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OPTIMAL workshop

OPTIMAL "all-in-one" laser lithography platform

PRESENTED BY MARKUS POSTL, JOANNEUM RESEARCH

DATE: 20TH NOVEMBER 2025 – WEIZ (AUSTRIA)

Joanneum Research - MATERIALS

Institute for Sensors, Photonics and Manufacturing Technologies

Director:
- Paul Hartmann

5 Research Groups
~ 90 Employees

3 Laboratories in Austria
- Weiz
- Niklasdorf
- Pinkafeld









Research Groups

Hybrid Electronics and Patterning
Barbara Stadlober

Light and Optical Technologies
Christian Sommer

Laser and Plasma Processing
Wolfgang Waldhauser

Sensors and Functional Printing
Jan Hesse

Smart Connected Lighting
Andreas Weiss

OPTIMAL project - overview

Start date: 01/10/2022
End date: 30/09/2026

Project team:

JOANNEUM RESEARCH MATERIALS
JOANNEUM RESEARCH LIFE
UNIVERSITÀ DI PARMA
SLOVAK CENTRE OF SCIENTIFIC AND TECHNICAL INFORMATION
UNIVERSITY OF ŽILINA
micro resist technology
DeltaPix - Discover the Details
Sony DADC
hypervision
BASF We create chemistry

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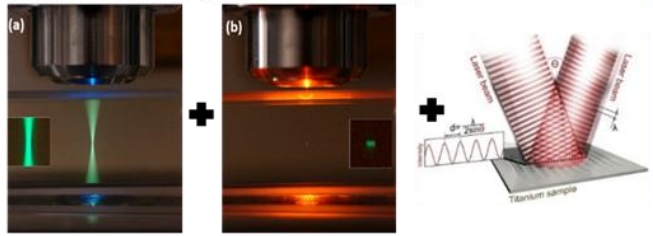
Laser lithography modules & processes

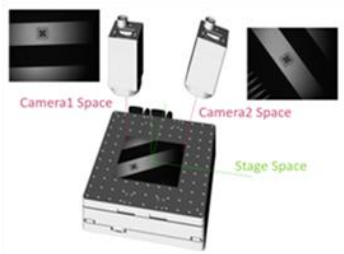
1Photon (1PL) Parallel patterning
2Photon (2PL) Serial patterning
Laser interference lithography (LIL)



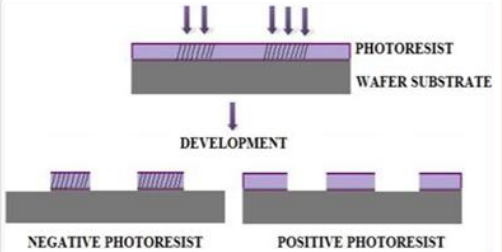
Inverse 3D printing of deep structures

All-in-one platform: *Area 2000 cm², Depth ≥ 150 µm, Speed 1 cm²/min, Critical dimension < 150 nm, Dimension 2.5D and 3D, hierarchical structures,* ***no post-processing****,* ***1st time right****, faster process.*

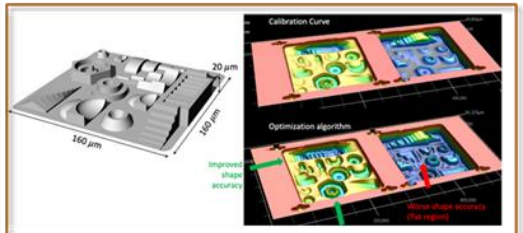
Quality monitoring



Photoresist materials



Virtual photomask



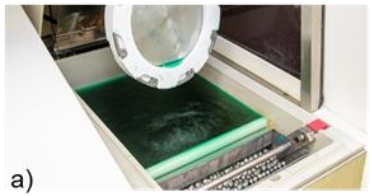
Sustainability assessment

- Required process iterations from 5 to 2
- Higher writing speed
- Bigger substrate / active area
- Tailored resins

Waste & energy reduction

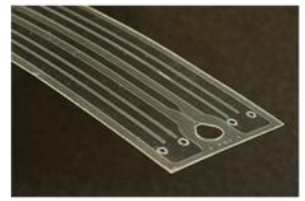
Applications

a) full-polymer micro lenses for industrial optics, b) hierarchical multifunctional drag reduction riblet structures for aviation, c) free-form lens arrays for high-end virtual reality displays and d) microfluidic hierarchical structures for lab on chip medical devices.


a)


b)


c)

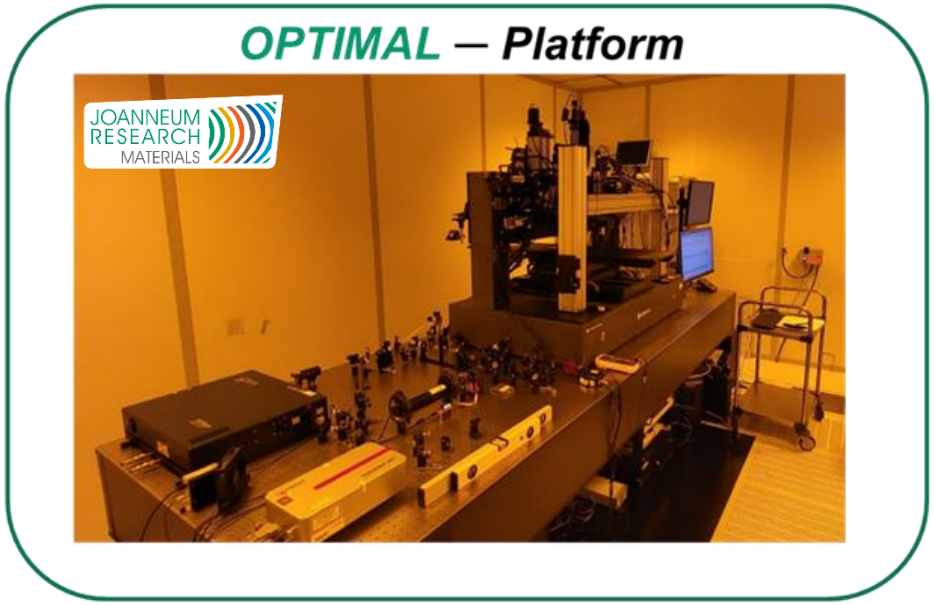

d)

Lab & stage system

At Joanneum Research – MATERIALS institute in Weiz (Austria) within a 40 m² yellow-light area that meets ISO 14644 **Class 6 cleanroom** standards and maintains a thermally stabilized environment using specifically arranged fan filter units.

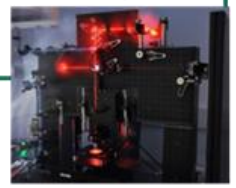
The vibration-isolated **optical table** is supplied by Newport, a custom-designed **high-precision XYZ positioning system**, and the Galvo scanner is manufactured by Aerotech.

The autonomous **software module**, which consists of a self-learning algorithm in conjunction with a dedicated database, as well as the main control software, is responsible for managing and coordinating the interaction of all the components.



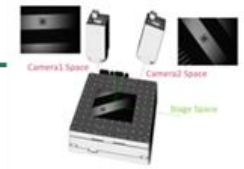
Writing modules

- One photon
- Two photon
- Laser interference lithography
- Parallel writing module via spatial-light modulator



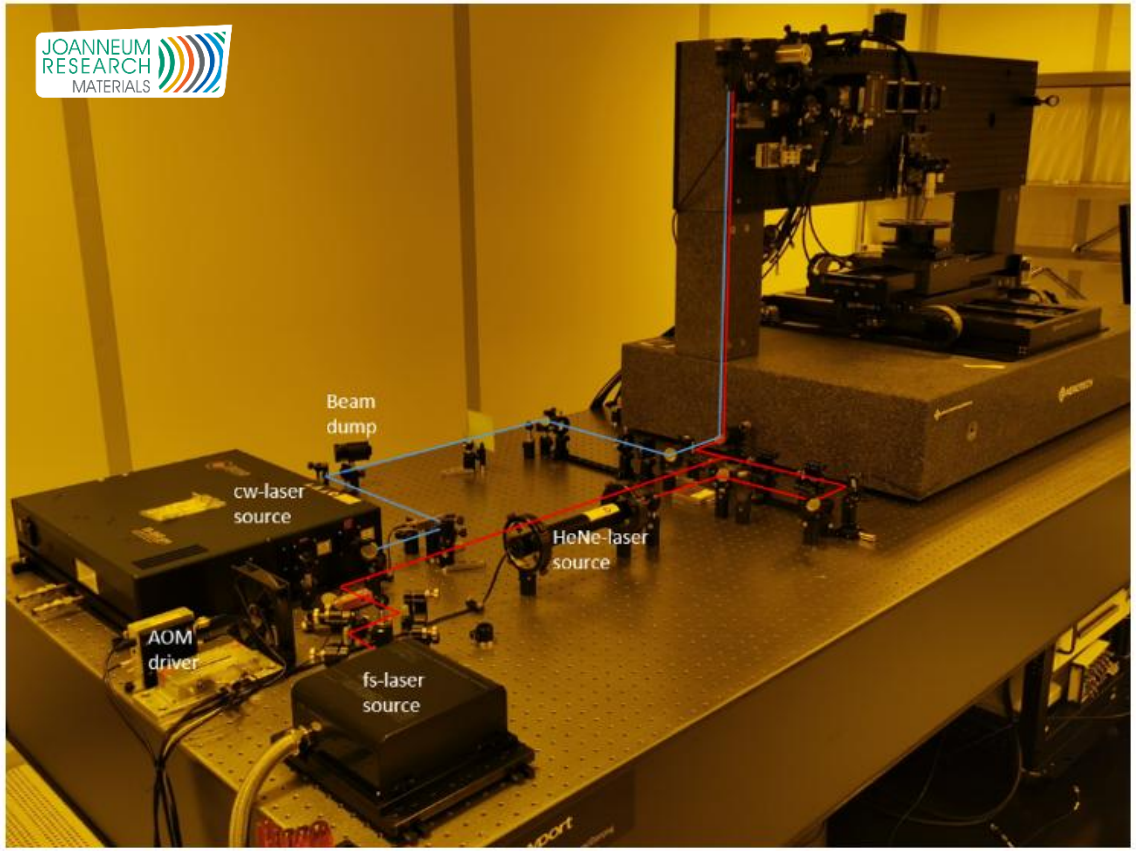
Vision system

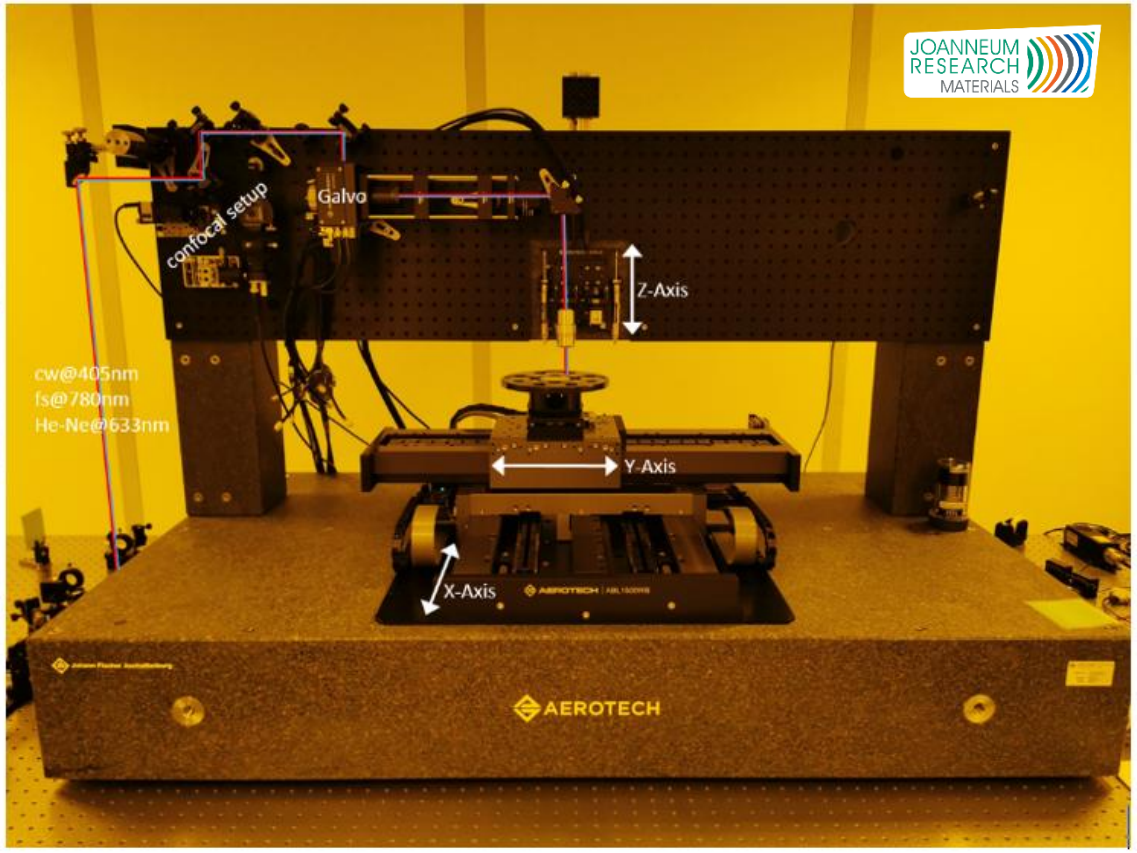
- Innovative dark-field and diffractive imaging
- Modules for fast focus determination and system calibration



Serial writing

The serial approach consists of one photon lithography (1PL) and two photon lithography (2PL), where the structure is written line by line.



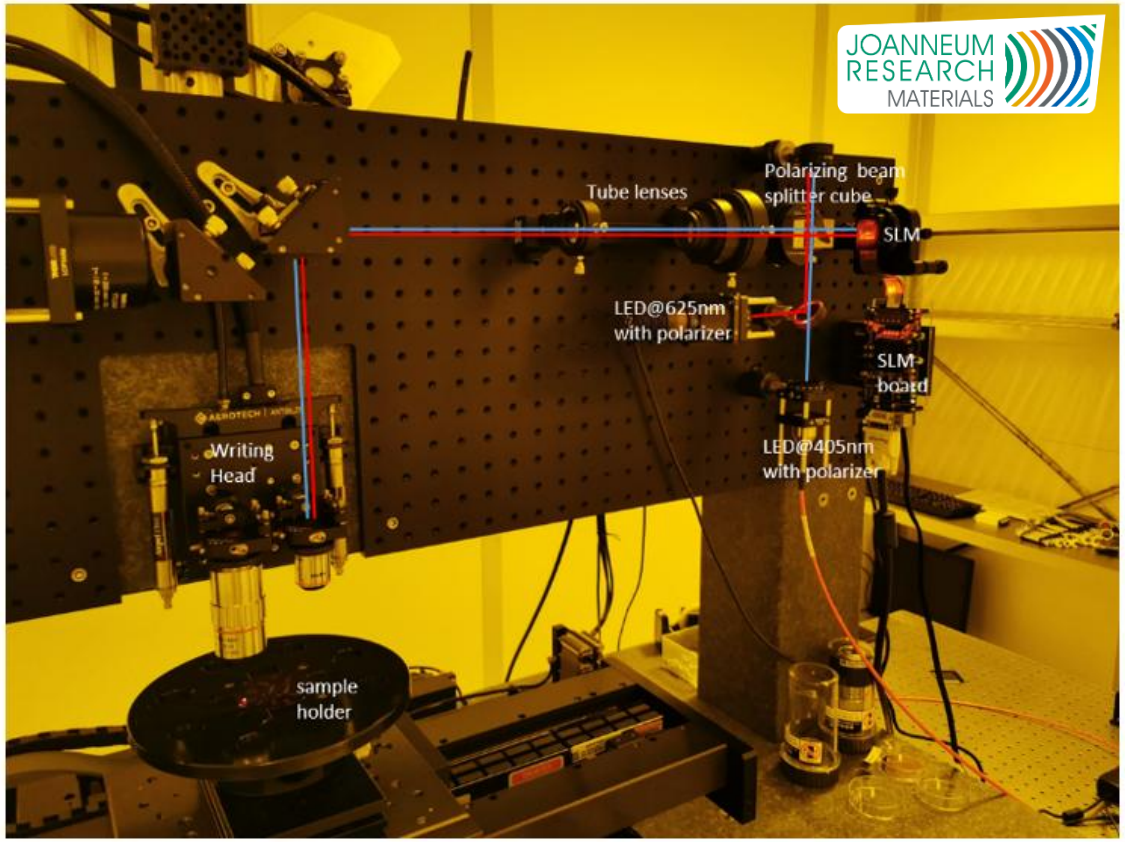


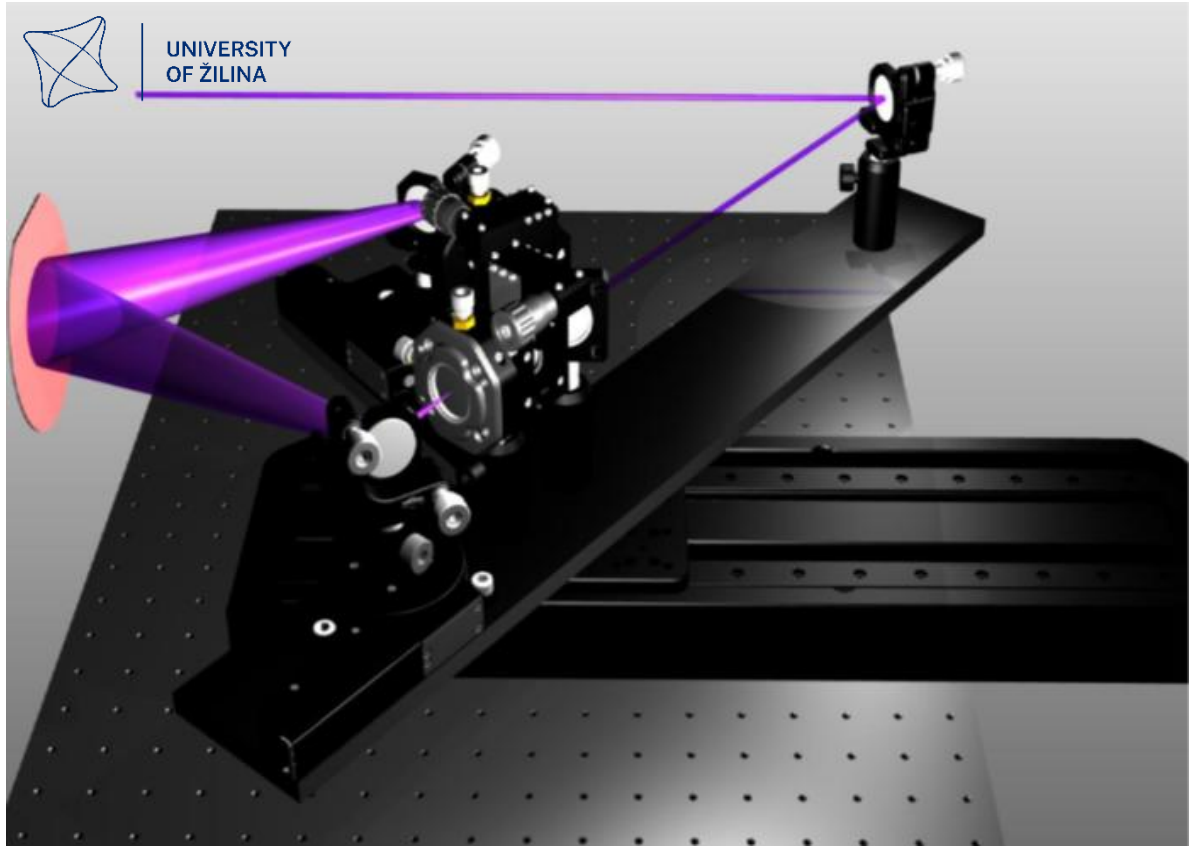
Serial writing features

- The 1PL module and the 2PL module can use the same laser beam deflection units for scanning the laser focus at high speeds and with high accuracy across the sample.
- The system configuration includes a galvanometer scanner capable of directing the laser focus across the sample with dynamic parameters - velocity, acceleration, and jerk - several orders of magnitude greater than those attainable with conventional linear stages.
- The optimized scanning and writing strategy implemented within the software control exploits the full dynamic range of the system and thereby enables the highest achievable production throughput.

Parallel writing

The parallel 1PL approach is including a spatial light modulator (SLM) and laser interference lithography (LIL), where a complete area is structured in one step.





Parallel writing features

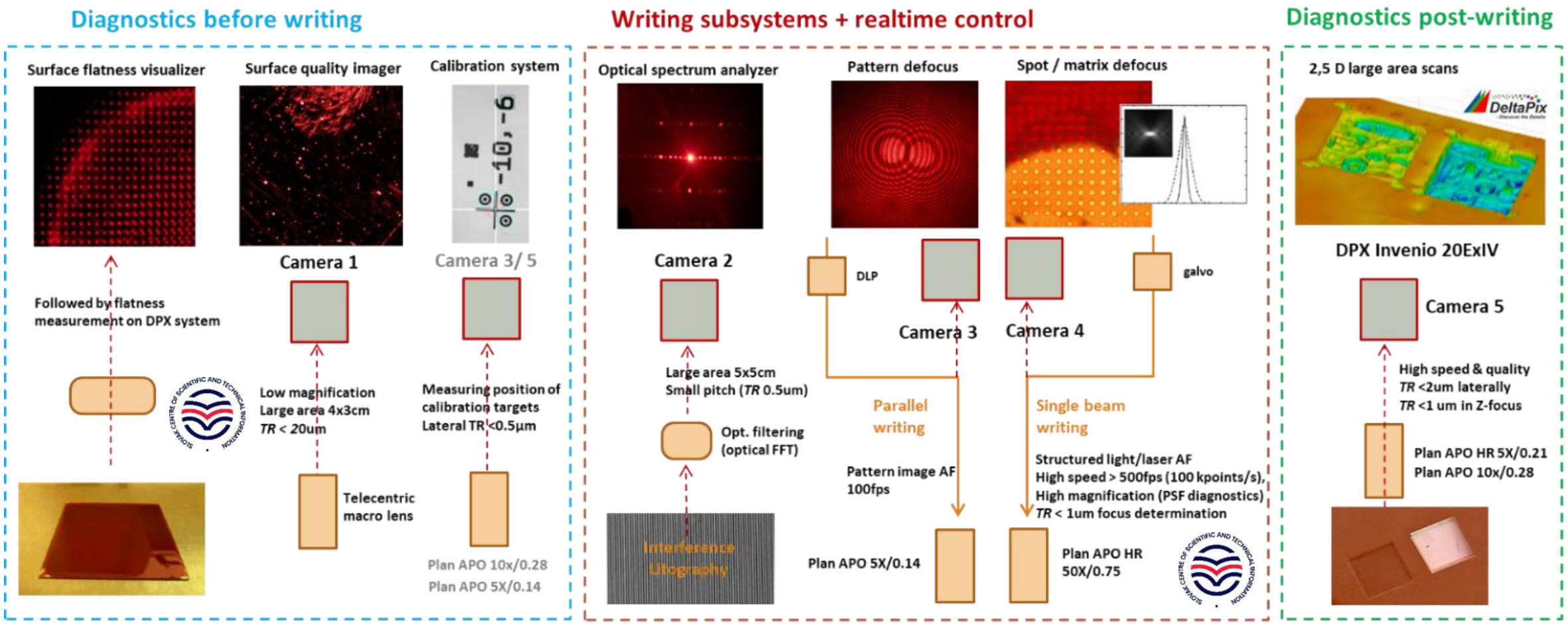
LIL module:

- The laser beams are expanded by 10x microscope objectives and homogenized by pinhole apertures.
- The arrangement of the outer and inner mirrors ensures optical field homogeneity in an area of 50 x 50 mm^2
- The use of a periscope to guide the laser into the module leads to a reduction in module size.
- The entire system is fully automated across the entire defined period range by a control software.

Spatial light modulator module:

- The main application of this module will not be to write smallest features instead it will be used to structure large areas with rather simple features.
- The main advantage is the writing without the typical writing line “shadow” of a serial writing approach. Using a 5× objective an area of approximately 1400 x 2500 μm^2 could be structured in one shot.

Vision modules



TR – Targeted resolution

Vision module features

Alignment and pre-processing modules:

- The initial qualitative assessment of surface quality and waviness is done by employing a modified **focus-variation microscope system** or by utilizing the in-line focus tracking systems. The system is now capable of precisely focusing on the surfaces of featureless, transparent objects, such as glass substrates coated with a photopolymer.
- The structured-light projection unit enables **accurate surface flatness monitoring** and is able to reach an axial resolution of 1.4 µm and a depth of field of 0.3 µm for the writing wavelength (405nm), and an axial resolution of 2.3µm and a depth of field of 0.5 µm for the 650 nm used for diagnostics.
- The **alignment** process operates on a pre-calibrated camera and objective system. Fast search for marks using the YOLO method scans the area by tile scanning and determines the approximate position of marks with real-time performance (detection speed of ~ 30 ms on the 4K image frame).

Vision module features

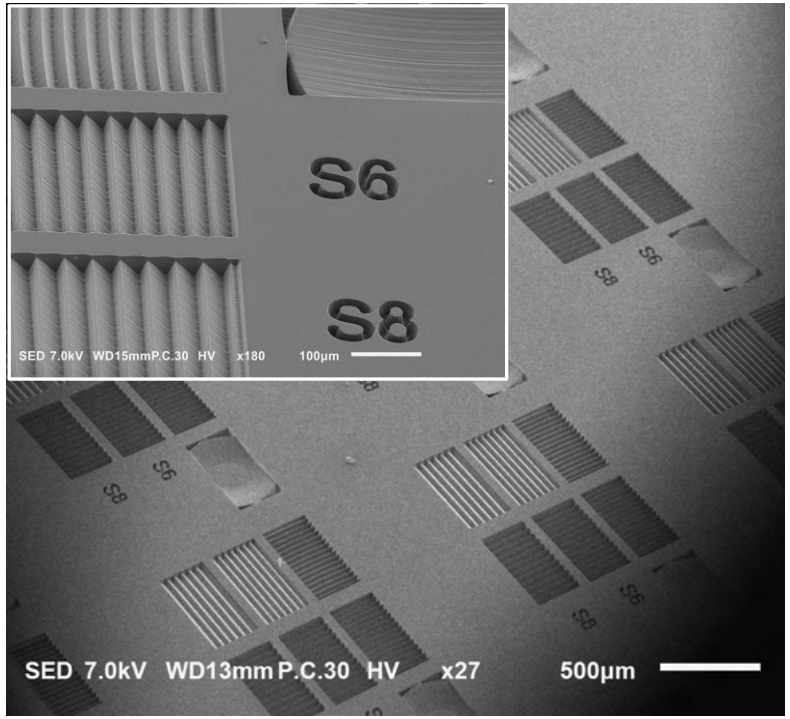
In-line monitoring modules:

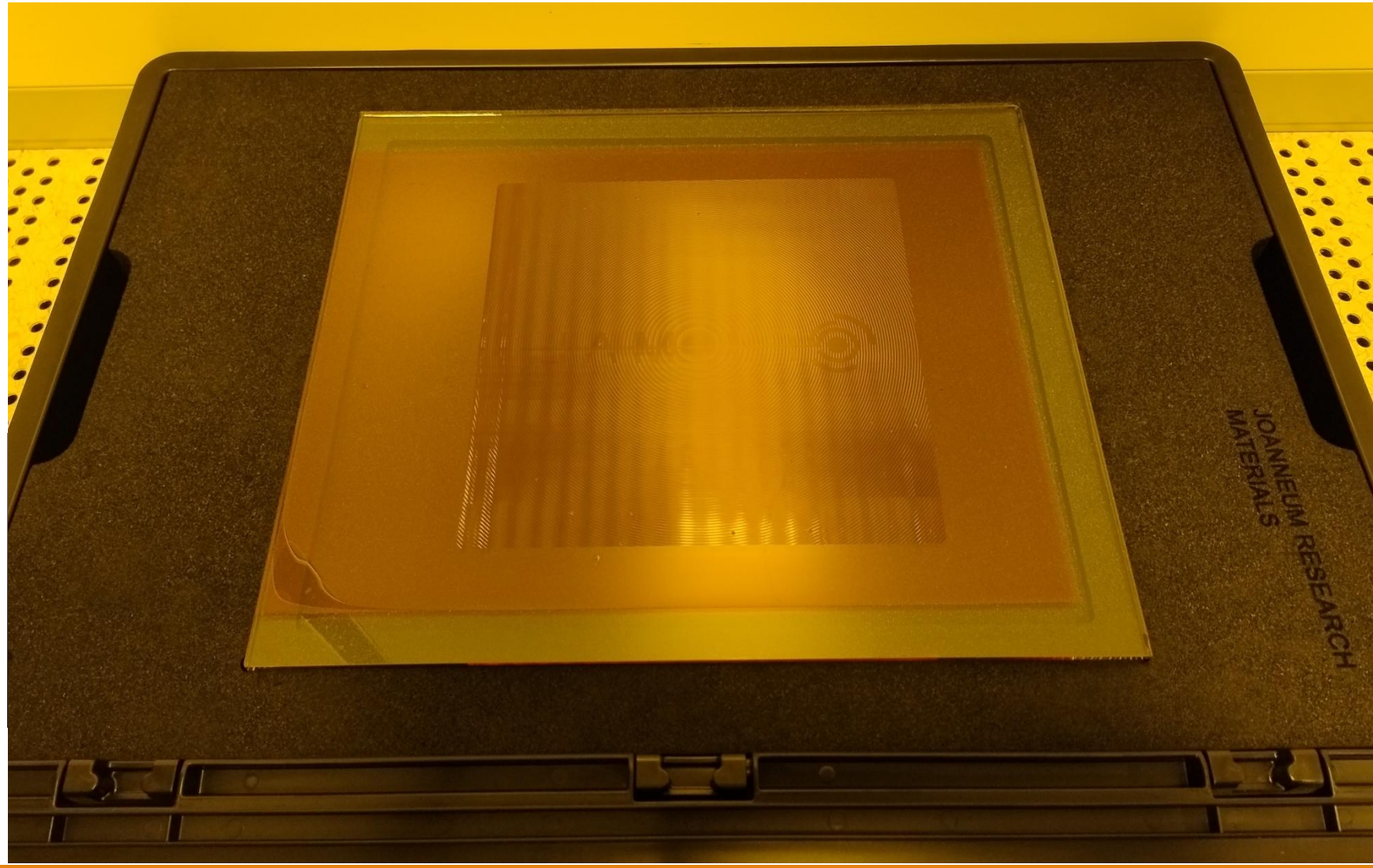
- The focus is detected by identifying selected image features, which are used by an AI to determine the distance and direction of the displacement in relation to the correct focus. A fully-analogue **laser focus monitoring** based on a position-sensitive detector is used as an input for the real-time feedback loop of the Aerotech stage controller in addition to the vision systems.

Off-line imaging system for quality control:

- The developed system is able to provide a **defect-mapping** of periodic and quasi-periodic surface structures, which were tested in both bright and dark-field imaging contrasts in combination with optical filter principles. It is also able to perform optical microscopy analysis of large-area samples, which could be used for the necessary image processing and data generation for the developed self-learning algorithms.

Examples of structures





Thank you for your attention!

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