EUV Interference Lithography with a Gas Discharge Source

S. Danylyuk[a], L. Juschkin[a], S. Brose[a], C. Dittberner[a], K. Bergmann[b], P. Loosen[a,b], D. Grützmacher[c]

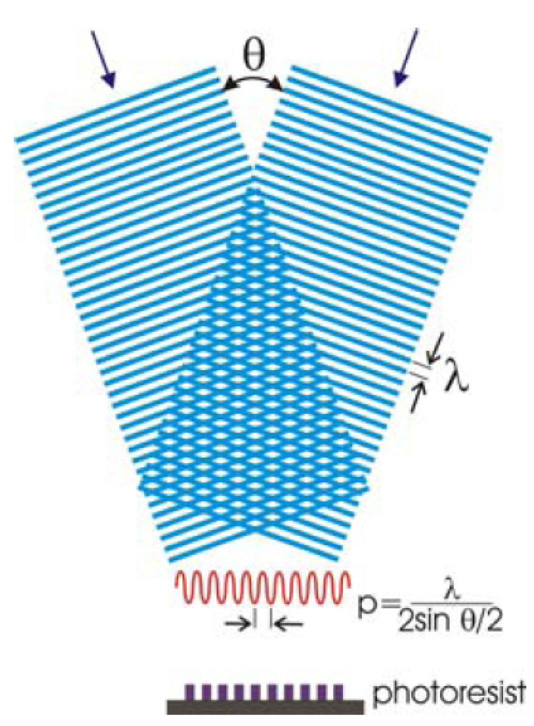
[a] Chair Technology of Optical Systems, RWTH Aachen, Steinbachstr. 15, 52074 Aachen and JARA – Fundamentals of Future Information Technology
[b] Fraunhofer Institute for Laser Technology ILT, Steinbachstraße 15, 52074 Aachen, Germany
[c] Institute for Bio and Nanoelectronics IBN-1, Forschungszentrum Jülich, 52425 Jülich

Abstract

In this work the feasibility of using a Talbot self-imaging effect for EUV interference lithography with laboratory gas-discharge sources is studied. Analytical modeling together with ray-tracing simulations are employed to formulate the requirements to emission parameters.

The obtained results show that Talbot interference scheme allows for doubling of the mask period and can be efficiently used for EUV-IL with an incoherent source, especially for structures with critical dimensions in sub-20 nm range.

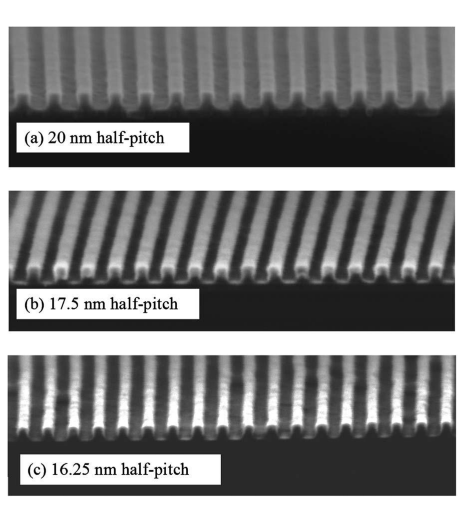
EUV Interference Lithography



- Large-area periodic structures
- Large depth of focus
- Requires a coherent light
- Low cost – no complicated and expensive optics
- Ultimate resolution for the wavelength (~λ/4) - e.g. 50 nm features with 193 nm light

EUV: λ=11 nm ➡ feature size: ~3 nm

Dense patterns with half-pitch down to 11 nm are already demonstrated with EUV-IL using synchrotron radiation

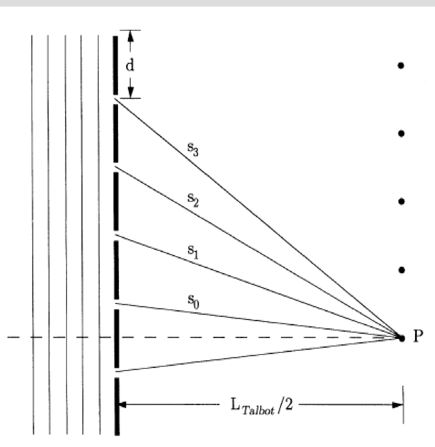


Enabling technology, if achieved with compact laboratory sources

Applications:

- Nanooptical systems (nanoplasmonics, nanophotonics)
- Sensor arrays (chemo- and biosensing)
- High-density magnetic storage
- Nanowire crossbar arrays
- ..and many more

Achromatic Talbot effect

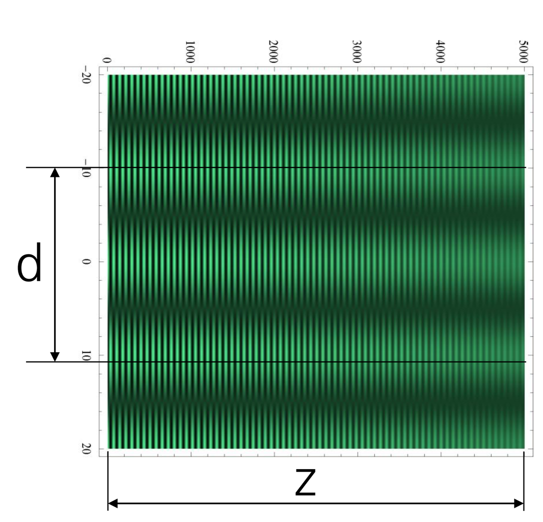


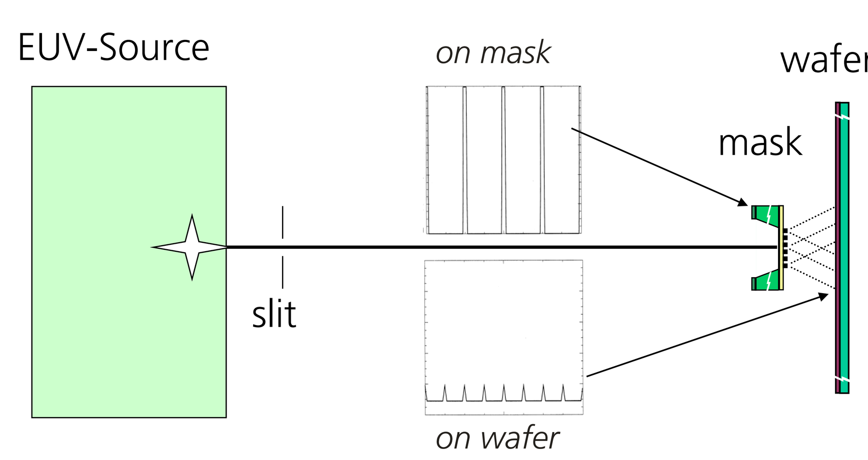
Self images of the grating at distances proportional to Talbot distance

$$L_{Talbot} = \frac{2d^2}{\lambda}$$

For not perfectly monochromatic light Talbot self images mix and form a stationary image with half of the grating period at a distance z (Δλ is a bandwidth of the source).

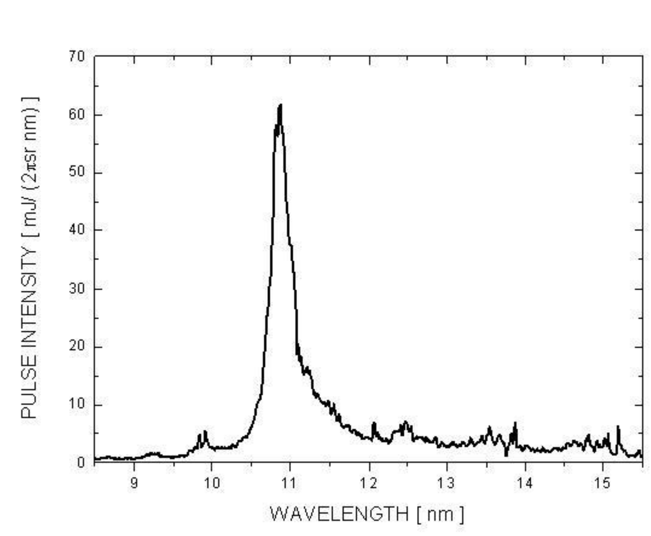
$$z = \frac{2d^2}{\Delta\lambda}$$





EUV gas discharge source

- Repetition rate: up to 2 kHz
- Input power: 6 kW
- Spot size / plasma diameter: 150-350 μm
- Optimized bandwidth @ 10.9 nm: 3.2 %
- Emission @13.5 nm (2 % b.w.): 6.6 mJ/(2πsr)
- Emission @10.9 nm (3.2 % b.w.): 20 mJ/(2πsr)
- Resist exposure times below 30 seconds with state-of-the-art sources



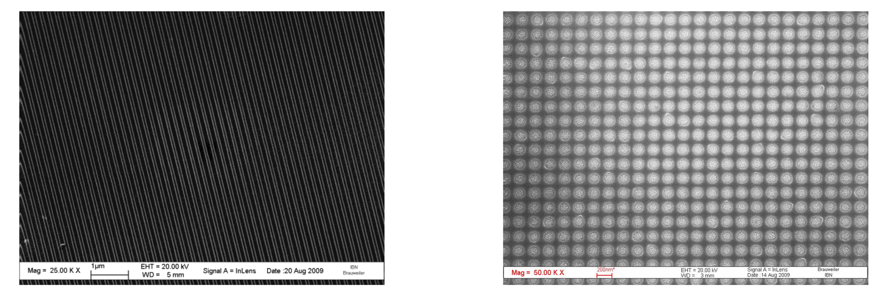
Emission spectrum of the optimized Xenon plasma

Transmission masks manufacturing

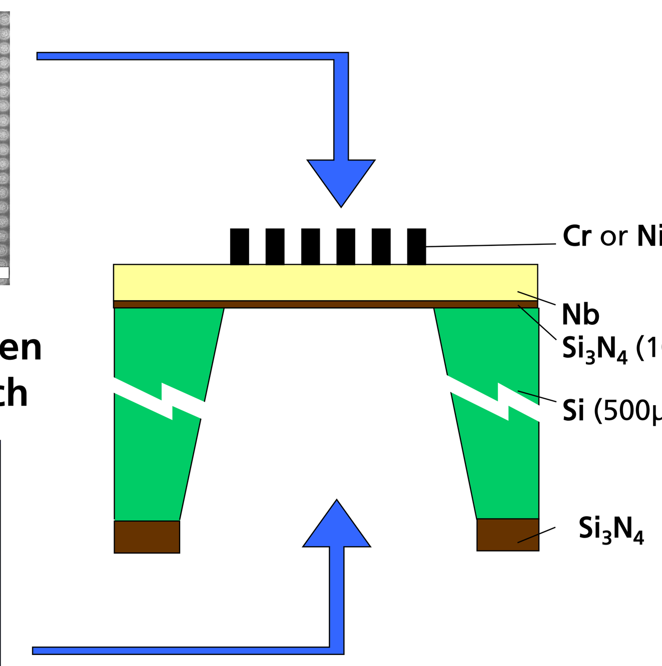
SiN_x- based masks can no longer be used at 11 nm – below Si L-edge!

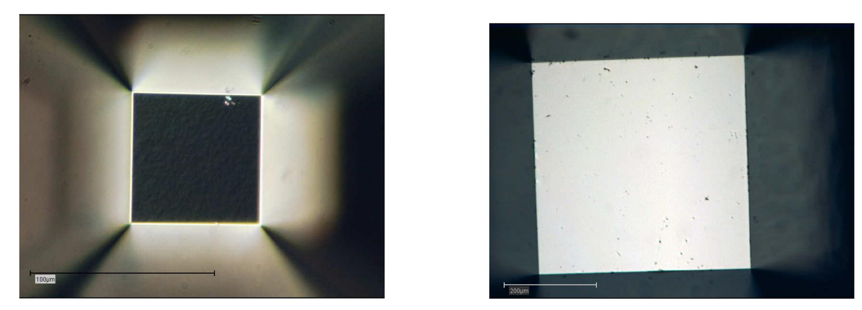
Niobium is a suitable substitution for silicon nitride as a support membrane @ 11 nm:

- Niobium with a thickness of 100 nm has a sufficient transmission of 65% at 11 nm
- Niobium as an built-in filter for wavelength > 18 nm
- Mechanically stable, used in MEMS technology



Gratings and pinhole arrays have been structured with e-beam with 100-150 nm pitch

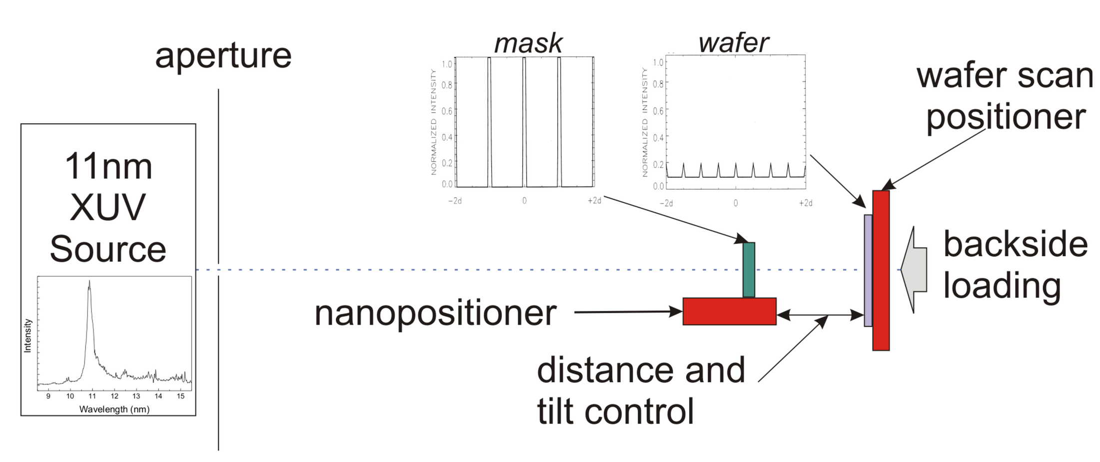




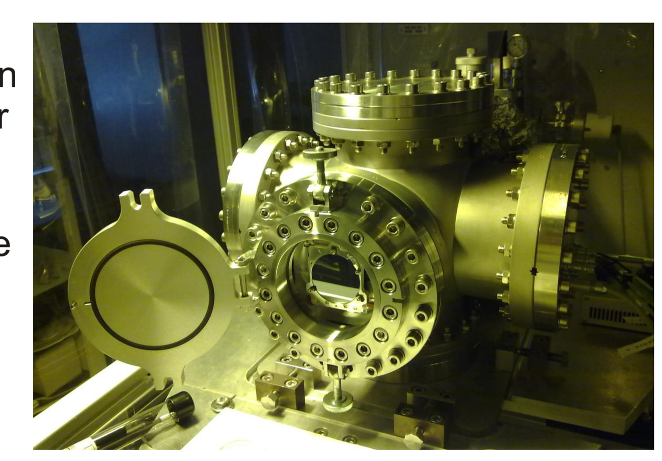
Nb(100nm)/Cr(100nm) Nb(50nm)/Cr(10nm)

Flat niobium membranes up to 465μm x 465μm areas are successfully manufactured

Illumination setup



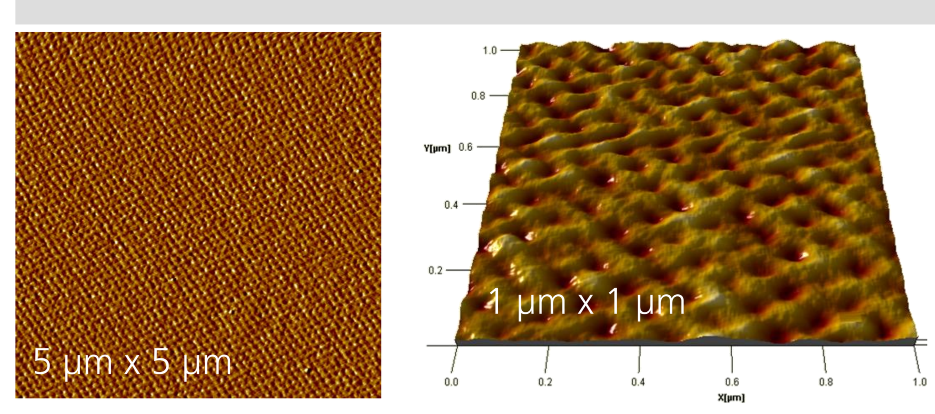
Resist illumination time <1min



Proof-of principle setup for illumination of 2" wafers

- Wafer-mask distance and tilt control with 10nm precision – *- necessary for Talbot lithography*
- Compact and rigid to minimise influence of vibrations – *- critical for targeted sub-20nm structures*
- Minimum optical components to reduce losses – *- increasing of the throughput*

First exposure results

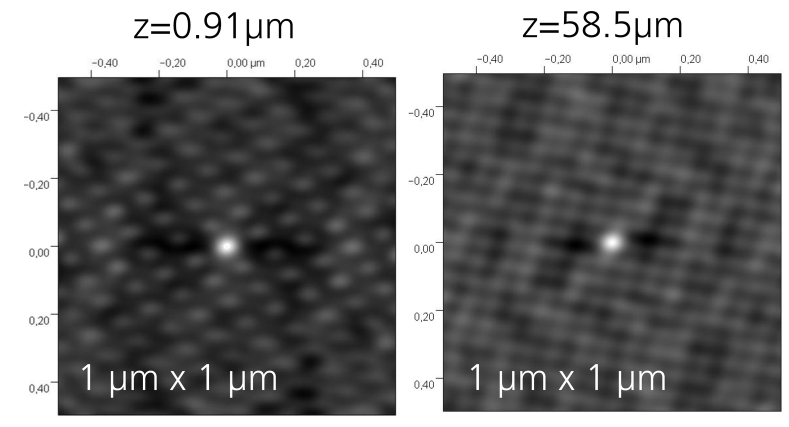


AFM measurements of PMMA resist structured with Nb/Ni pinhole mask in the contact mode.

- Period of structures - 100 nm
- Hole diameter – 40 nm
- Array size - 265 x 265 μm

2D autocorrelation function of PMMA resist exposed in monochromatic and achromatic Talbot modes.

Period is reduced by factor $\sqrt{2}$



Summary

- XUV interference lithography with compact sources allows for high throughput patterning with high resolution and has a huge potential for applications
- Modelling of achromatic Talbot lithography with gas discharge sources have been performed to determine the requirements to the source and illumination setup.
- Emission of gas discharge source was optimised to achieve highest possible intensity within 3.2% bandwidth
- Free standing thin Nb membranes for necessary transmission masks were manufactured with areas exceeding 0.2 mm² and patterned with e-beam
- Proof-of-principle setup for XUV patterning based on compact gas discharge plasma XUV source was designed and realized for sub 20 nm structures

JARA-FIT Fundamentals of Future Information Technology
TOS RWTH Rheinisch-Westfälische Technische Hochschule Aachen – Lehrstuhl für Technologie Optischer Systeme
JÜLICH Forschungszentrum
Fraunhofer ILT