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DTU Physics
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# Microfabrication of gratings for X-ray Imaging

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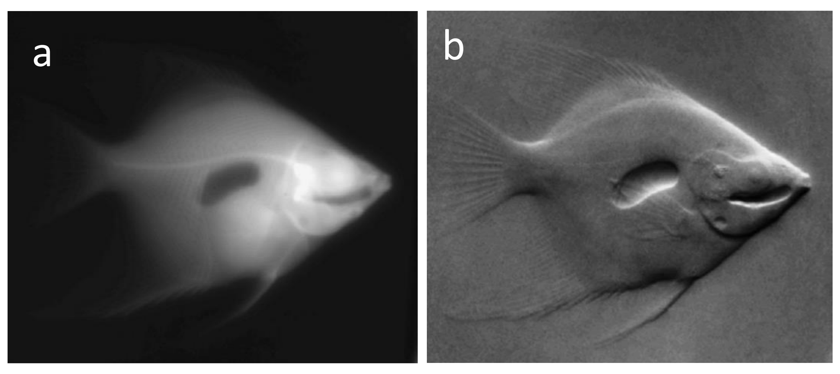
## Introduction

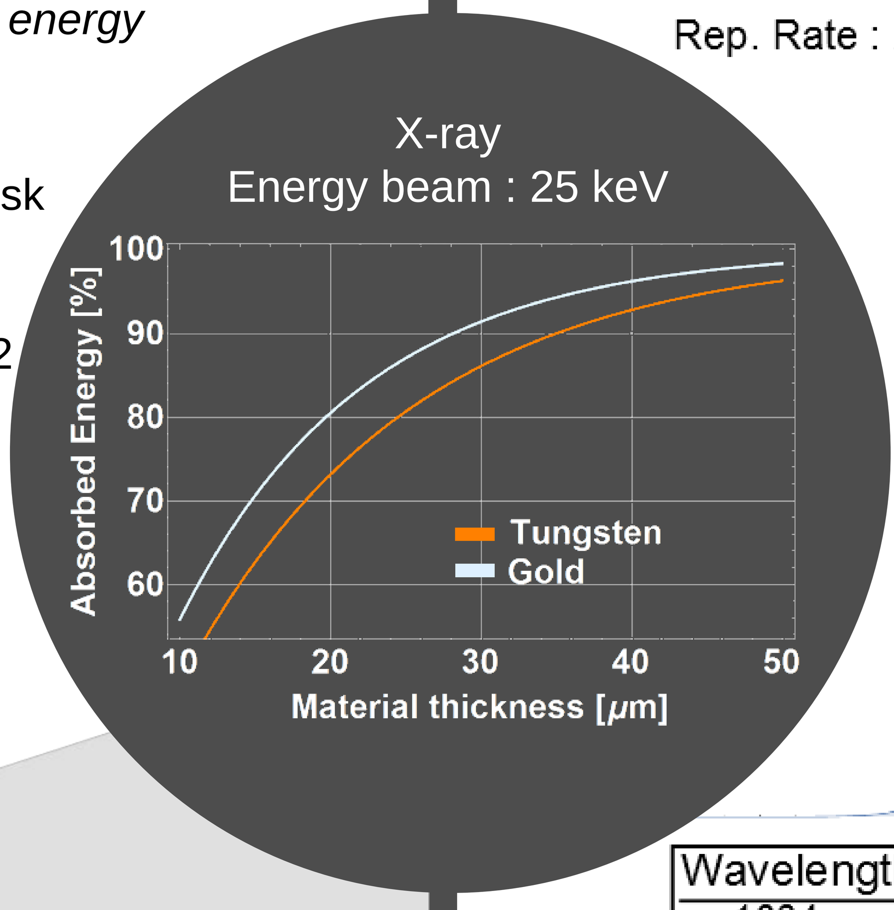
Conventional X-ray radiography relies on the differences in absorption of the constituent of a sample. For biological tissues, polymers or other organic materials, the absorption is so weak that high contrast imaging is very difficult to achieve.

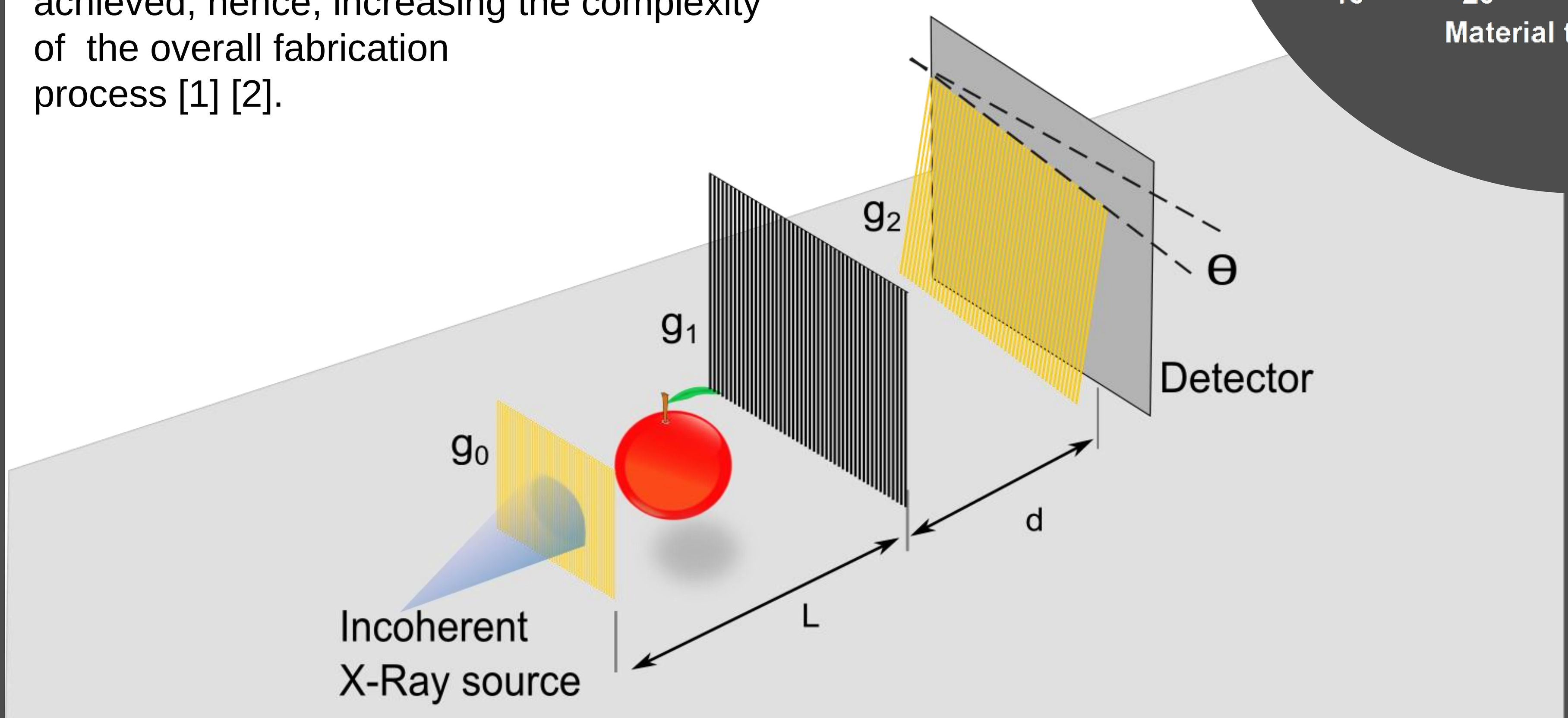



*X-ray image of a fish (C. David et al.) (a) in conventional absorption (b) in phase contrast using photon energy 7.5 keV [1]*

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 build 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 electrodeposition 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].



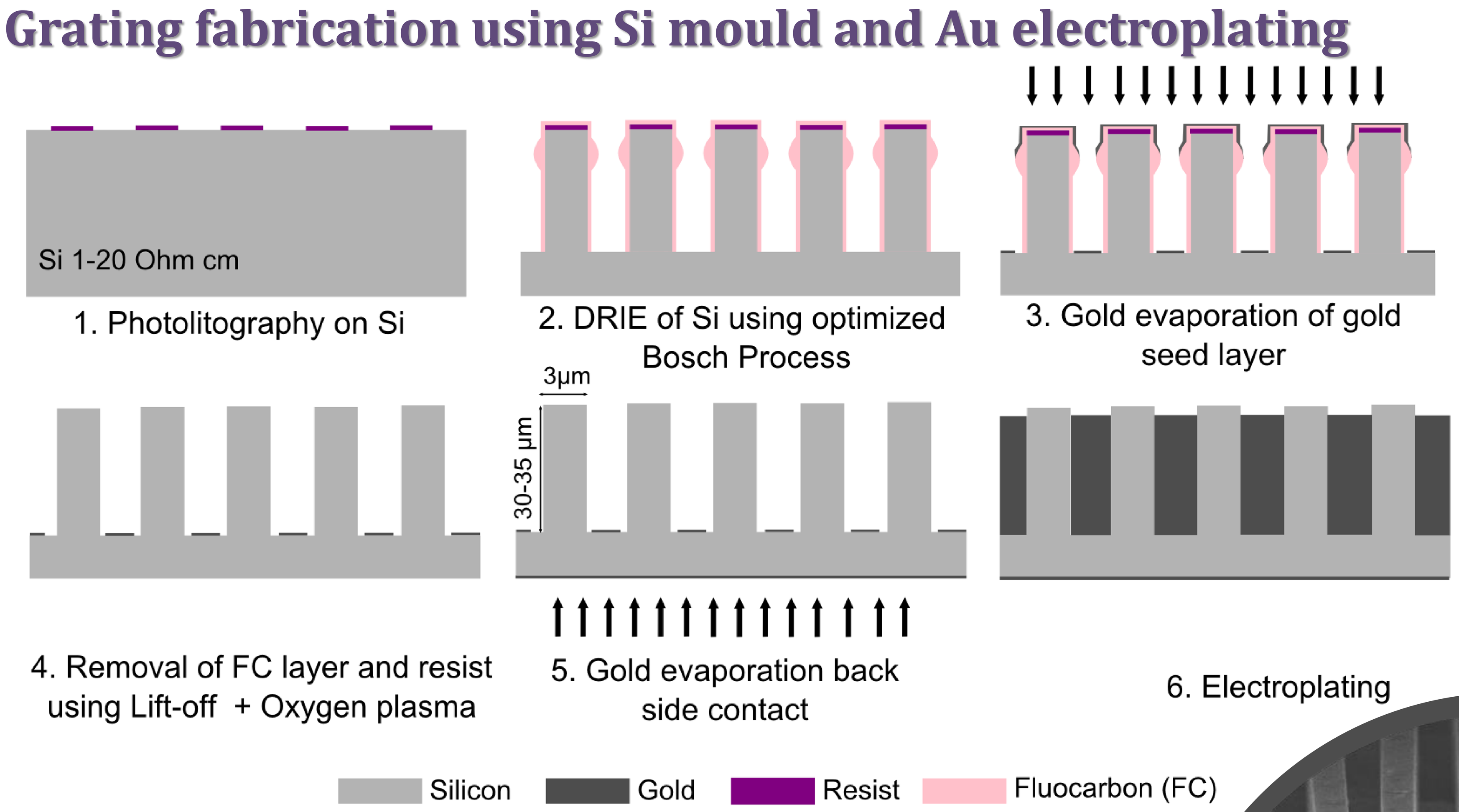



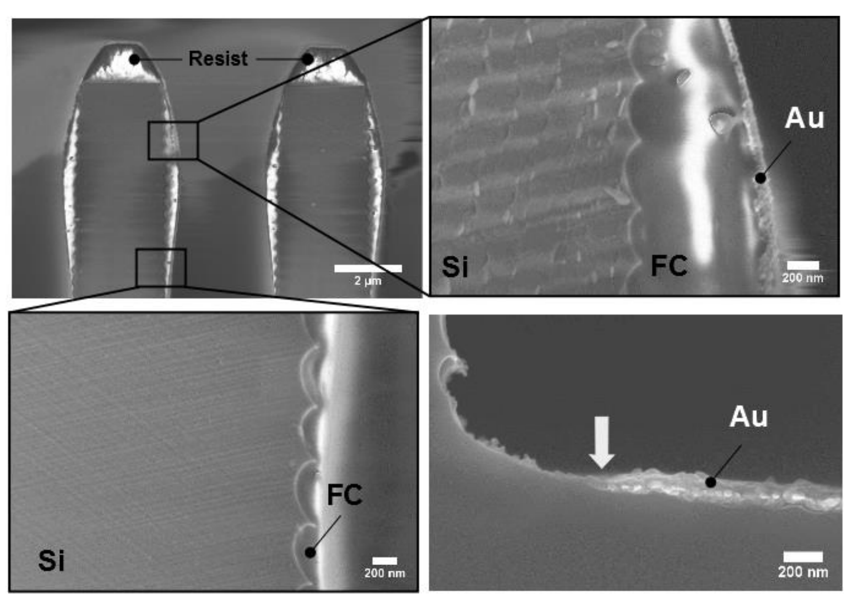

## Objectives

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

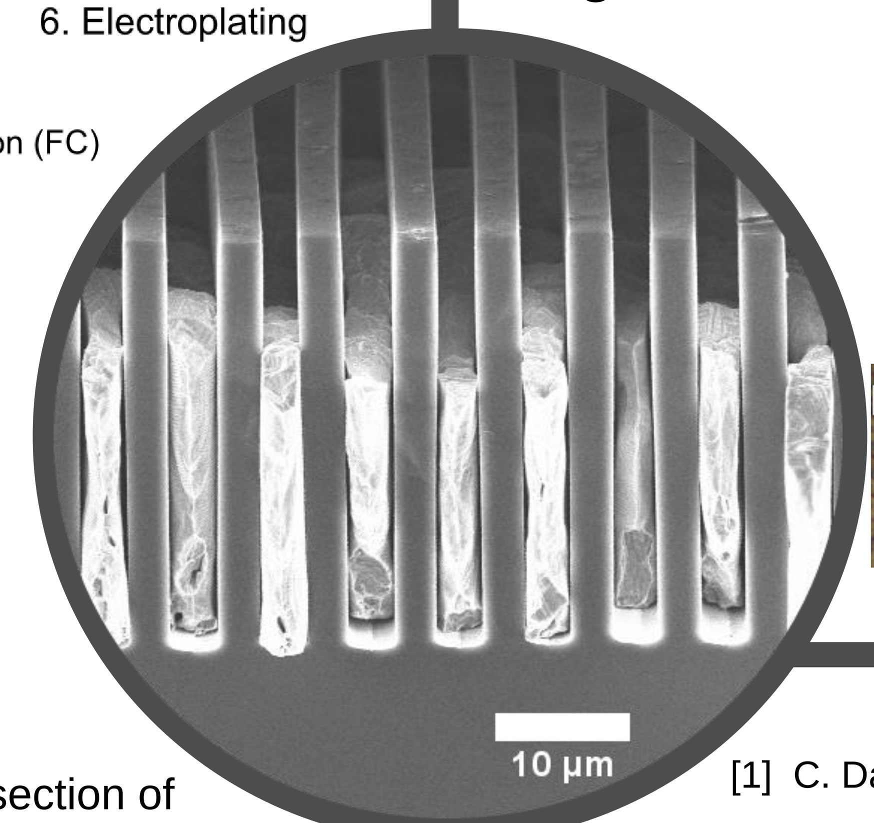
- **Reproducibility** of the fabrication process for industrial large scale fabrication
- **Reducing the fabrication complexity** by decreasing the number of process steps
- Evaluating the possibilities to pattern **cheaper absorbing materials**

## Grating fabrication using Si mould and Au electroplating




⇦ SEM image of metal deposition on the FC layer. Bottom right image shows the limit (see arrow) of the metal deposition at the bottom of the trench.

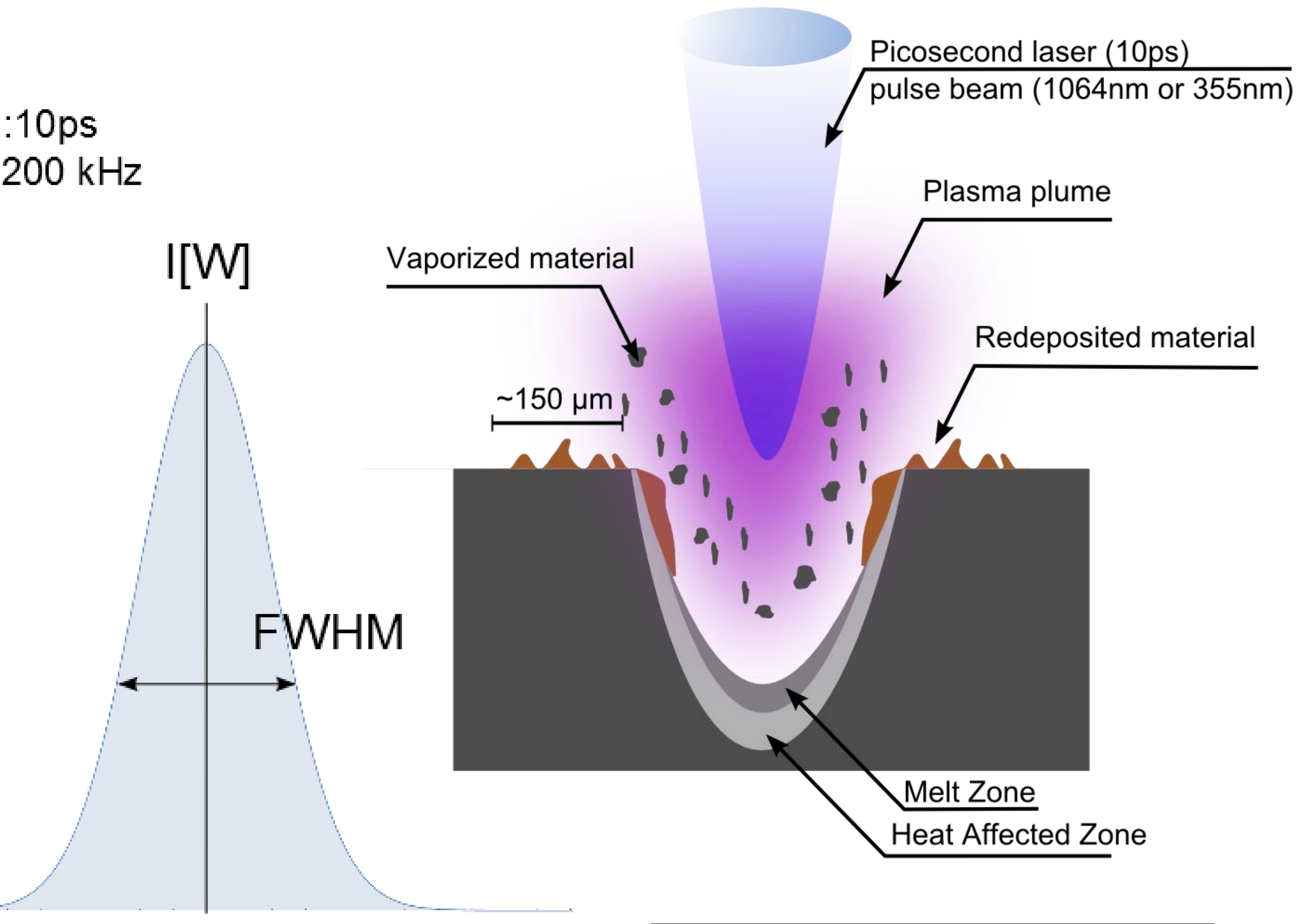



⇨ SEM cross-section of partially electroplated grating with 6μm pitch

## 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.

Pulse width :10ps
Rep. Rate : 200 kHz

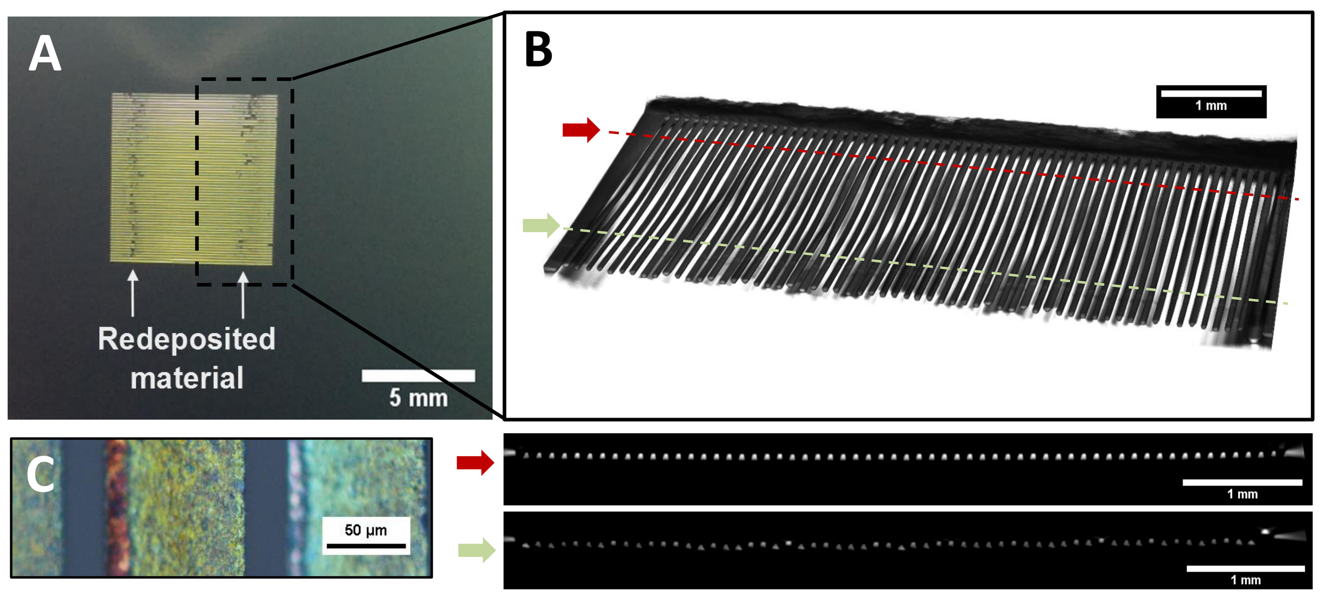



| Wavelength | FWHM | Fluence [J/cm$^2$] |
|---|---|---|
| 1064nm | 50.4μm | from 0.25 to 5.1 |
| 355nm | 10.1um | from 0.12 to 27 |

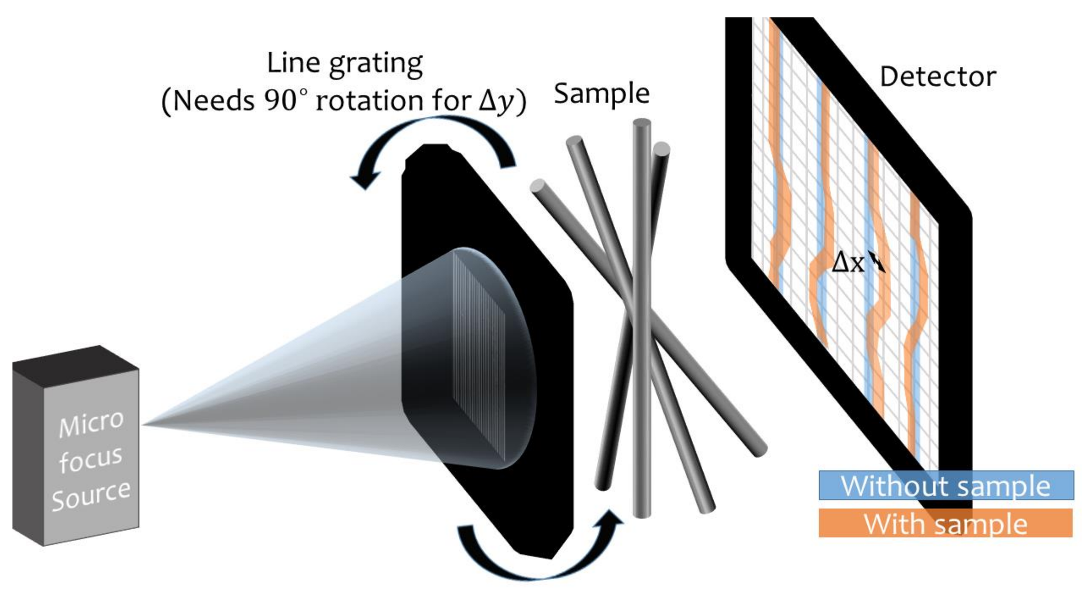
$$\text{Fluence} = \frac{\text{Pulse Energy [J]}}{\text{Spot Area [cm}^2\text{]}}$$

⇨
Wavelength : 1064nm
Mark speed : 200 mm/s
Beam passes : 20
Fluence : 2.6 J/cm$^2$
Line width : 27 ± 1μm

A : photograph
B : tomography
C : micrograph

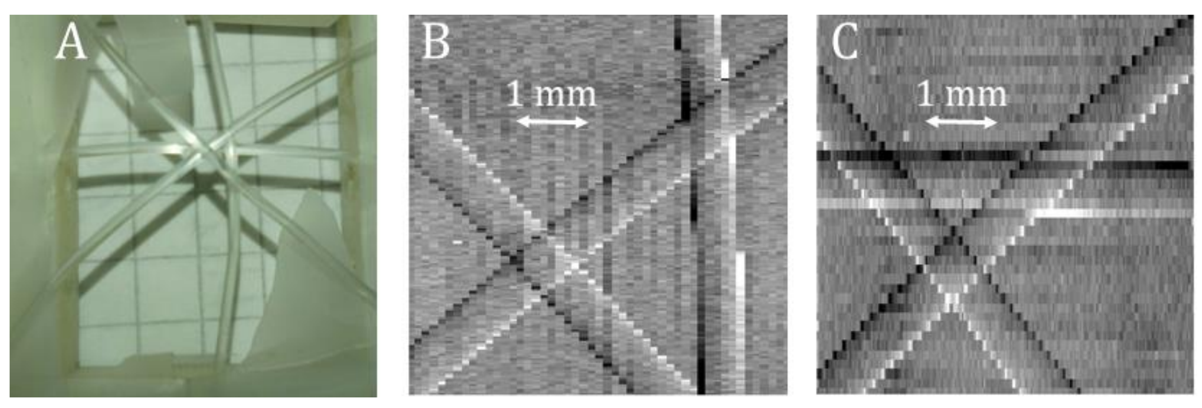



### First test of X-ray phase contrast imaging at DTU Physics



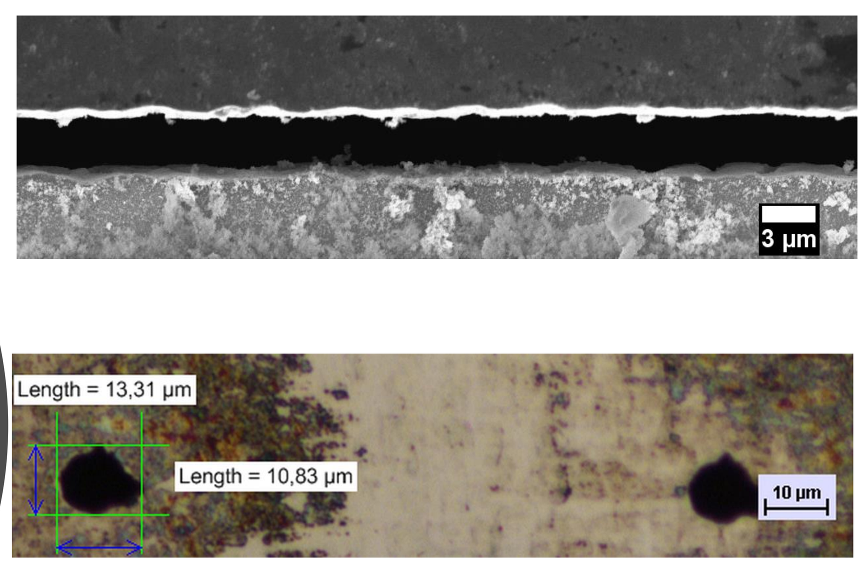

⇦ Sketch of the single grating phase contrast setup under development at DTU Physics. The line array grating creates a pattern on the detector. The phase contrast images of a sample can be found from measuring the horizontal (Δx) or vertical (Δy) shift of the projected X-ray pattern when inserting a sample.

⇨ (A) Fishing line used as sample in the DTU Physics setup. (B) Horizontal and (C) vertical X-ray phase contrast images obtained using the 27μm W grating at a source voltage of 75 kVp.




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

UV wavelength: 355nm
Tungsten thickness : 50μm




⇦ *SEM*
Beam passes : 220
Mark speed : 20mm/s
Fluence : 1.2 J/cm$^2$
Line width : 3.1 ± 0.5μm

⇦ *Micrograph*
Number of pulses : 15000
Fluence : 25 J/cm$^2$
Hole Ø : 11.0 ± 1.5 μm

## References

[1] C. David, et al. Fabrication of diffraction gratings for hard X-ray Phase contrast Imaging, Microelectronic Engineering, 2007
[2] S. Rutishauer et al. Fabrication of two-dimensional hard X-ray diffraction gratings, Microelectronic Engineering, 2013