø: 11.0 ± 1.5 µm

Next steps toward Laser Ablation of Tungsten for X-ray gratings

References