Character projection e-beam lithography for wafer level nano-fabrication

Uwe Hübner, Mario Ziegler, Thomas G. Mayerhöfer, Sophie Patze, Richard Knipper, Dana Cialla-May, Karina Weber, Juergen Popp

Outline

- Introduction
- The write time issue of the electron beam lithography
- Nanodevices on waferscale: E-beam lithography with Character Projection as enabler
    - Write time benefit
    - Line with control and proximity correction
    - Flexibility
- Summary

Introduction

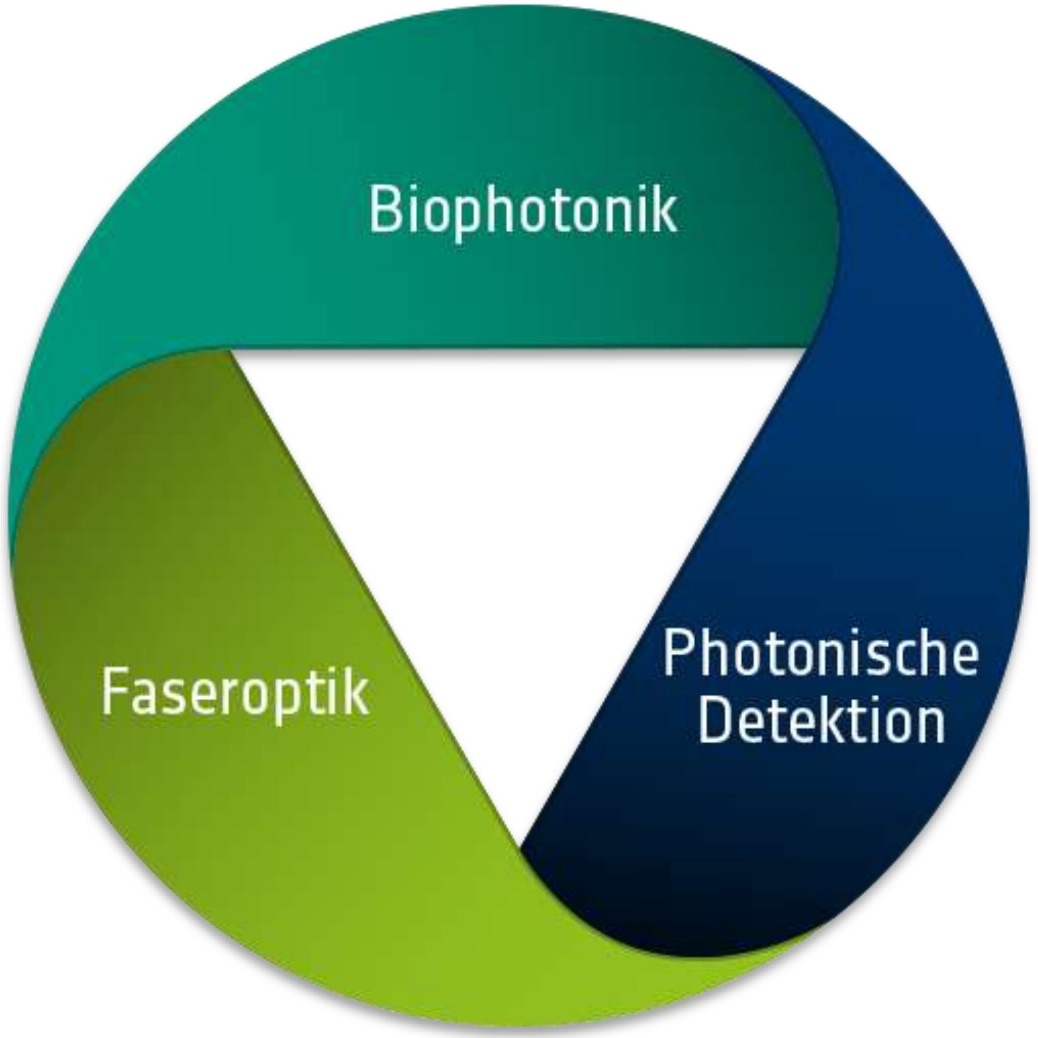
The IPHT building on the Beutenberg Campus in Jena (Thuringia)

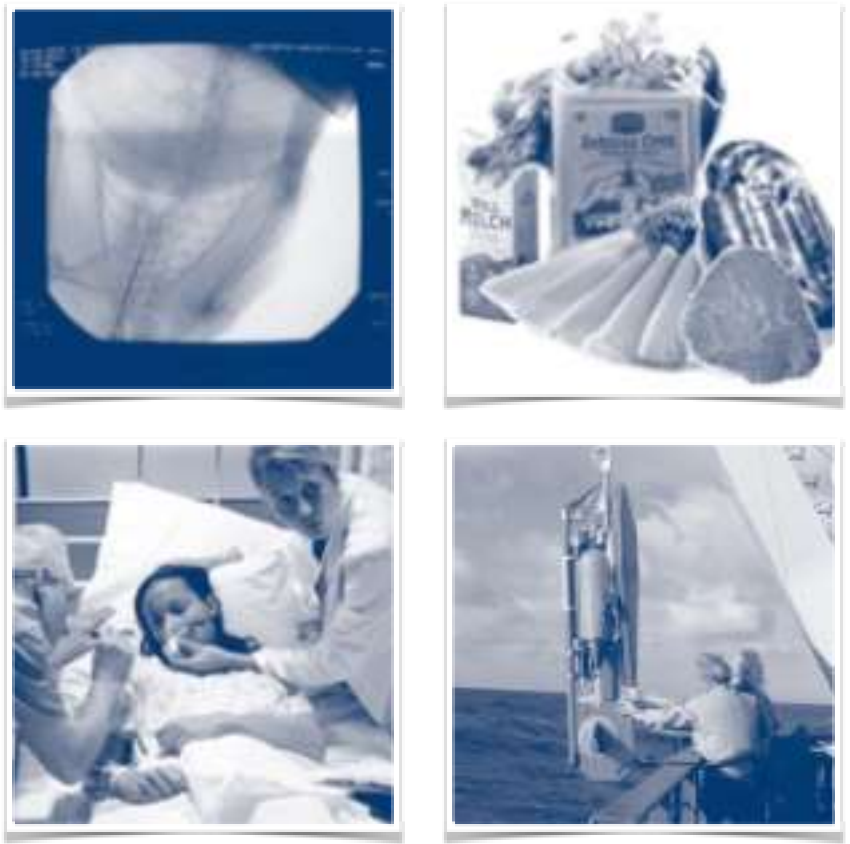
The main research fields of the Leibniz Institute of Photonic Technology (IPHT)

Leibniz ipht

PHOTONICS FOR LIFE

from Ideas to Instruments





→ Key function between photonis, life and environmental sciences as well as medicine

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Key Figures:

Employees: **330**

Including Doctoral Candidates: **100**

Publications/Year : **ca. 200**

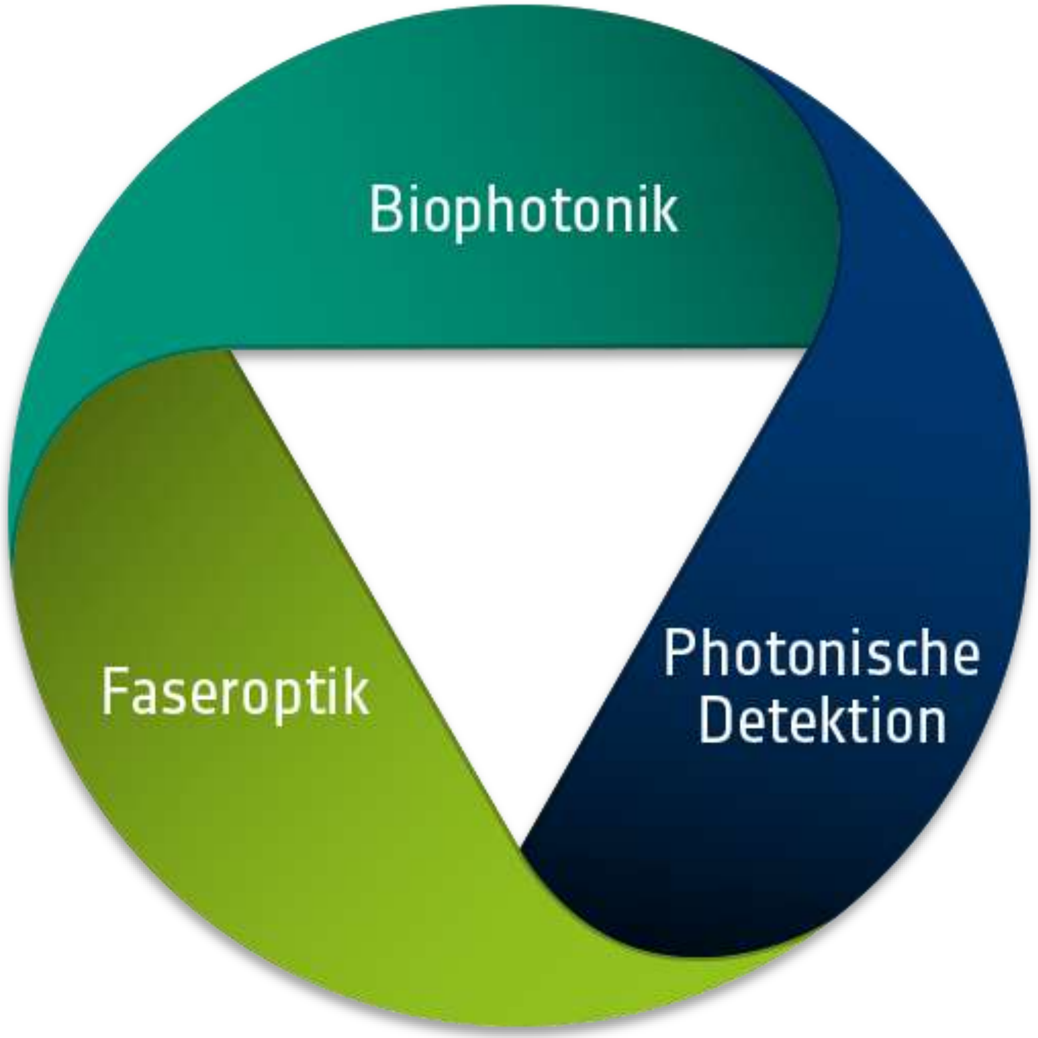
General Budget: **ca. 21 Mio. €**

Incl. Project Funding: **ca. 11 Mio. €**

The basic technologys of the Leibniz IPHT

PHOTONICS FOR LIFE

from Ideas to Instruments



- Optical fiber technology

- Micro- and nanotechnology

Leibniz ipht

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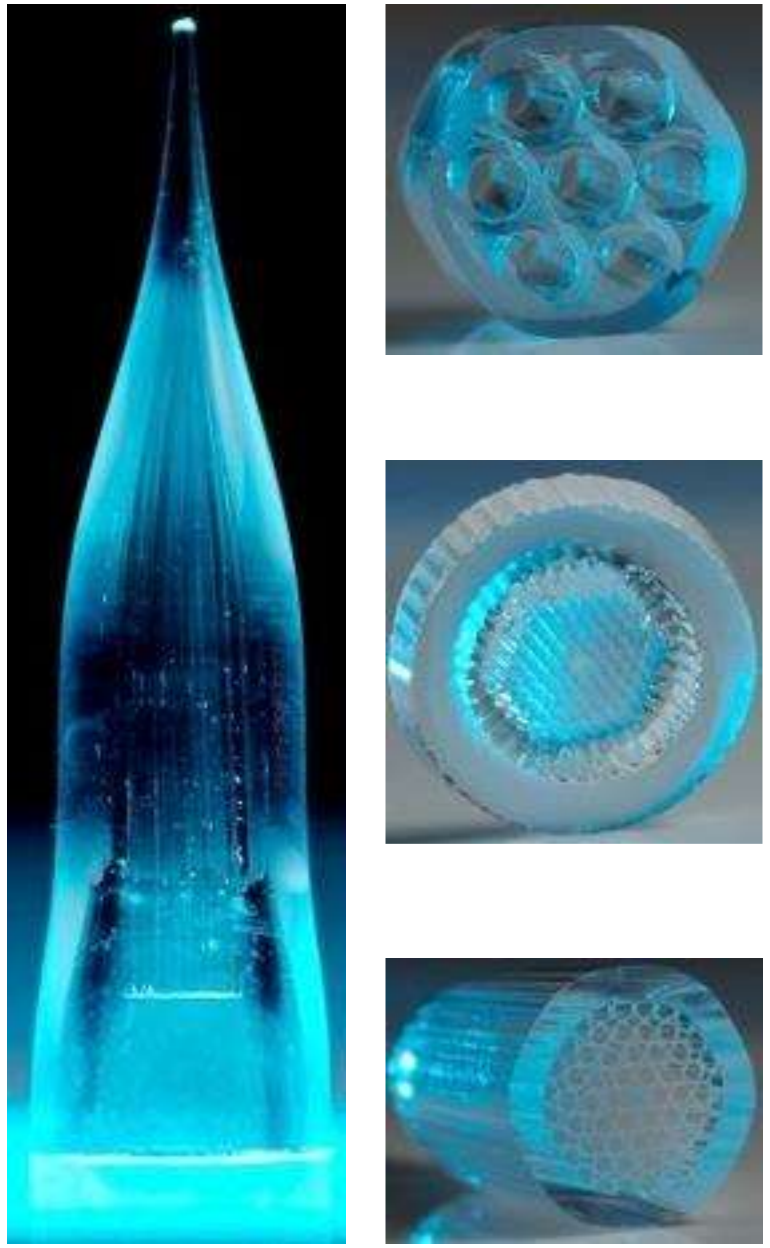
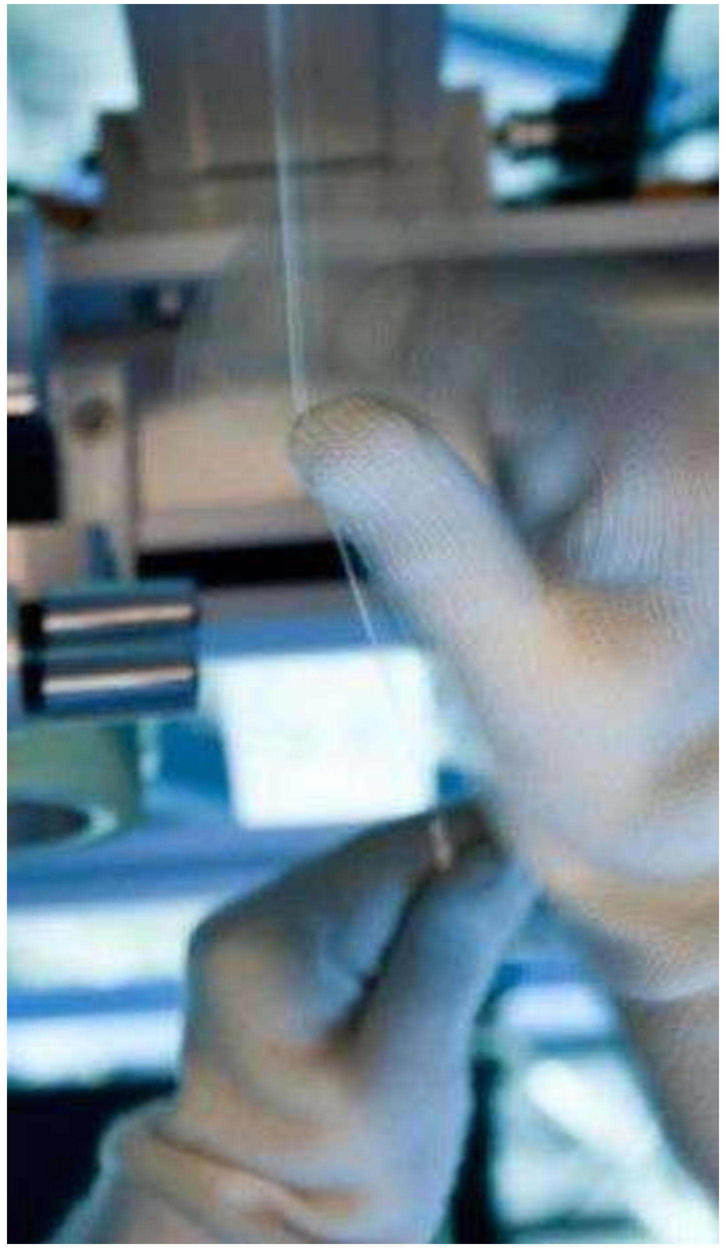
Optical fiber technology

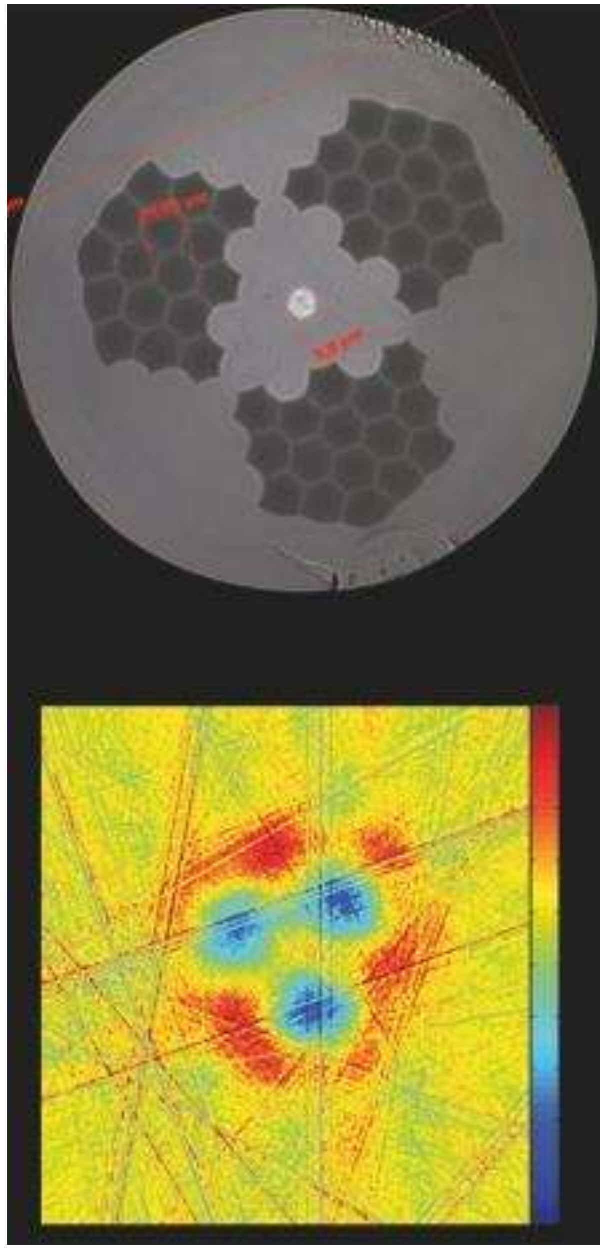
Optical Fibres for Biophotonics



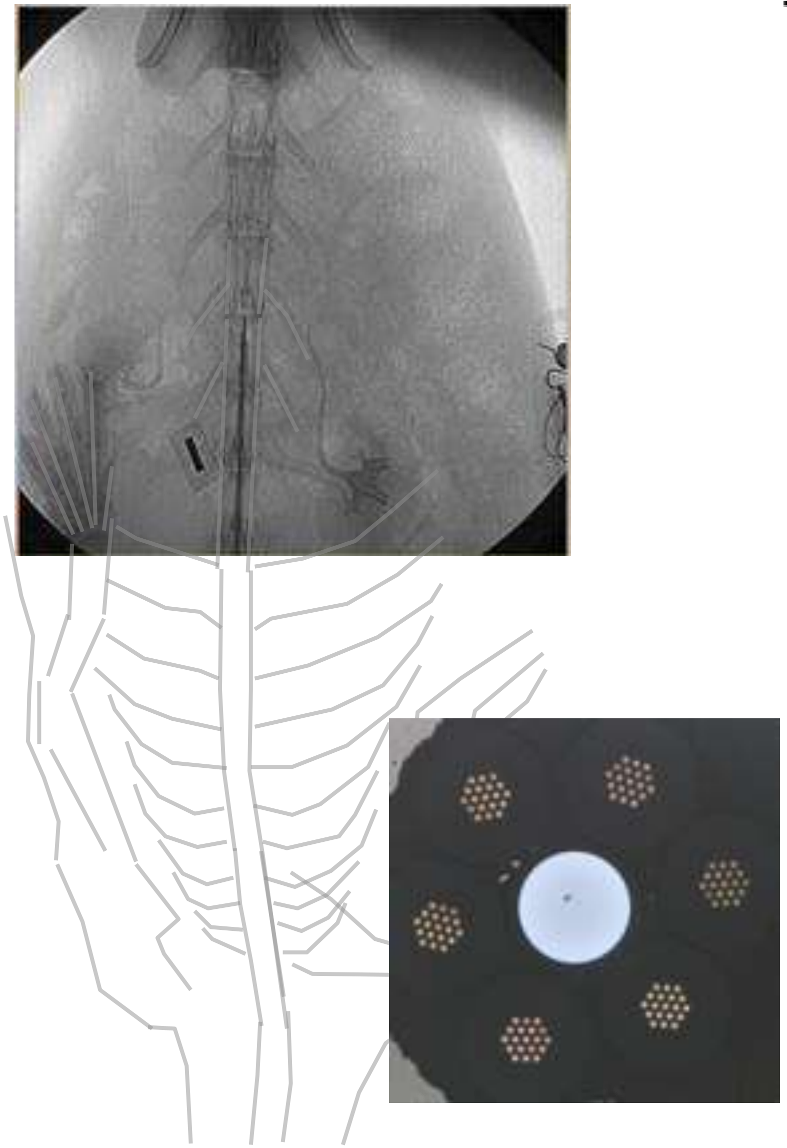
Material development and preform production



Fiber drawing



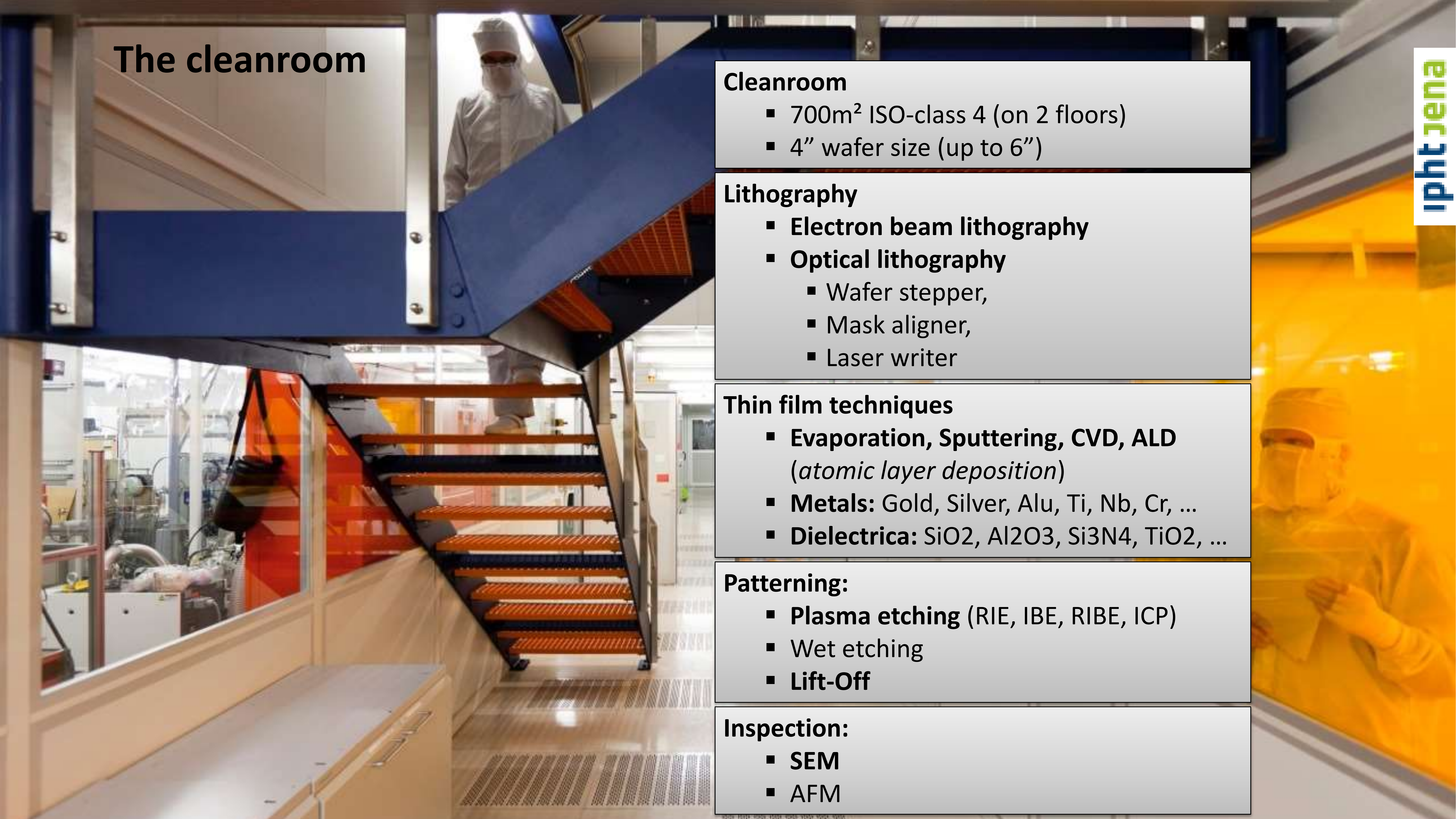
characterization



Fiber probe for medical diagnostics

Member of the Leibniz Leibniz Association

The cleanroom



Cleanroom
- 700m² ISO-class 4 (on 2 floors)
- 4” wafer size (up to 6”)

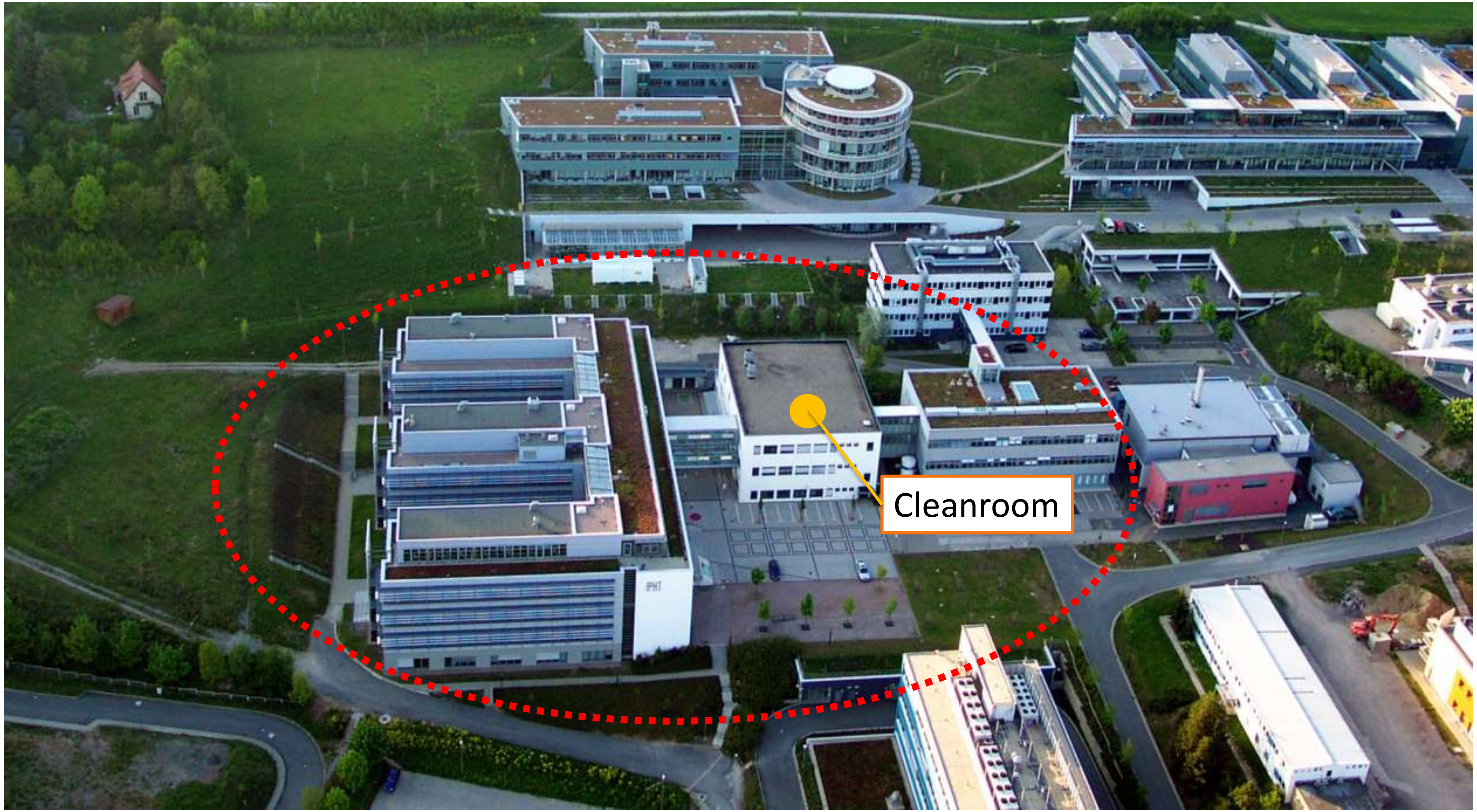
Lithography
- **Electron beam lithography**
- **Optical lithography**
  - Wafer stepper,
  - Mask aligner,
  - Laser writer

Thin film techniques
- **Evaporation, Sputtering, CVD, ALD** (*atomic layer deposition*)
- **Metals:** Gold, Silver, Alu, Ti, Nb, Cr, …
- **Dielectrica:** SiO_2, Al_2O_3, Si_3N_4, TiO_2, …

Patterning:
- **Plasma etching** (RIE, IBE, RIBE, ICP)
- Wet etching
- **Lift-Off**

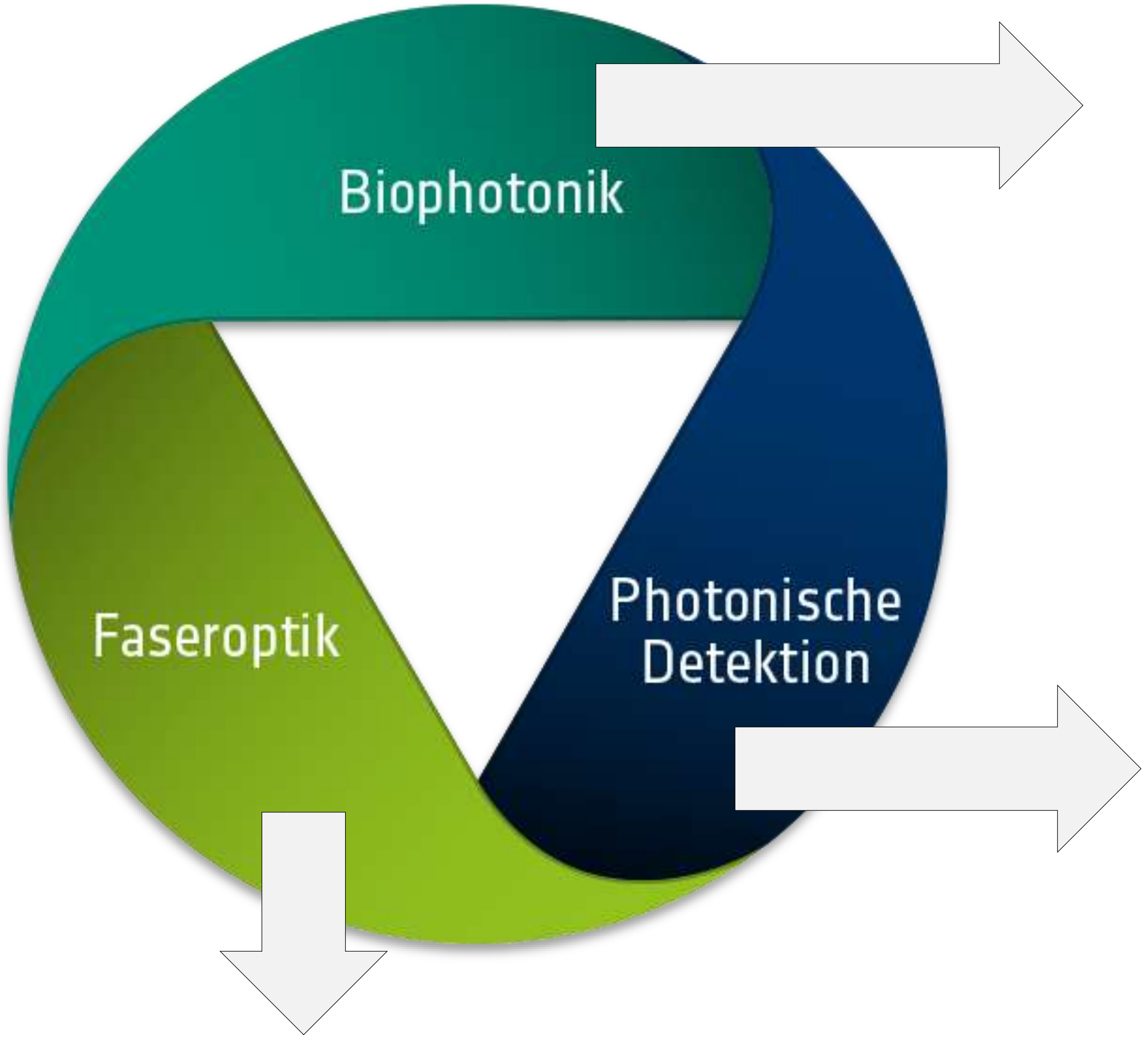
Inspection:
- **SEM**
- AFM

The cleanroom



The IPHT building on the Beutenberg Campus in Jena (Thuringia)

The role of the microfabrication at the IPHT

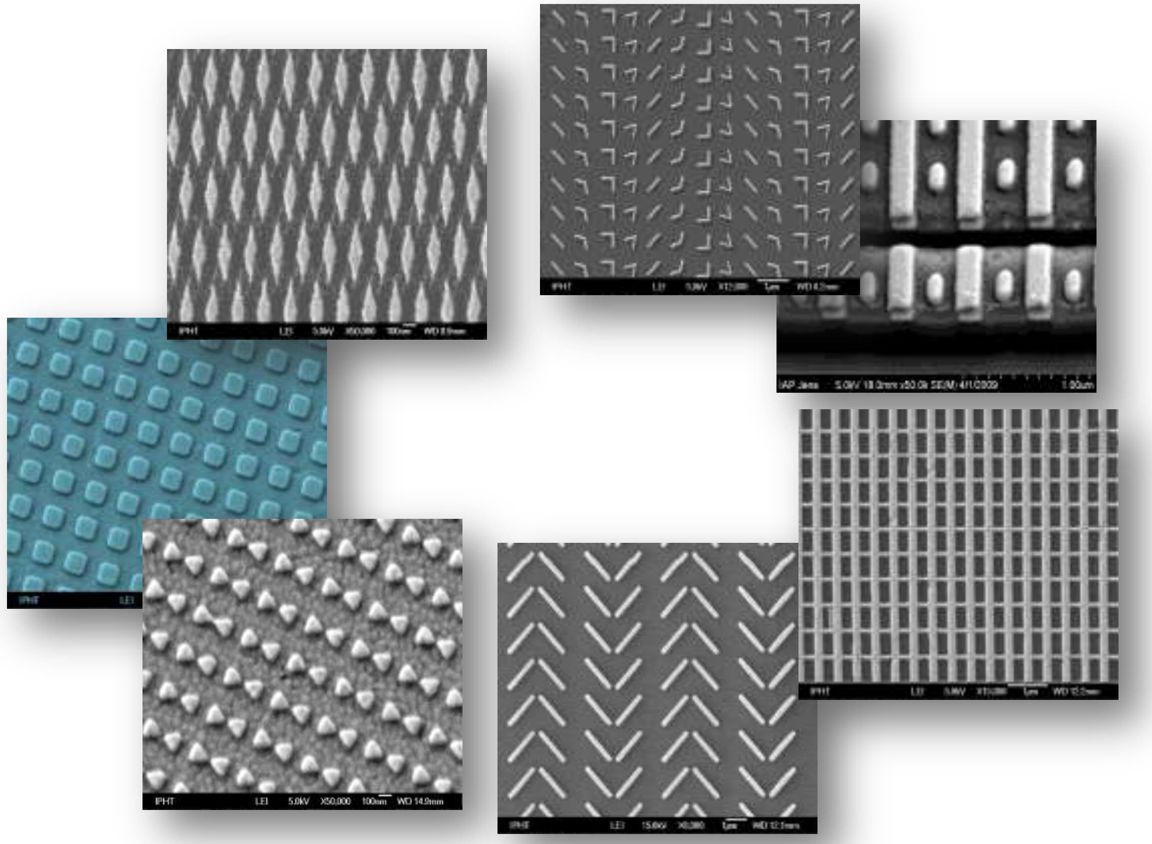


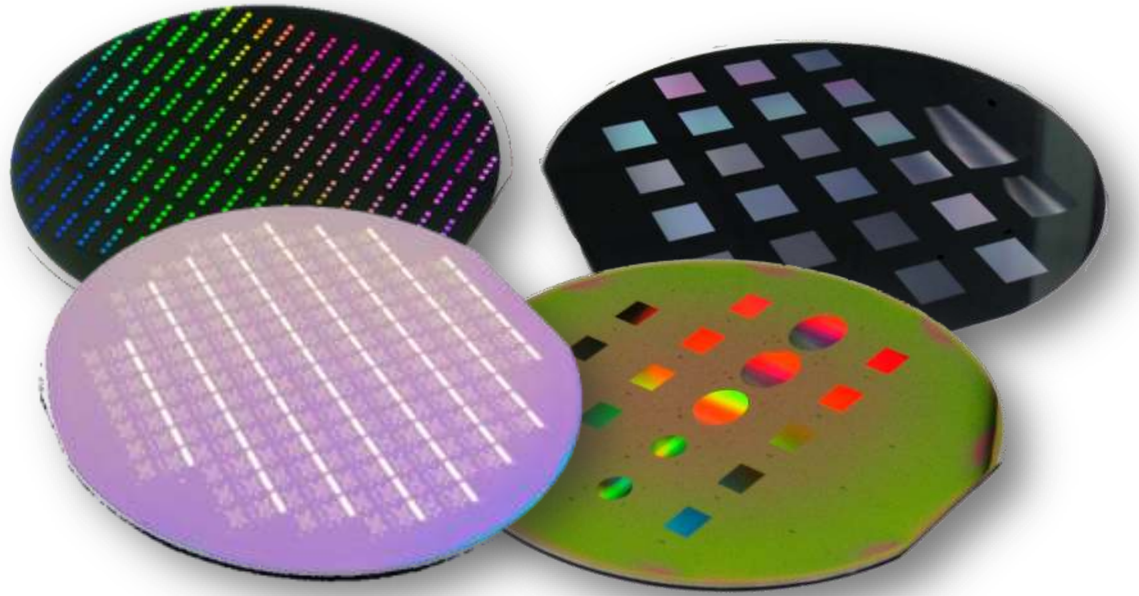
- **Plasmonic substrates** for surface enhanced spectroscopy
- Microfluidic devices
- Micro optical devices, optical **gratings** and planar waveguides

- Radiation detectors (Bolometer, THz-imaging)
- IR-sensors
- SQUID-systems (ultrasensitive magnet field devices)

- Fiber and
- Fiber-endface patterning

Introduction





Plasmonic devices/metamaterials = subwavelenght pattern

- **For <u>basic research</u>:**

Large number of different concepts and often with frequently changing layouts

→ Need of **flexible nanotechnology**

- **For <u>routine use</u> in our labs and for applications:**

Sufficient number of test objects, chips etc. for daily use

→ Need of **wafer level fabrication**

(Large pattern areas with a few million nanostructures per mm²)

E-beam lithography

☺ High pattern resolution, flexible

☹ Time-consuming **serial writing** method

The write time issue of the electron beam lithography

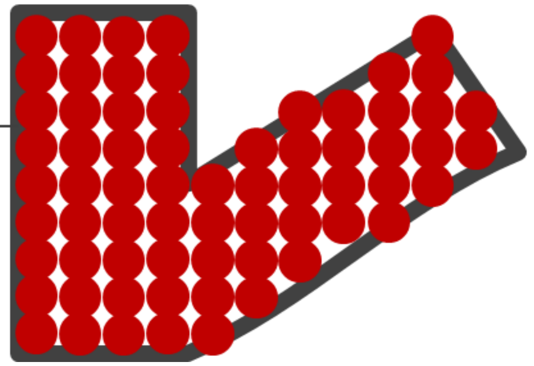
Write time issue of the electron beam lithography

- **High resolution**
  - nm-size beam diameter
  - Pattern dimension << 100 nm

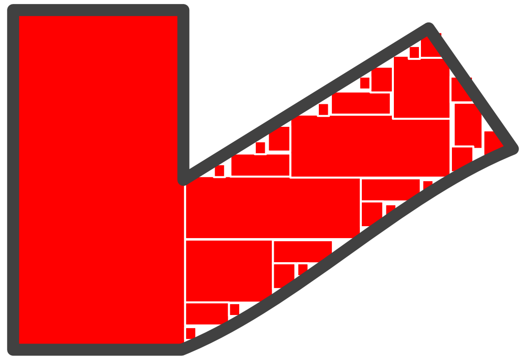
- **Time-consuming**
  - Serial writing method: **Writing time ~ “Shot number”**

Gaussian point probe

Pattern-shape



(rectangular) **Shaped beam**



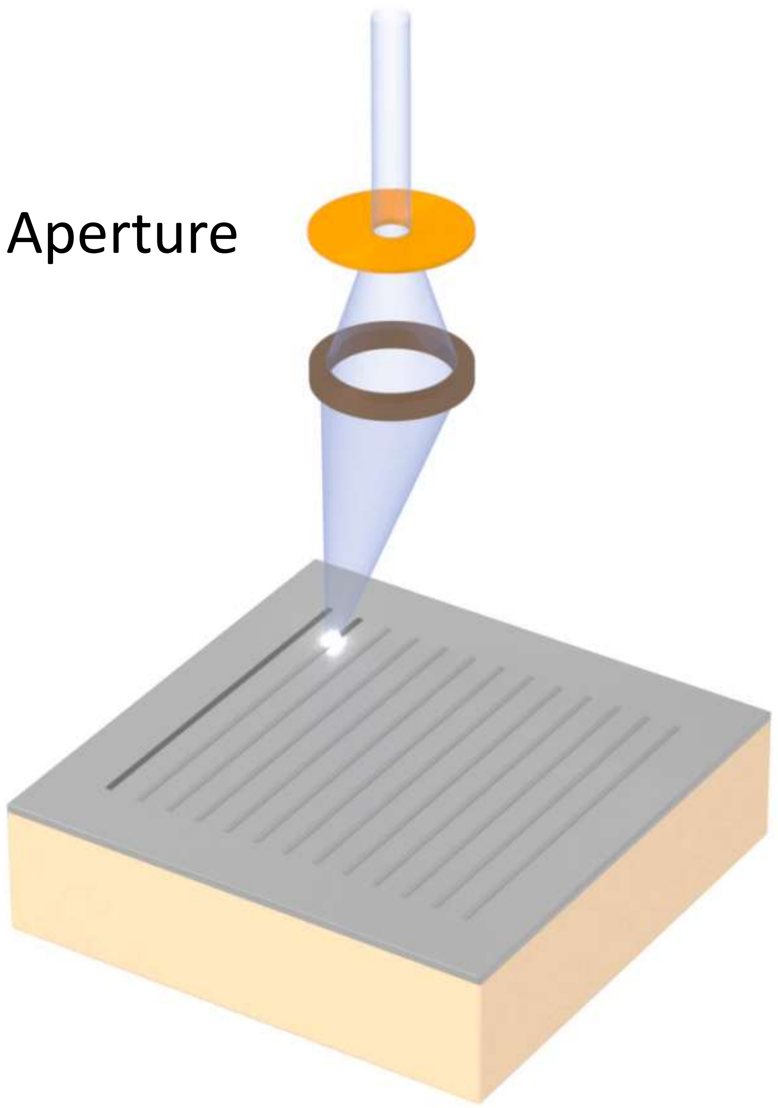
Fracturing in rectangular shots

→ Shot number ~ Degree of the edge decomposition

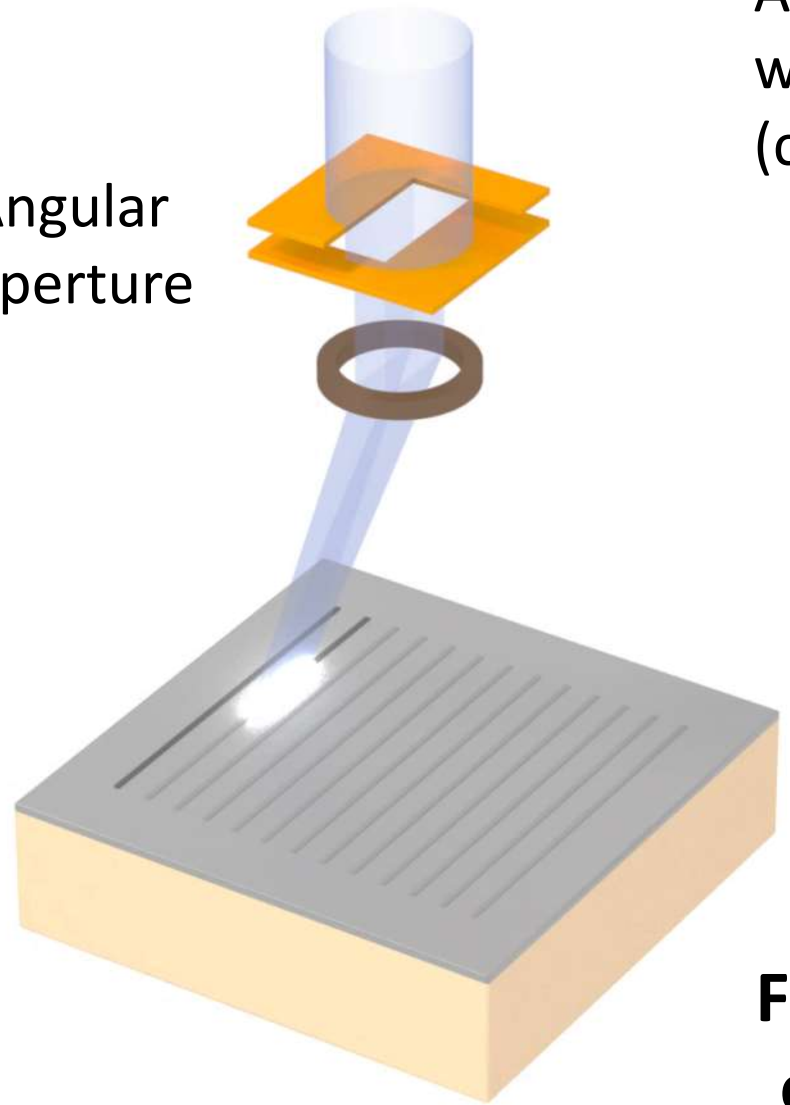
Write time issue of the electron beam lithography

Gaussian beam (GB)	Variable shaped beam (VSB)	Variable shaped beam with Character-Projection (CP)

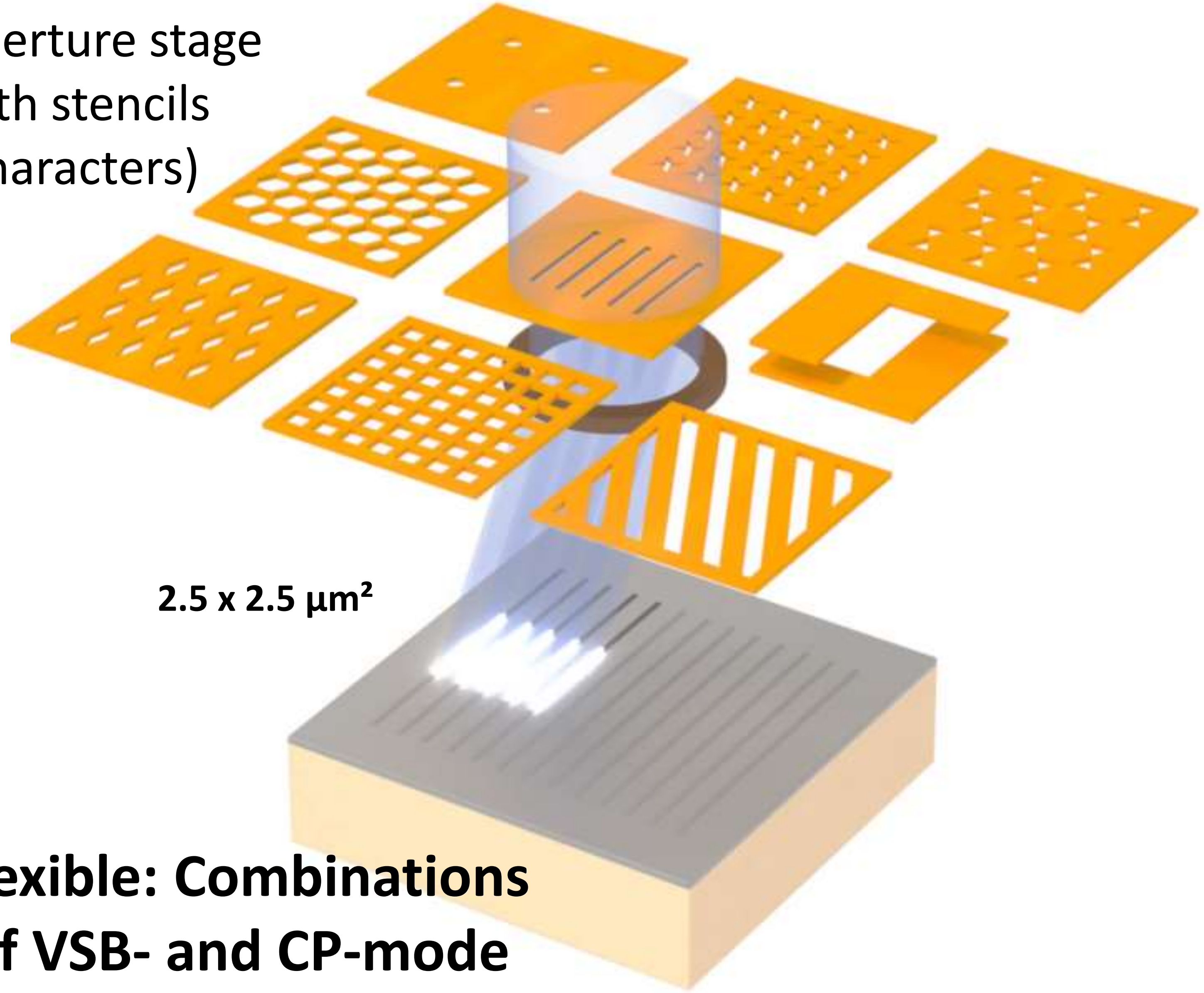
Aperture



Angular aperture



Aperture stage with stencils (characters)



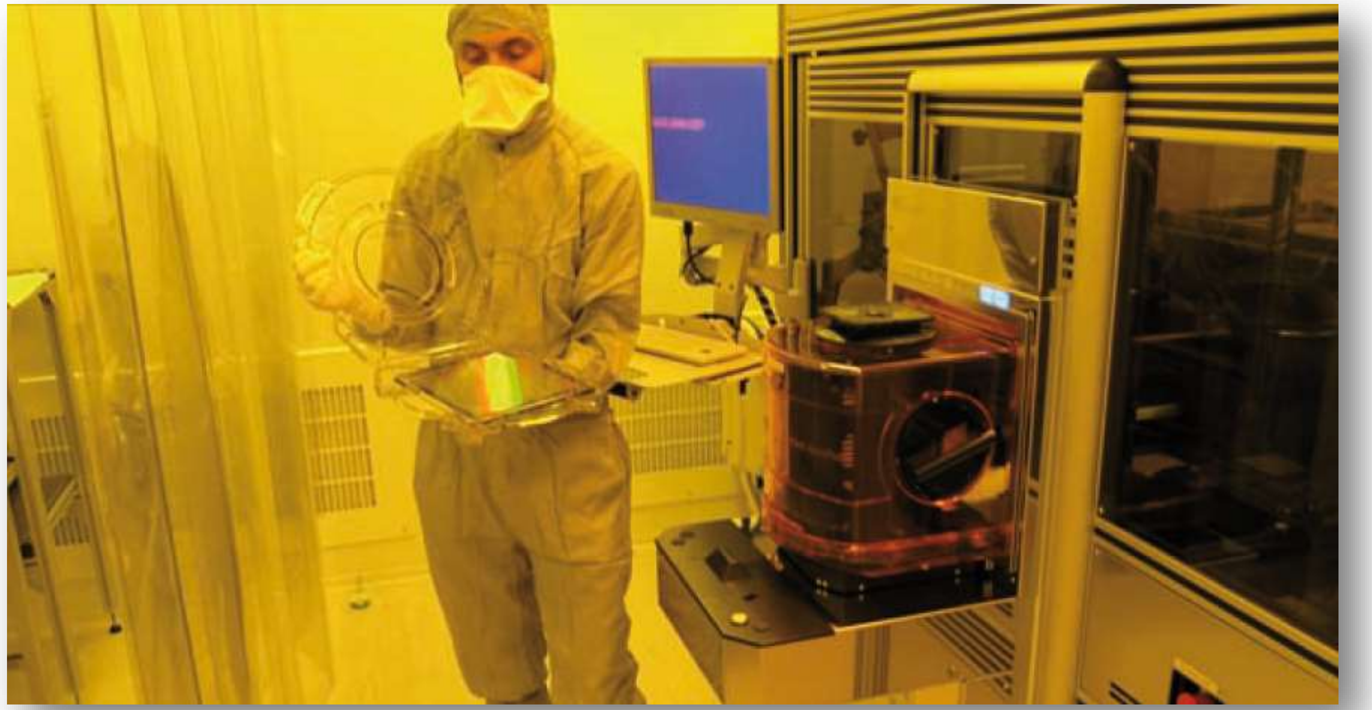
Flexible: Combinations of VSB- and CP-mode

Serial	Write mode	Serial	Quasi-parallel
Slow	Write speed	**Fast**	**Very fast**
100.000	Time factor	**100**	**1**

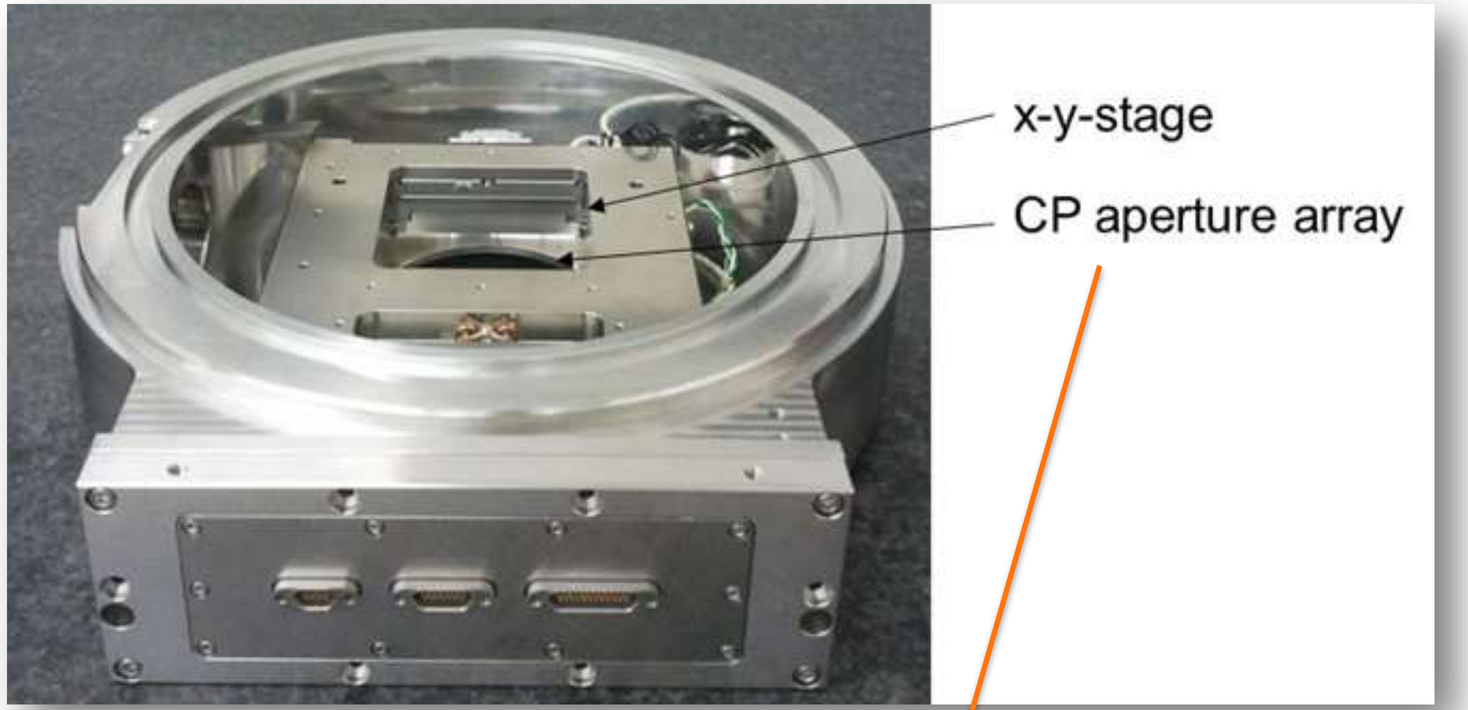
E-beam lithography with Character Projection as enabler:

Nanodevices on wafer level

E-beam lithography: SB350OS with Character Projection (CP)



Courtesy of IOF Jena

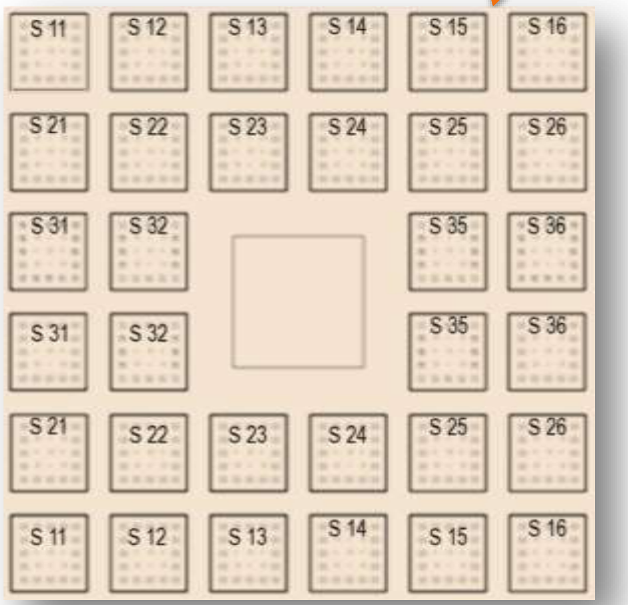


Character aperture stage

Vistec* **SB350 OS**

- **Principle:** Variable shaped beam,
- **Beam energy:** 50 keV,
- **Resolution:** 65 nm node,
- **Wafer size:** up to 300 mm

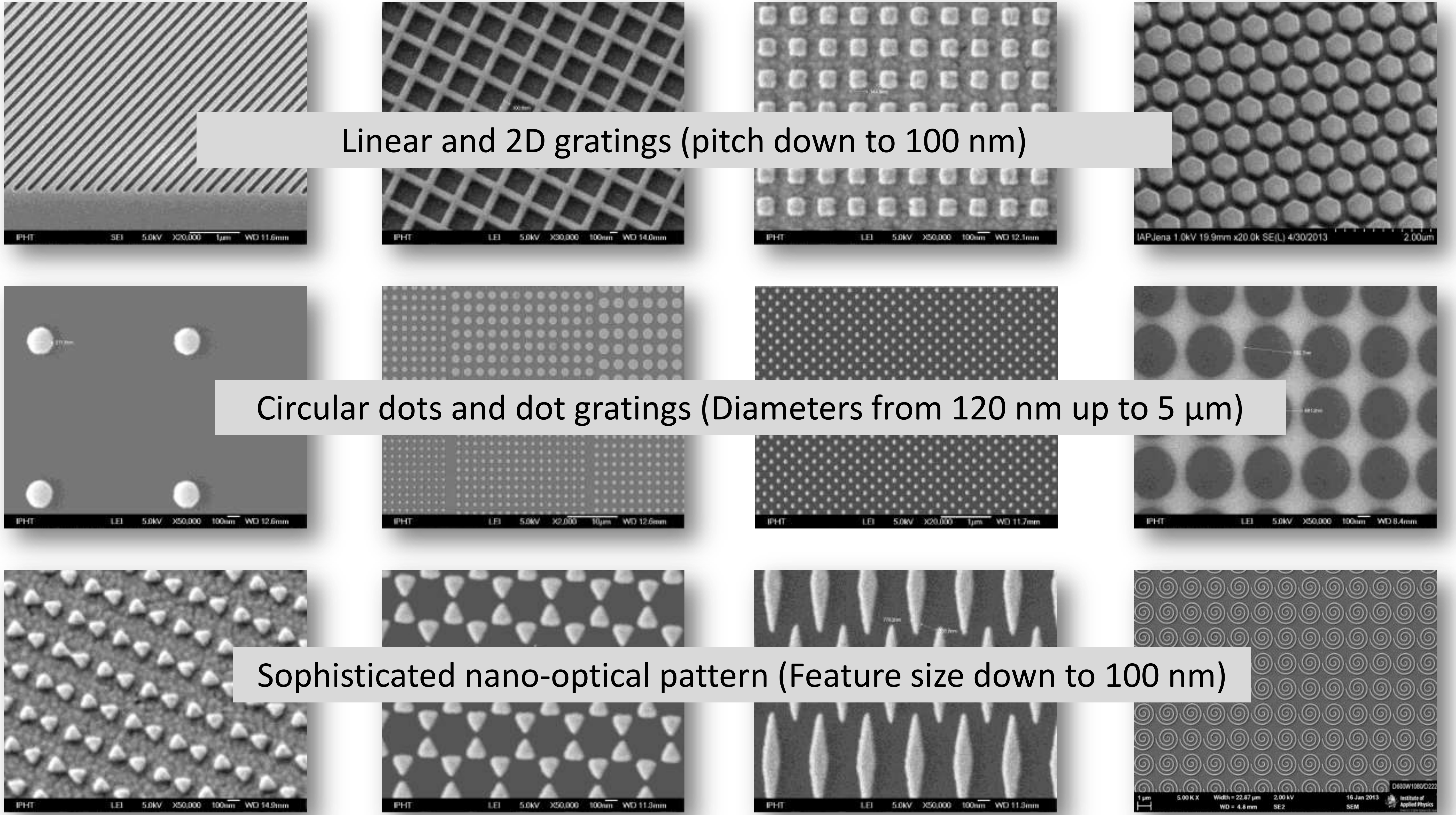
- **Location**: Cleanroom IOF Jena, sharing IAP, IOF and IPHT



Multi-stencil wafer with characters

* Vistec Electron Beam GmbH Jena

SB350 OS with CP: > 500 types of characters



A selection out of the > 500 types of characters
(the pictures show realized structures)

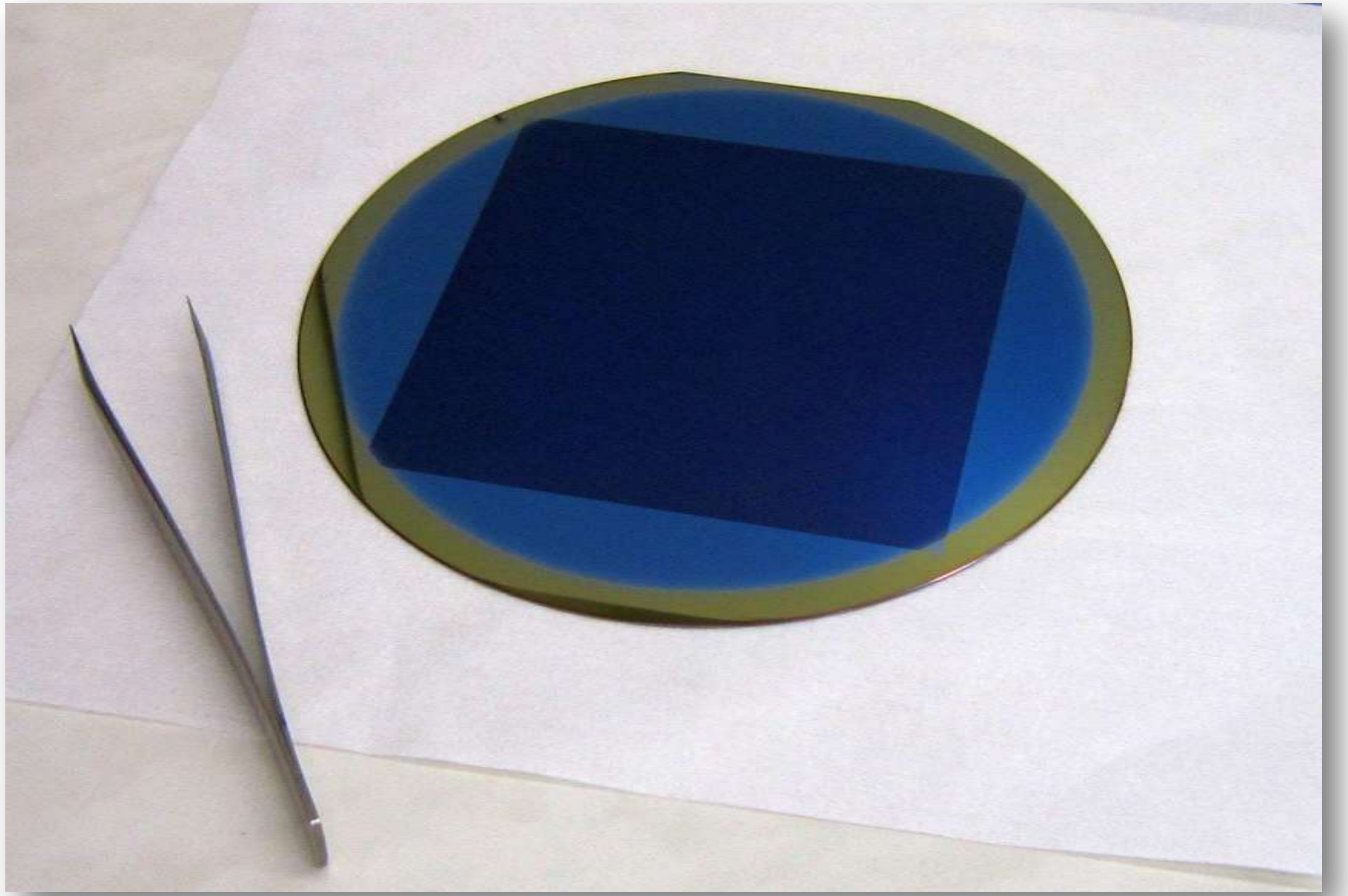
U. Hübner et al., Proc. SPIE 9231, 30th EMLC, 92310E (2014)

E-beam lithography with Character Projection as enabler:

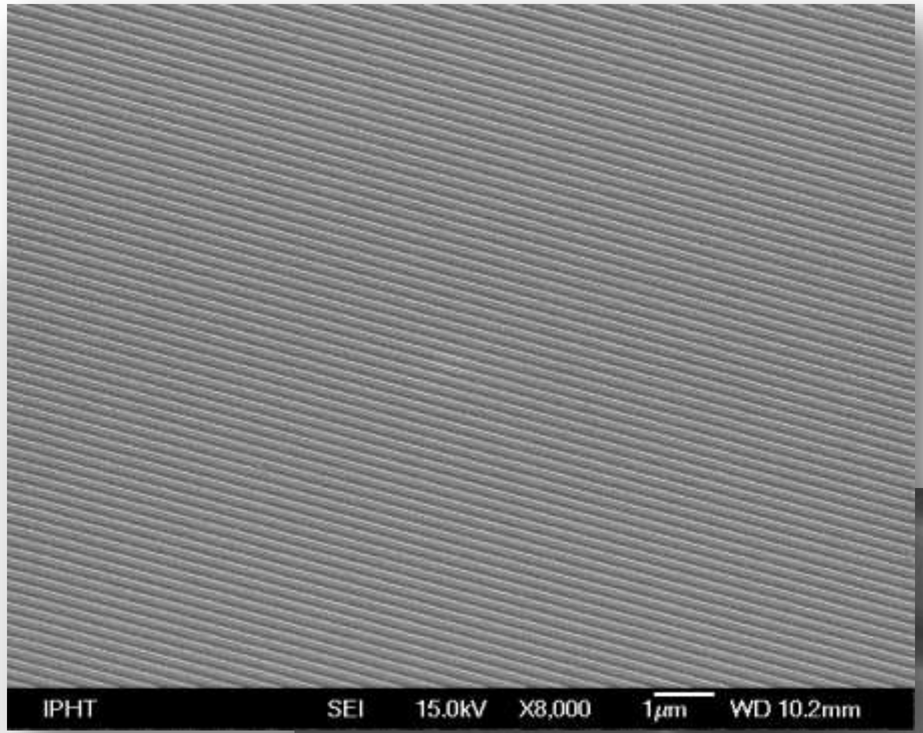
Write time benefit

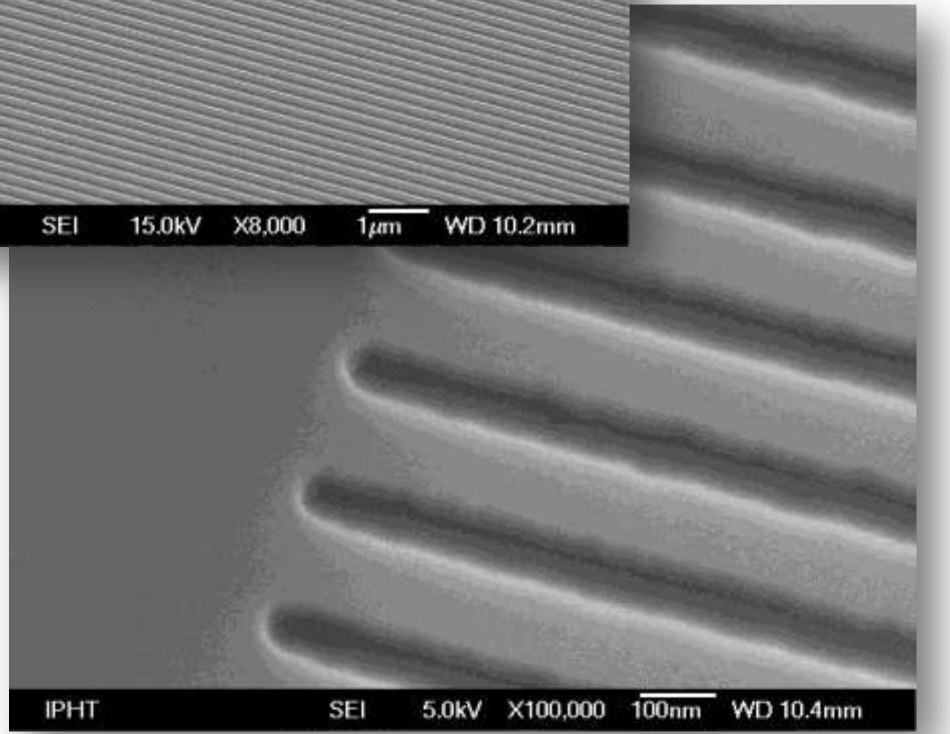
SB350 OS with CP: Write time benefit

- 6” NIL-master: 10 x 10 cm² 1d-grating



150 mm Si Wafer with 10 x 10 cm² grating area (pitch 200 nm)





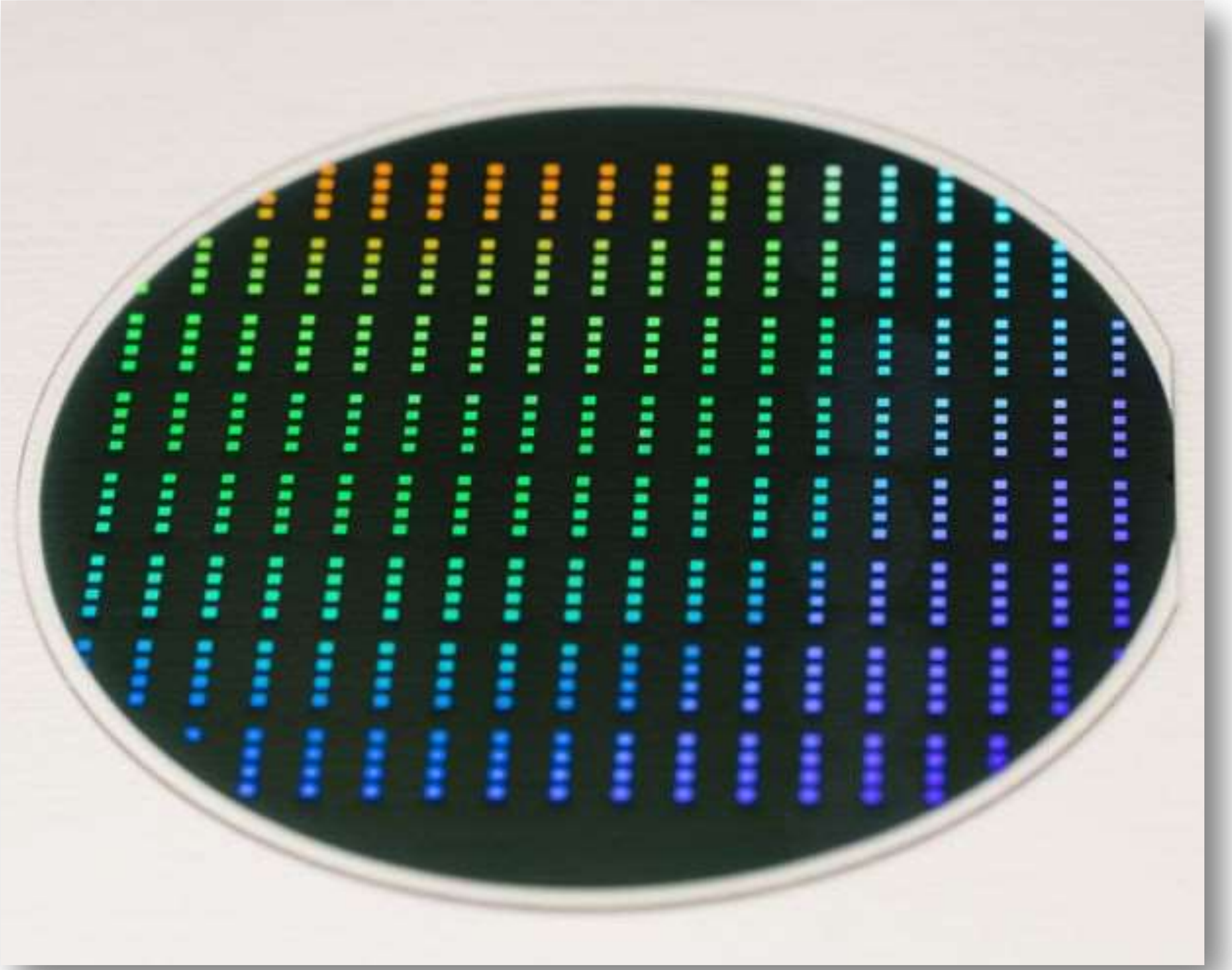
Writing time

Gaußbeam-tool:	10 month*
SB350 in VSB-mode:	2 weeks
SB350 in CP-mode:	**12 h**

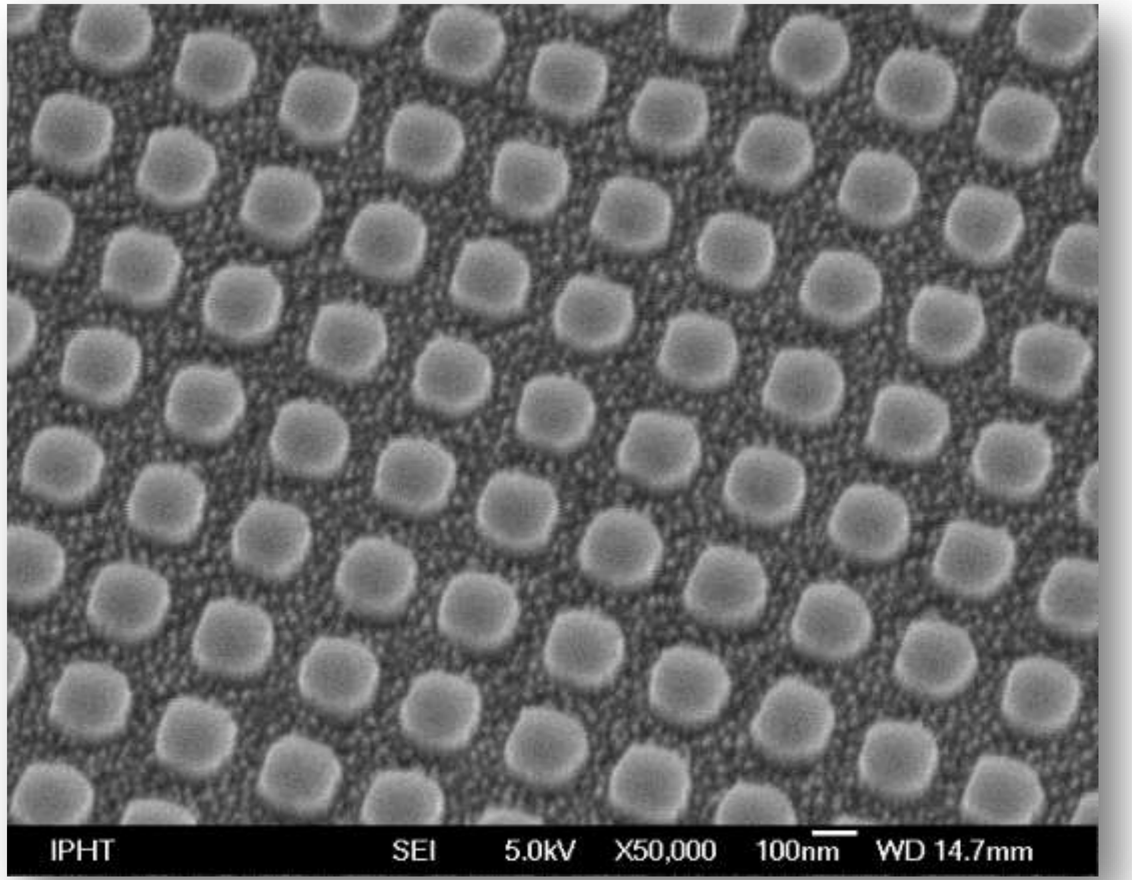
*estimated for a SEM with write unit, beam current 100pA, step size 10 nm, dose 400 µC/cm²

SB350 OS with CP: Write time benefit

- **2d-Quartz-gratings as template for SERS-substrates**



4“ Quartz-wafer with ~ 550 mm² nanogratings for SERS (2D-gratings, Pitch: 250 nm)



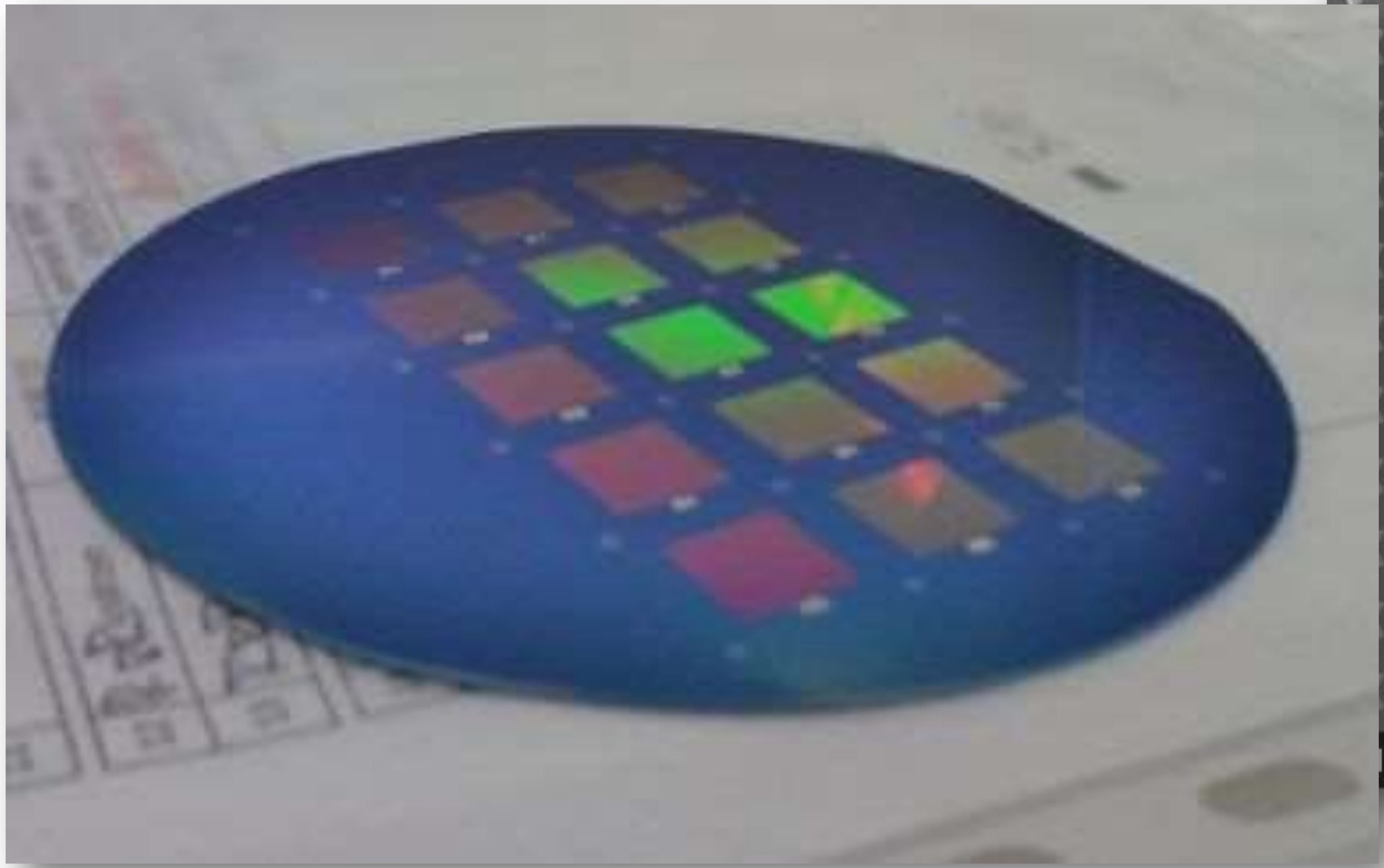
Writing time

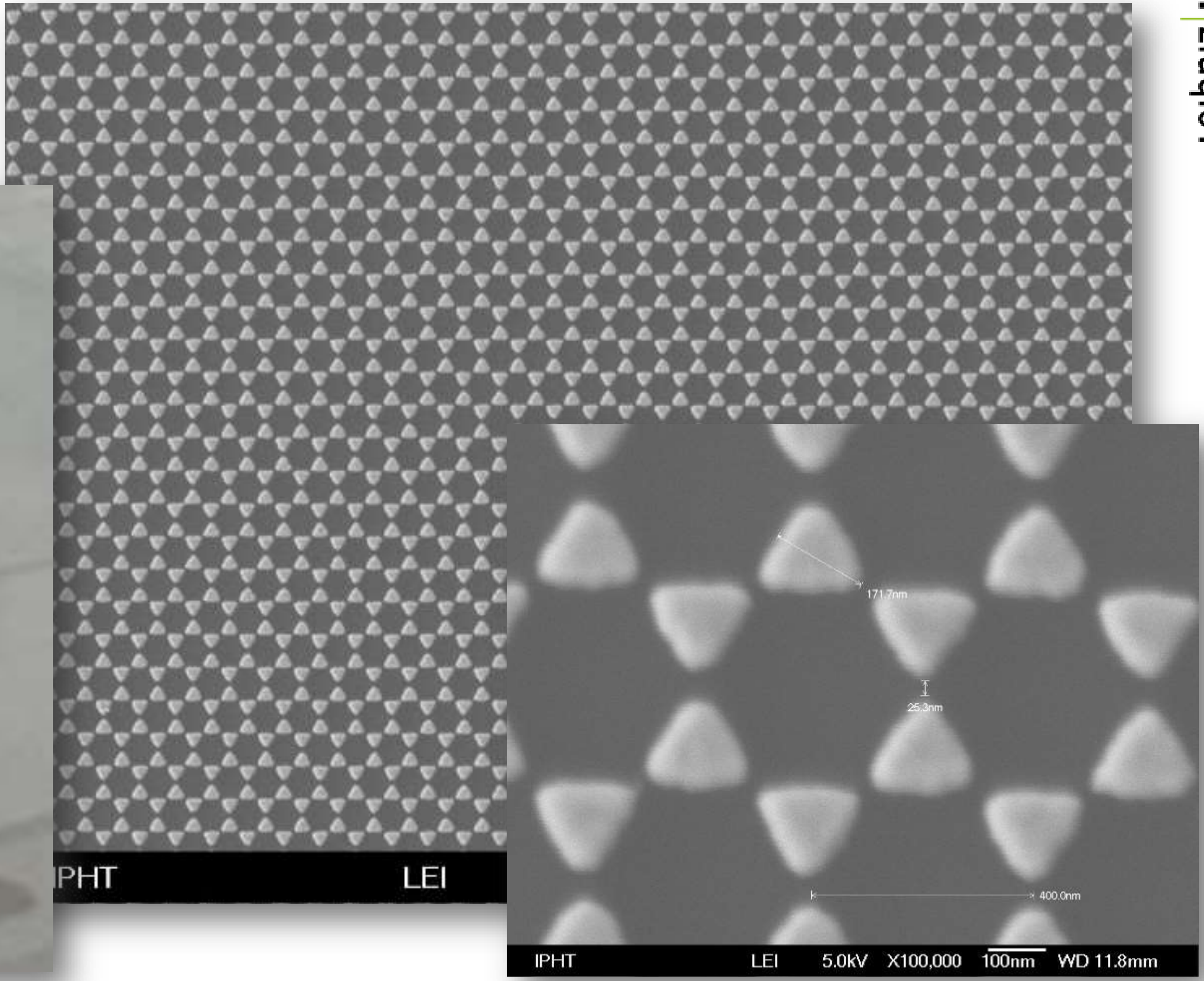
Gaußbeam-tool:	86 days*
SB350 in VSB-mode:	60 h
SB350 in CP-mode:	**3 h**

*estimated for a SEM with write unit, beam current 100pA, step size 10 nm, dose 400 µC/cm²

SB350 OS with CP: Write time benefit

- **Gold-bowtie-gratings as template for SERS**





4“ (100 mm) Si wafer with 15 hexagonal Bowtie-gratings
(each 1 x 1 cm², pitch 400 nm, lift-off-process, Gold on Si)

Writing time

Total grating area:	15 cm²
VSB-mode:	17 days
CP-mode:	**3,3 h** → 4,5 cm²/h

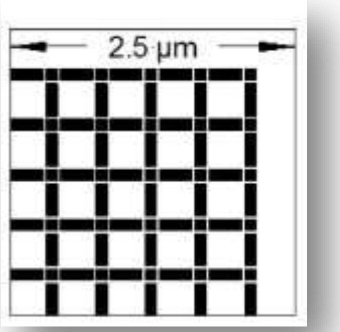
E-beam lithography with Character Projection as enabler:

High quality – line with control and proximity correction

SB350 OS with CP: Line-width-control and proximity-correction

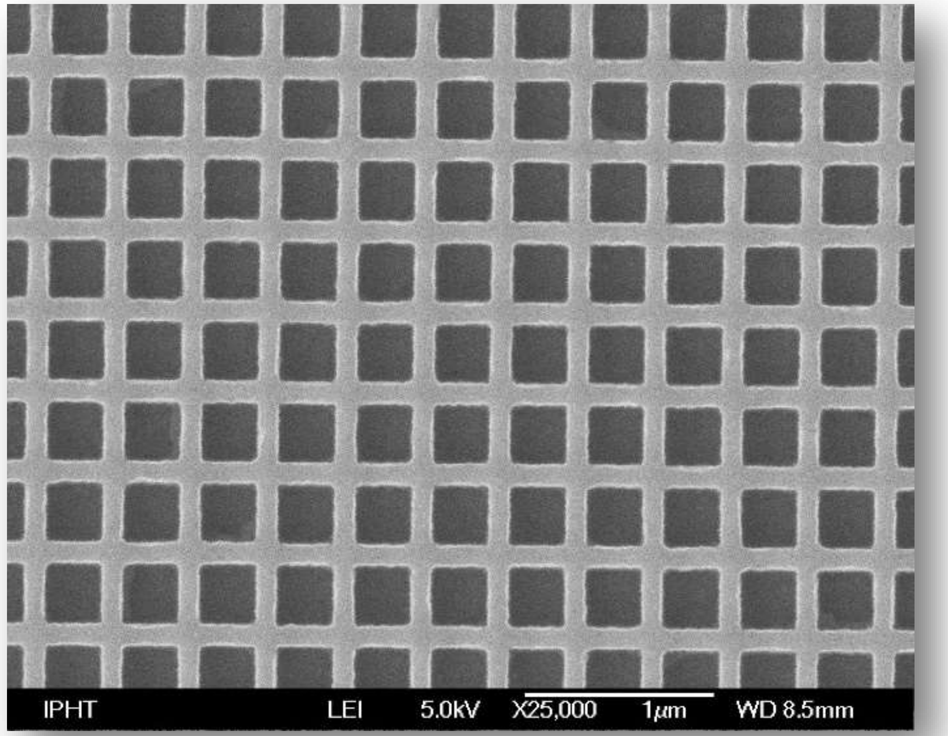
- **Electron dose based line-width control**

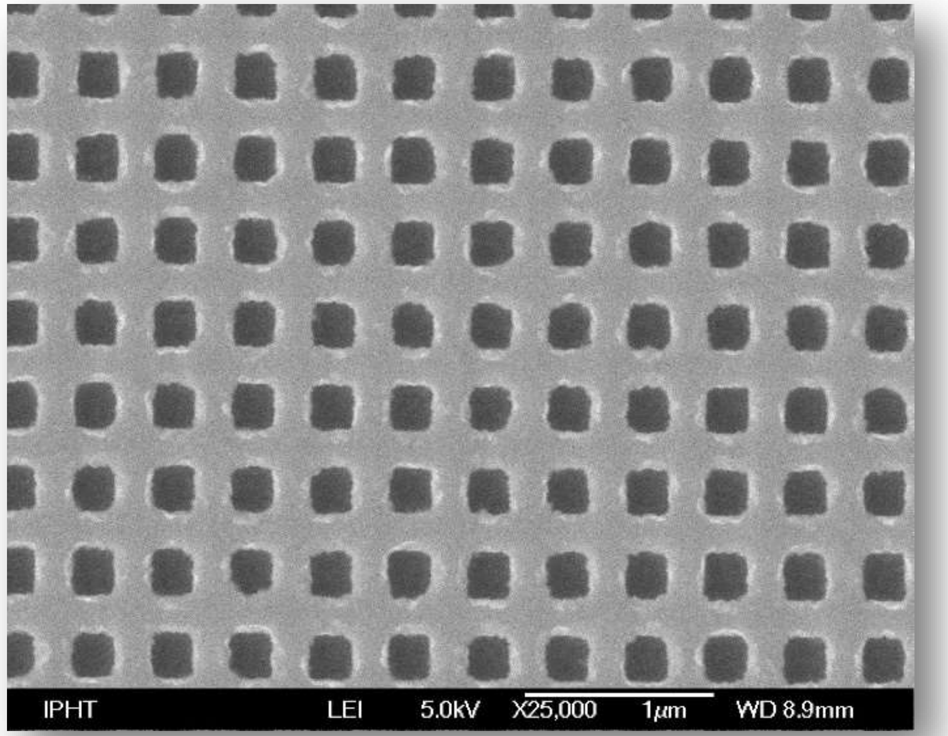
One character



Lower dose

Higher dose





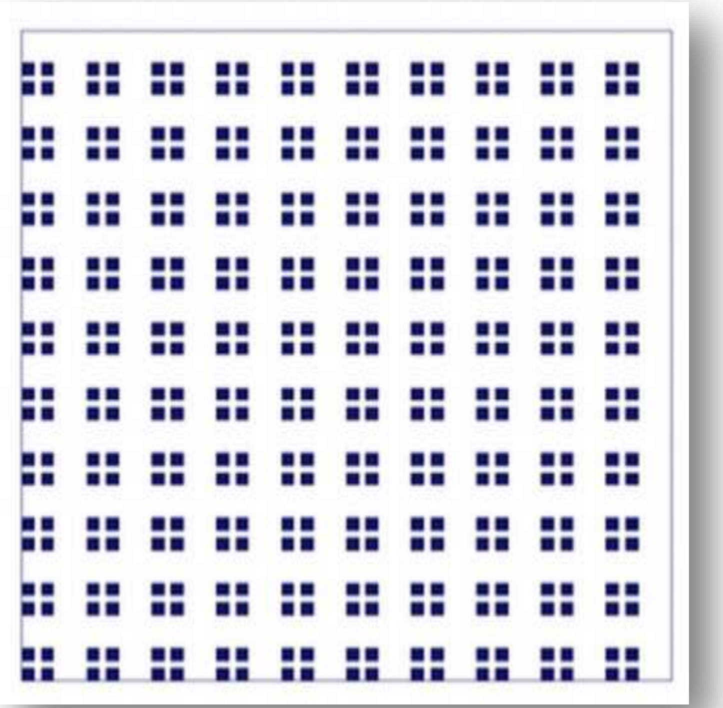
The SEM-pictures show the line-width control by changing the exposure dose (negative resist).

SB350 OS with CP: Line-width-control and proximity-correction

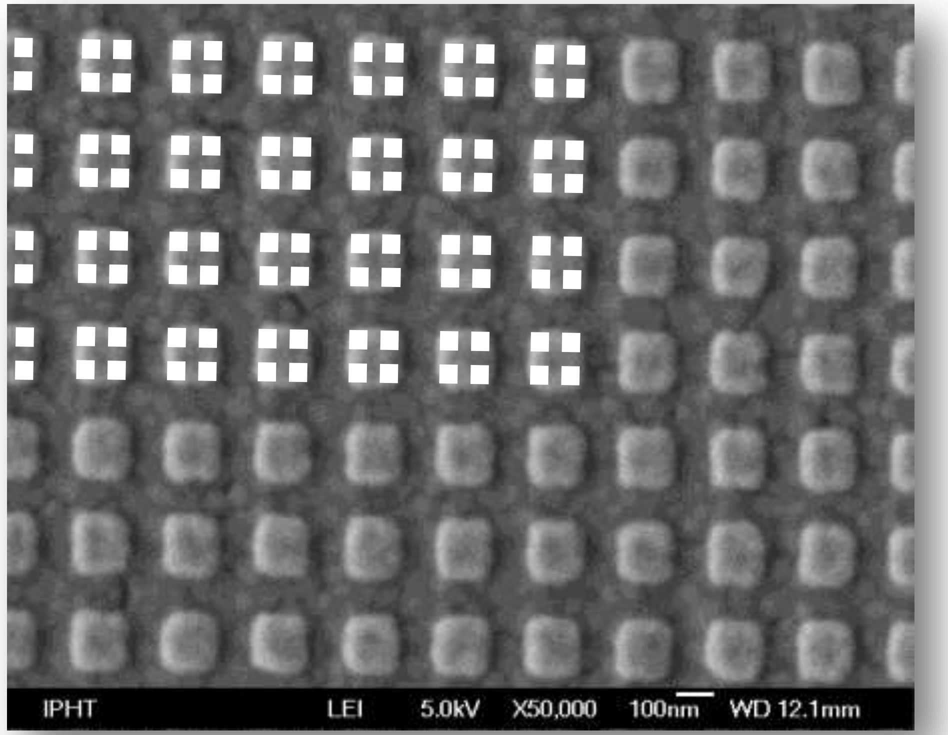
All patterns which are included in the hard coded character will get the **same electron dose**.

- **Short range dose correction**

→ **Geometrical pre-corrected character layouts**



Character layout

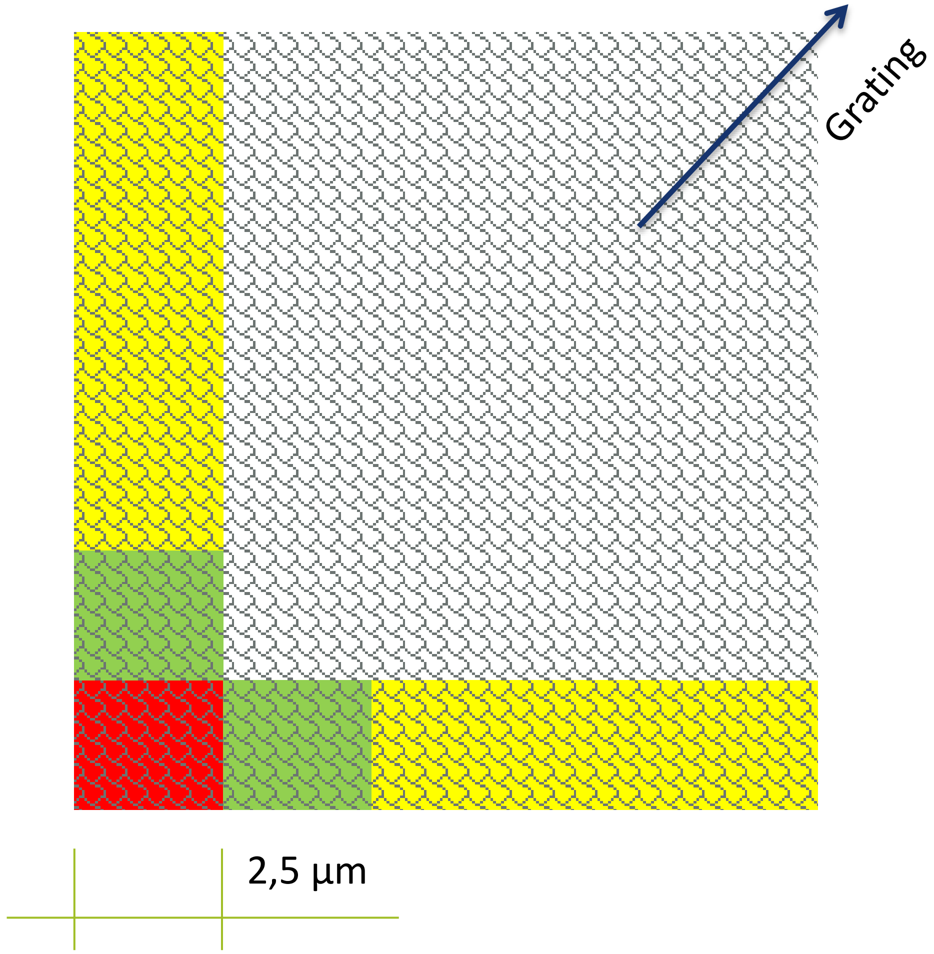


Lifted gold dots

SB350 OS with CP: Line-width-control and proximity-correction

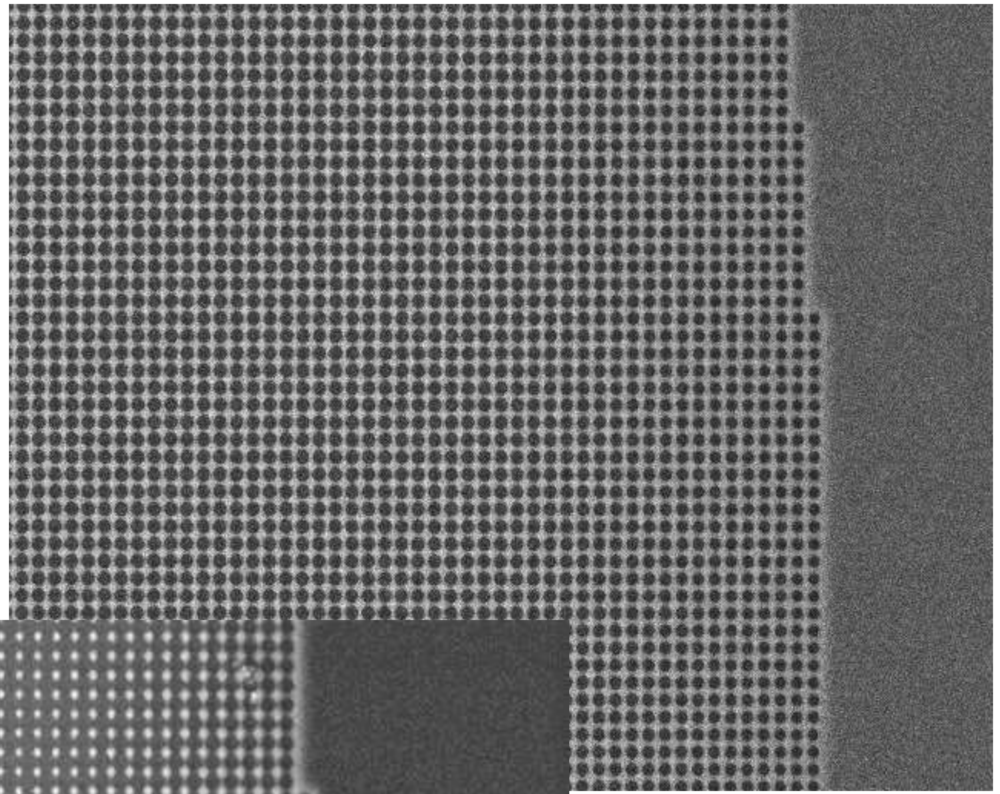
All patterns which are included in the hard coded character will get the **same electron dose**.

- **Long range dose correction**

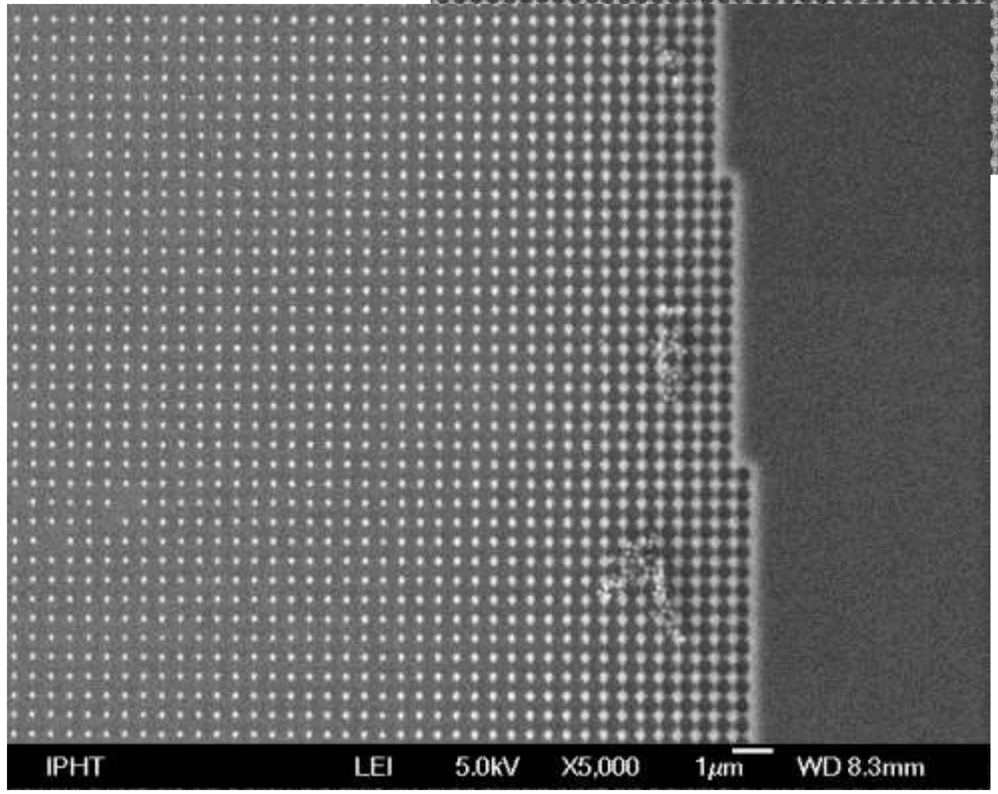


Schematic dose distribution on a grating edge
(Colors = different dose-values)

Proximity-corrected exposure



Non-corrected



E-beam lithography with Character Projection as enabler:

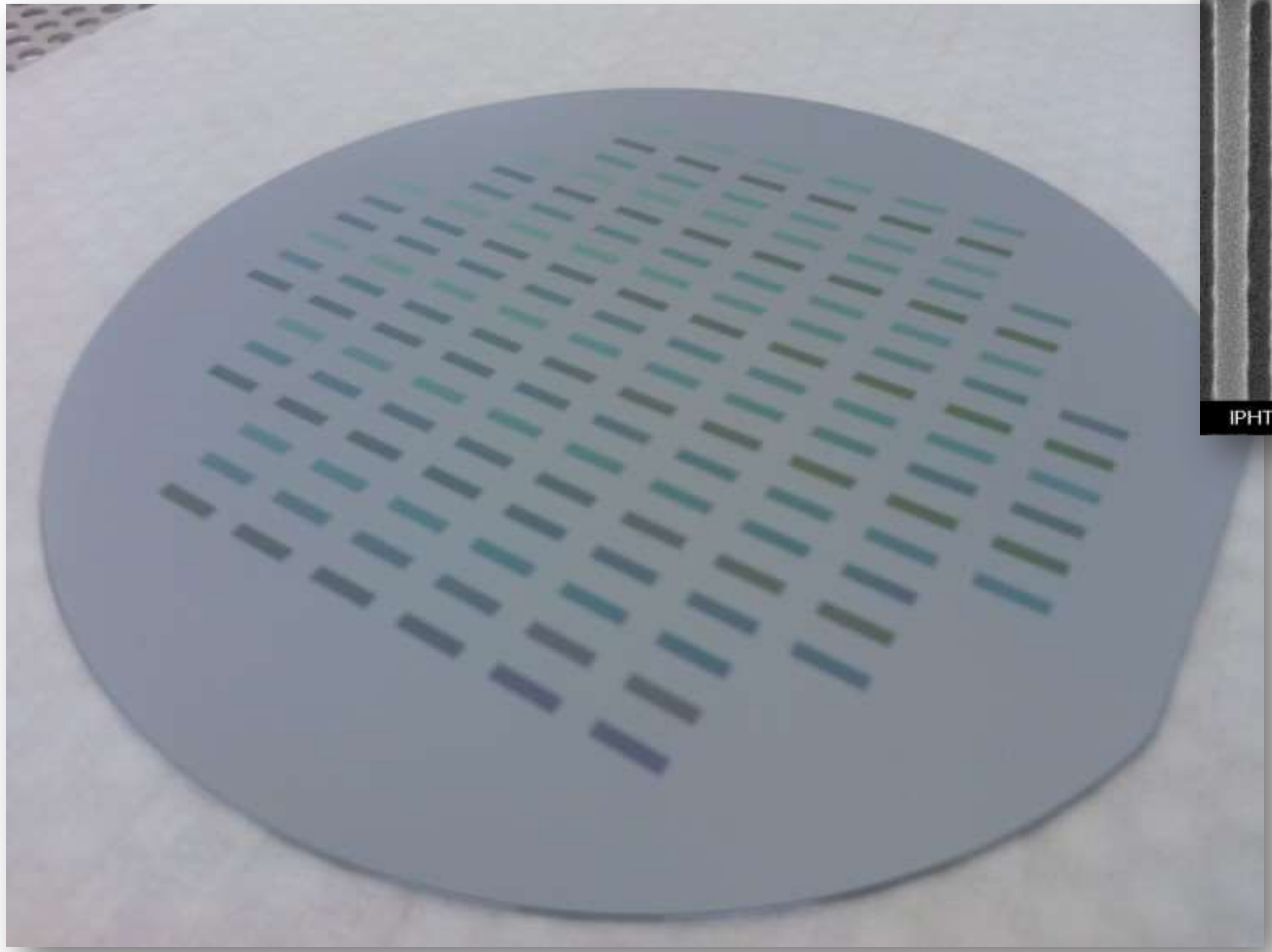
High flexibility:

Combination of VSB- and CP-mode

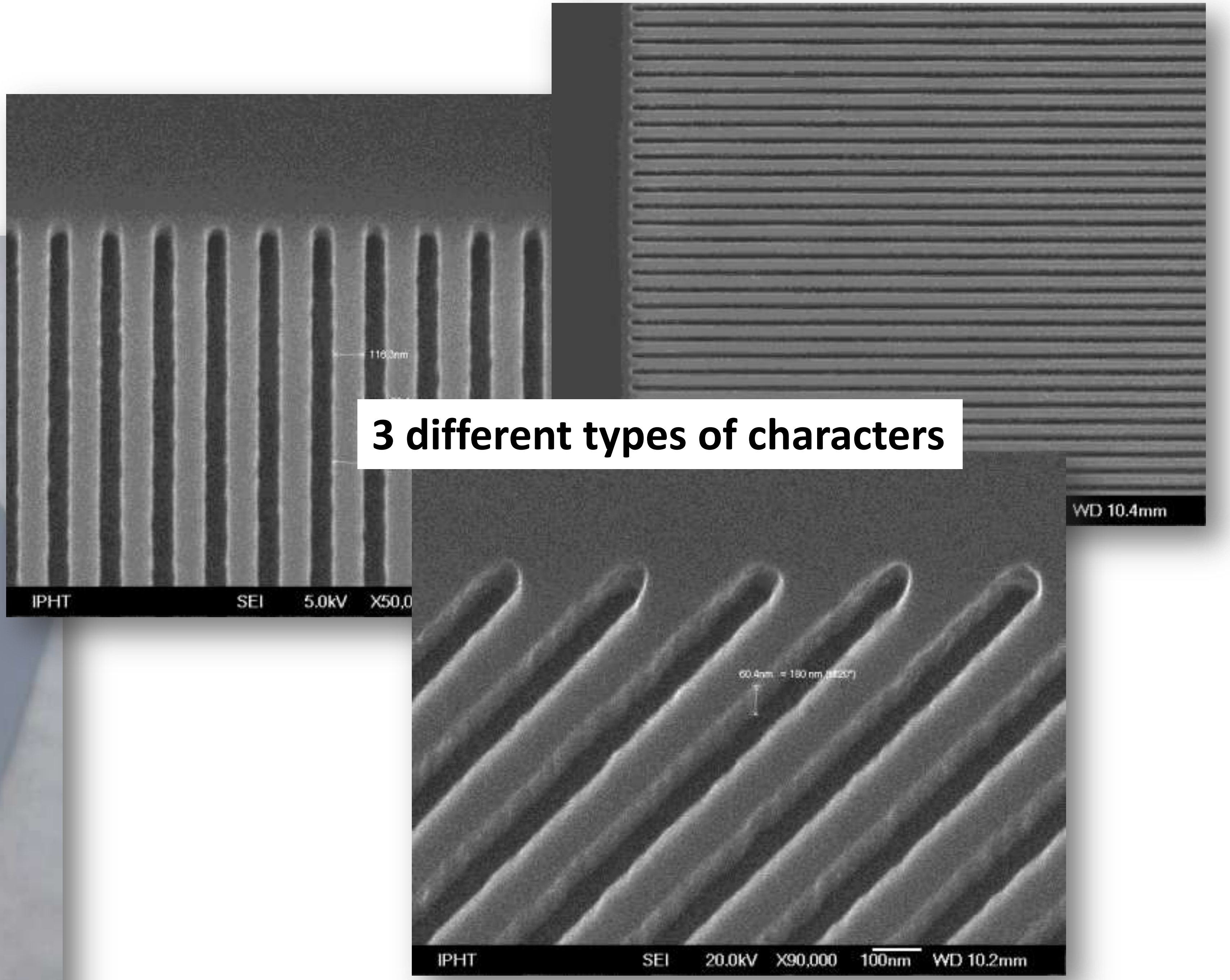
Mix of different technologies

SB350 OS with CP: Flexibility

- **NIL-master: 6” wafer scale 1d-grating**



150 mm Si Wafer with 23 cm² grating area (pitch 200 nm)



Writing time

SB350 in VSB-mode:	20 days *
SB350 in CP-mode:	**5 h**

*calculated

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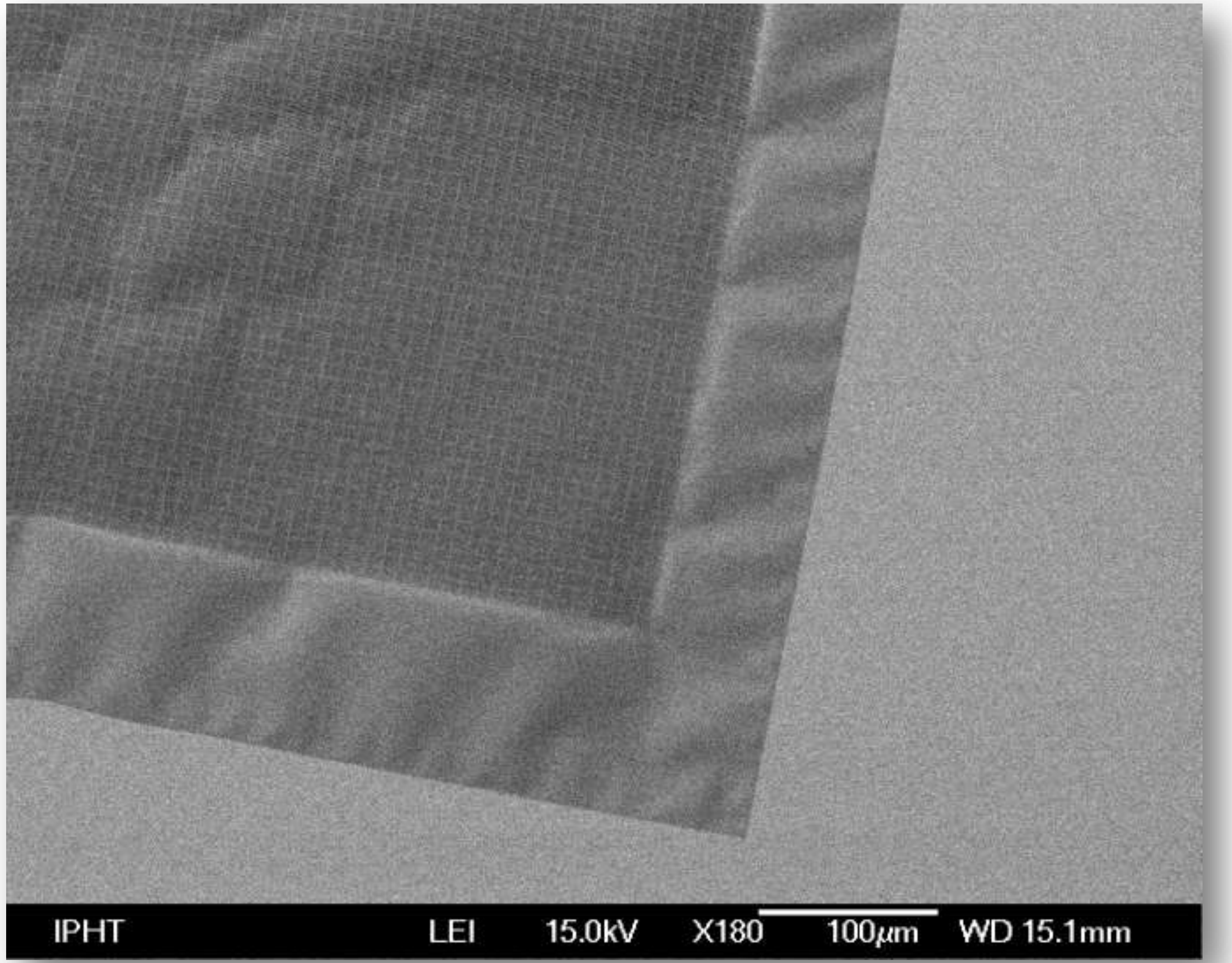
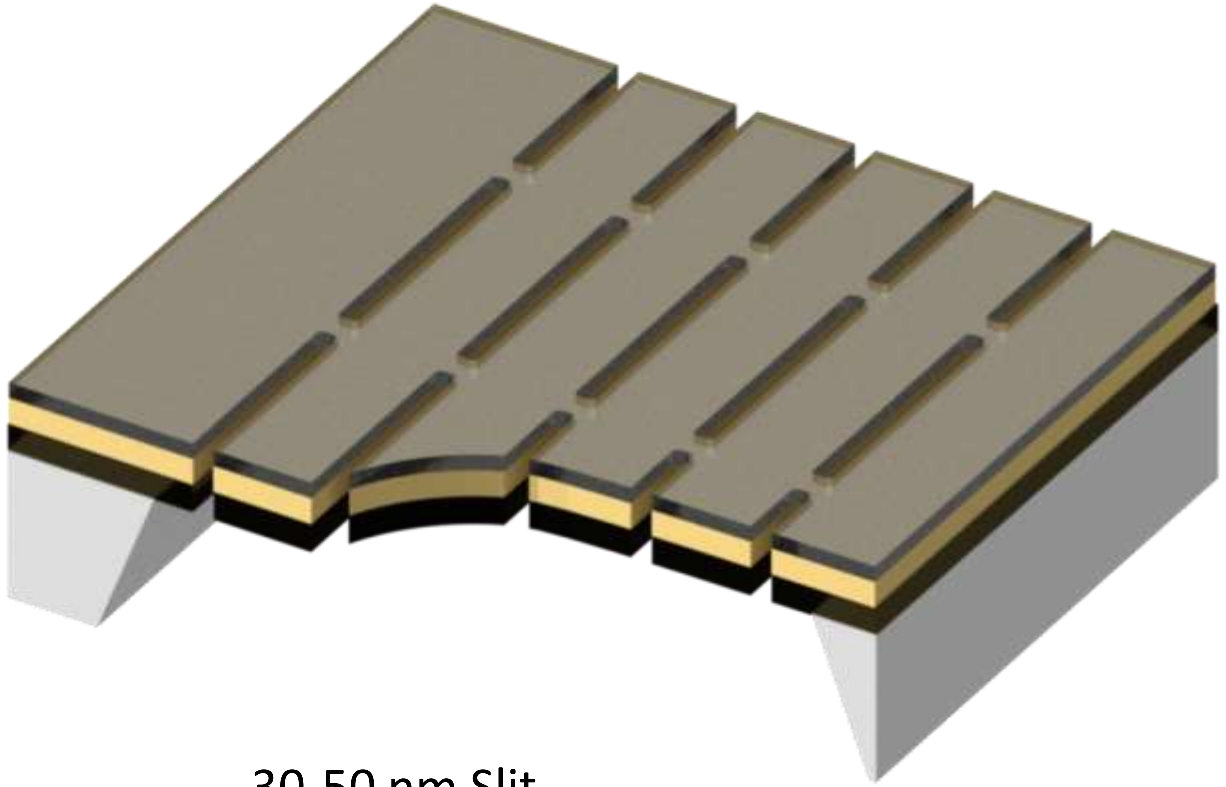
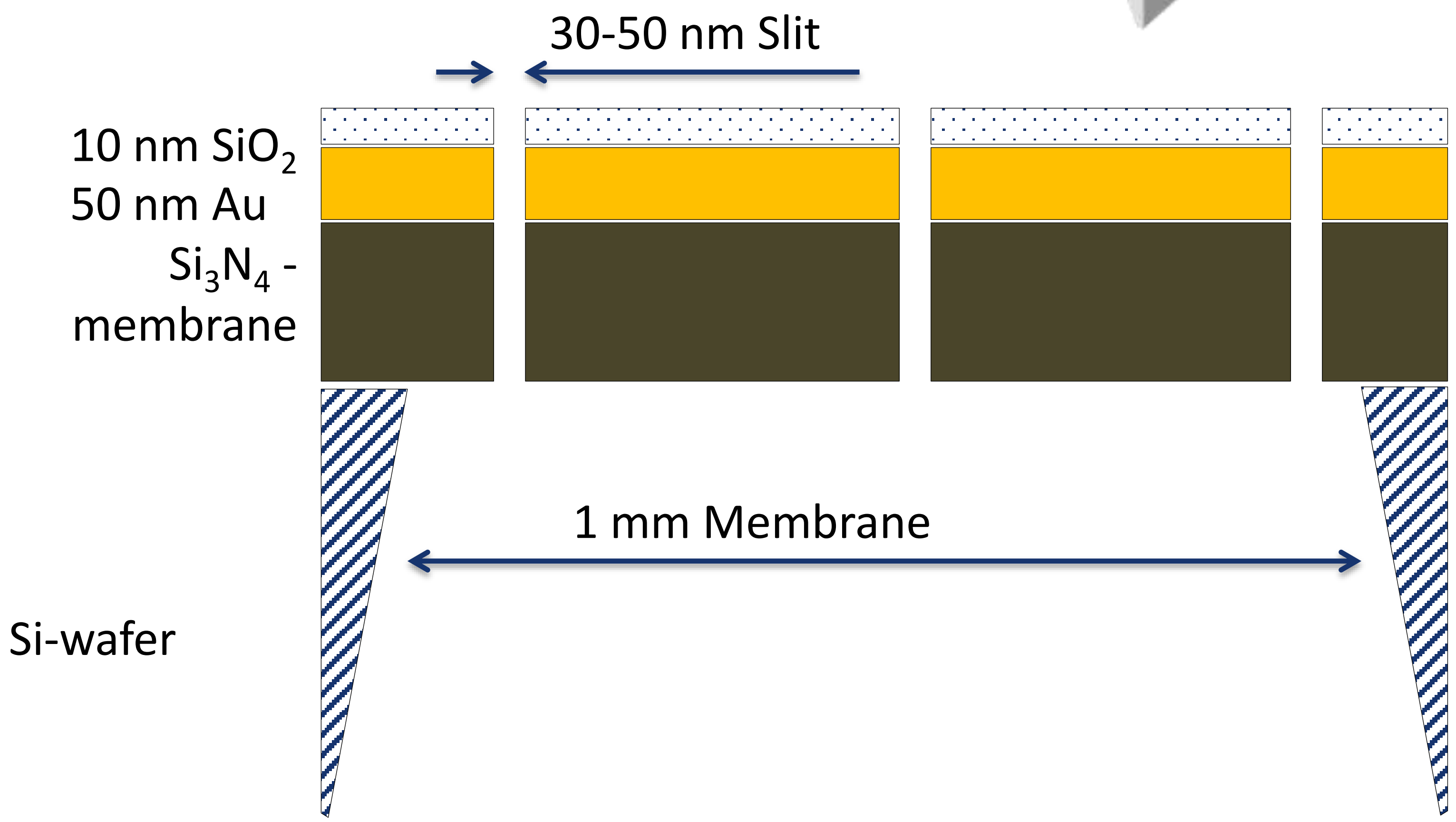
SB350 OS with CP: Combination with MEMS-technology

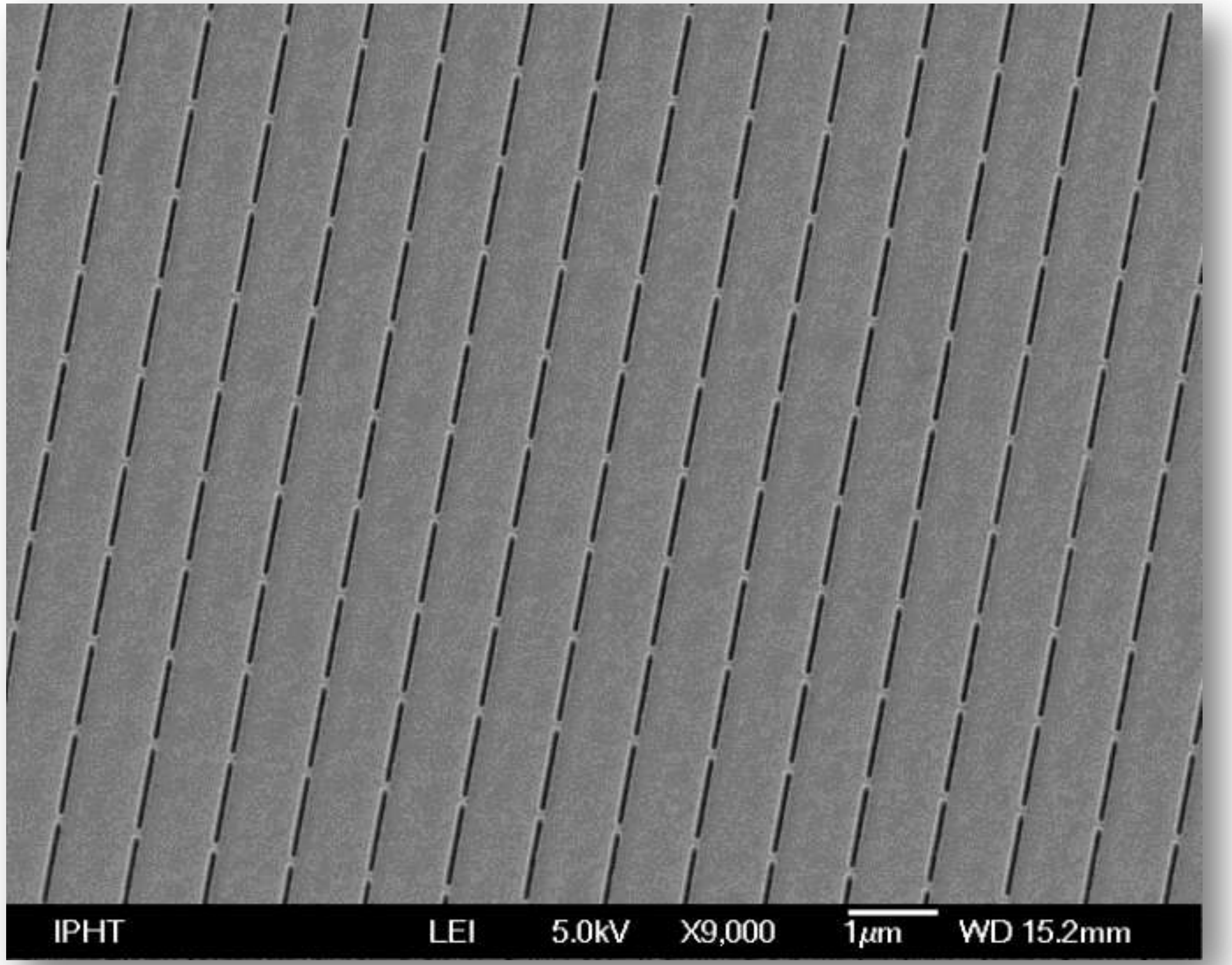


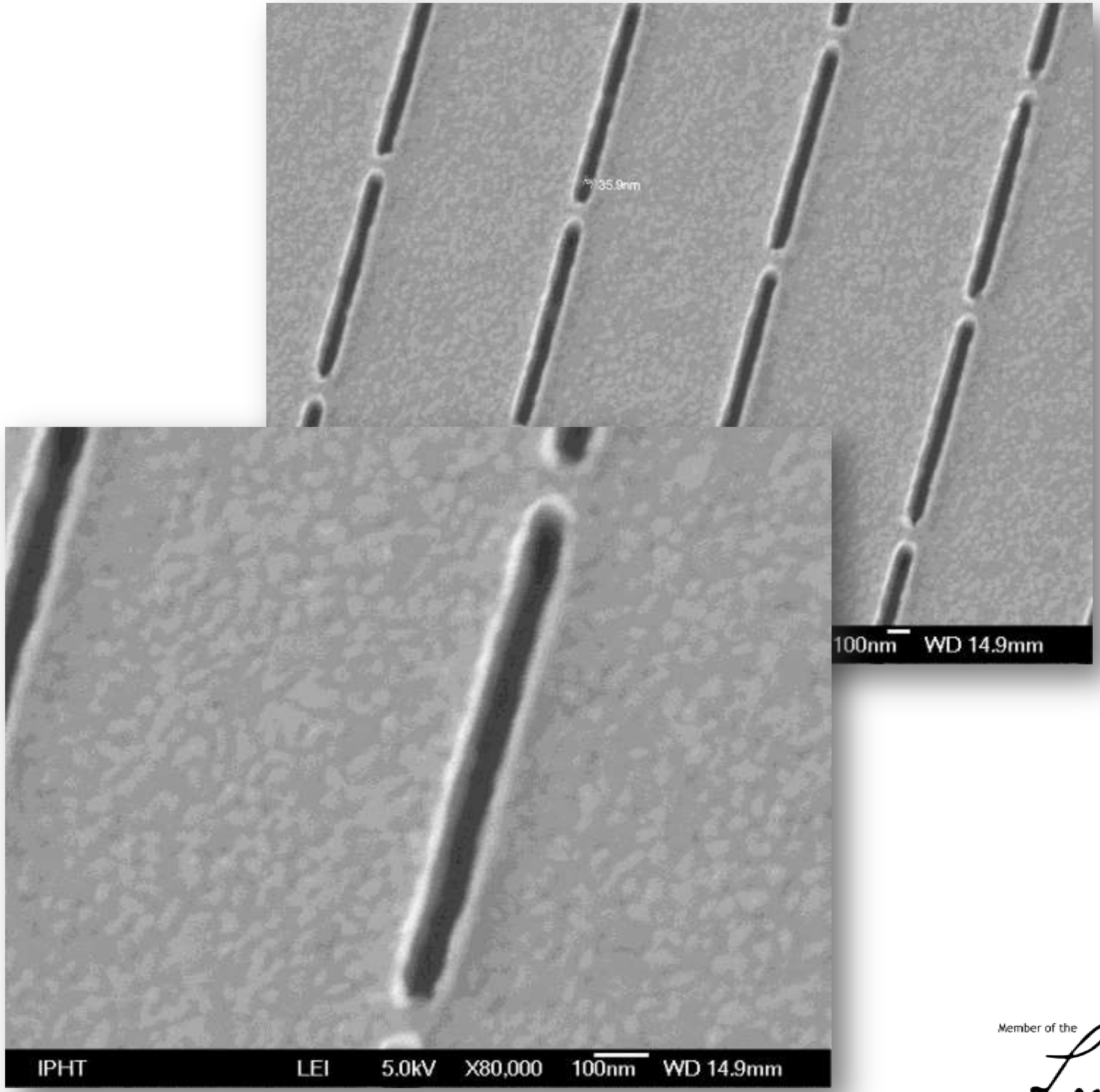




Nano-perforated, **40 nm** thick SiN membrane

SB350 OS with CP: Combination with MEMS-technology





SEM-pictures of the nano-perforated SEIRA-substrates (tilt 25°)

Summary

- **CP + VSB e-beam technology**
  → Strong reduction of writing time
  → Top-down **nanofabrication on wafer level**

- **Combination** of waferscale nanopatterning with MEMS methods
  →Great potential by mixing different technologies

- **Open for cooperation**

Acknowledgement

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Vistec: M. Banasch

Illustrations: Burkhard

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