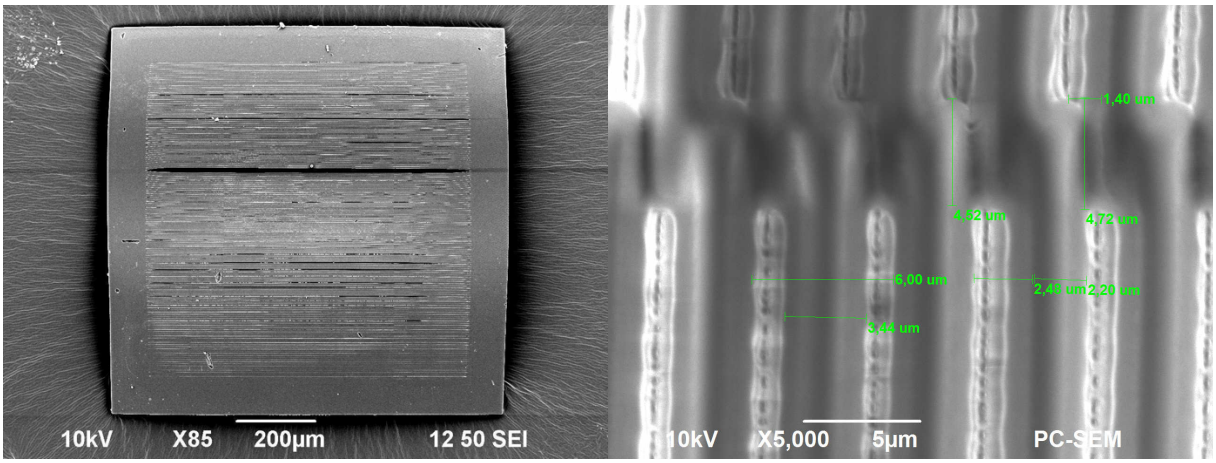
High-Fidelity 3D Printing of Microstructured X-Ray Gratings

Two-Photon Polymerization · Microfabrication · X-Ray Imaging



Research Area

High-resolution additive manufacturing, two-photon polymerization, micro- and nanofabrication, dimensional metrology, X-ray imaging

Background

Advanced X-ray imaging techniques can extract information far beyond conventional absorption radiography. In particular, **grating-based phase-contrast and dark-field imaging** use precisely manufactured microstructures to manipulate the X-ray wavefront and provide sensitivity to structures and material variations that are difficult to resolve with conventional X-ray imaging.

Producing these gratings with the required geometric accuracy is challenging. Conventional fabrication relies on specialized microfabrication processes, while recent advances in **two-photon polymerization (2PP)** provide a potential route to directly manufacture complex three-dimensional structures with features on the micrometre and sub-micrometre scale.

This interdisciplinary project is conducted in collaboration with the **TUM Professorship of Biomedical Imaging Physics**.

Objective

The goal of this thesis is to determine whether two-photon polymerization can produce **high-fidelity microstructures suitable for next-generation X-ray gratings**.

The emphasis is not simply on achieving the smallest possible feature. Instead, the central challenge is to understand and control the complete relationship:

CAD geometry → 2PP process → printed geometry → dimensional error → functional grating quality

The project will systematically investigate how printing strategy and process parameters influence the quality of demanding high-aspect-ratio periodic structures.

Individual Tasks

Depending on the final scope, the work may include:

- Translating target X-ray grating geometries into 2PP-compatible CAD designs
- Designing test structures for systematic print-quality assessment
- Fabricating structures using a high-resolution two-photon polymerization printer
- Investigating process parameters such as:
    - voxel size and orientation
    - laser exposure
    - slicing and hatching strategy
    - print orientation
    - feature spacing
    - aspect ratio
    - development and drying
- Quantifying dimensional accuracy and print fidelity using optical microscopy and/or SEM
- Evaluating deformation, shrinkage, collapse, surface quality, and feature-to-feature consistency
- Iteratively improving the designs and printing strategy
- Identifying a robust process window for repeatable grating fabrication
- Fabricating demonstrator gratings for subsequent X-ray characterization with the collaborating imaging group

Depending on progress, the project can also investigate more complex three-dimensional or non-conventional grating geometries that would be difficult to manufacture with traditional processes.

Research Questions

Examples of questions the thesis could address are:

- What minimum feature dimensions can be reproduced reliably rather than merely printed once?
- What limits the achievable aspect ratio?

- How do voxel geometry, scan strategy, development, and drying affect dimensional accuracy?
- Can predictable design compensation be introduced for systematic fabrication errors?
- Can 2PP enable grating geometries that are inaccessible to conventional fabrication routes?

Prerequisites

Required

- Strong interest in experimental microfabrication
- Careful and systematic laboratory working style
- Interest in optics, X-ray imaging, materials science, or precision manufacturing
- Experience with CAD or strong motivation to learn it

Beneficial

- Experience with additive manufacturing or lithography
- Optical or electron microscopy
- Image analysis, Python or MATLAB
- Fundamentals of optics or X-ray physics
- Experimental design and statistical analysis

Prior experience with X-ray imaging or two-photon polymerization is **not required**.

What You Will Learn

You will work at the interface between **advanced manufacturing and biomedical imaging**, gaining practical experience with:

- Two-photon polymerization
- High-aspect-ratio microfabrication
- CAD-to-print process development
- Optical and electron microscopy
- Quantitative dimensional metrology
- Design of experiments
- X-ray grating technology and phase-contrast imaging

Most importantly, the project has a clear engineering objective: determining whether an emerging additive-manufacturing process can replace or extend conventional routes for manufacturing precision X-ray optical components.

Suitable for: Master's thesis / semester thesis