Nanostencil project (FET-Open project)
A brief review of progress

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www.nanostencil-eu.com

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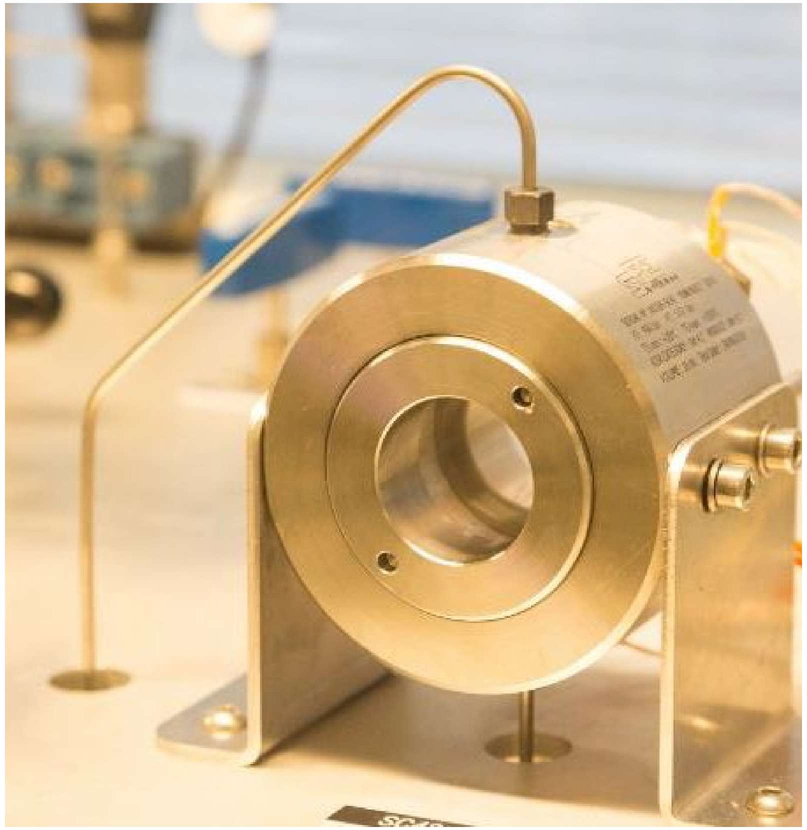
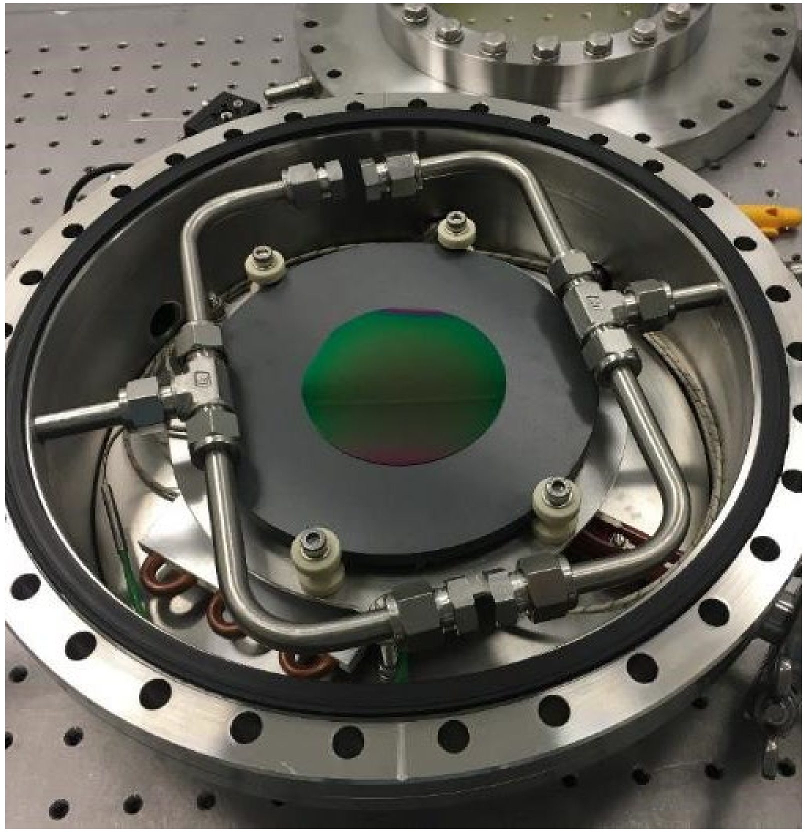
Nanoscale self-assembled epitaxial nucleation controlled by interference lithography

- Aim is to produce dense arrays of nanostructures by performing in-situ laser interference during materials synthesis
- **DLIPS with surface reaction (low energy ~ 10's mJ/cm^{-2})**
- Laser interference periodic patterning via ablation or reaction of materials is well established. We want to use laser interference to form the structures in the first place
- Wish to demonstrate this across several diverse materials systems with device outputs in electronics, photonics, sensing, biomedicine etc

III-V MBE



$scCO_2$ oxidation



ZnO CVD

Three different materials approaches: three different reactors

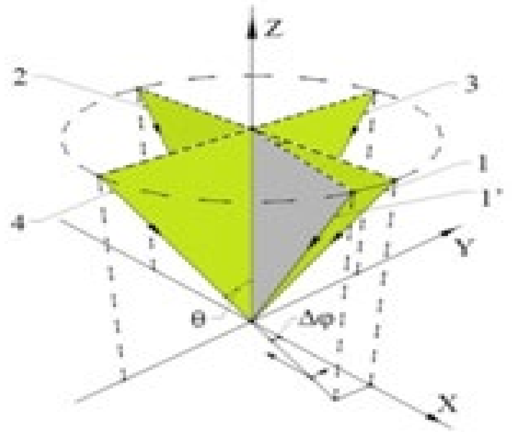
Multi beam Laser Interference Lithography

University of Bedfordshire
+ other partners

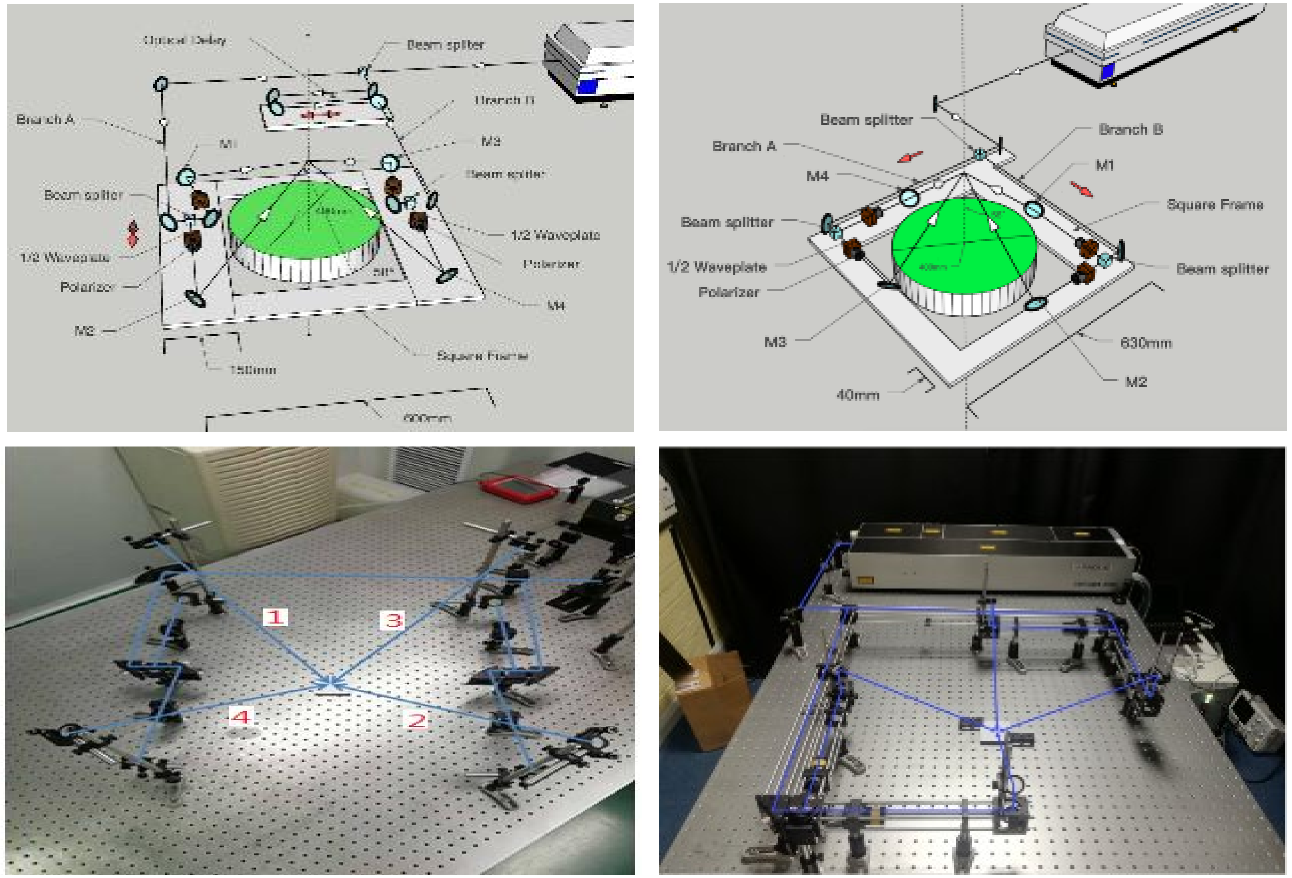
LIL sub-system design and experimental examination

Key factors of LIL should be controlled:

1. Equal optical length;
2. Pointing (incident and azimuth angle);
3. Polarization combination;
4. Energy density distribution at the superposition area.

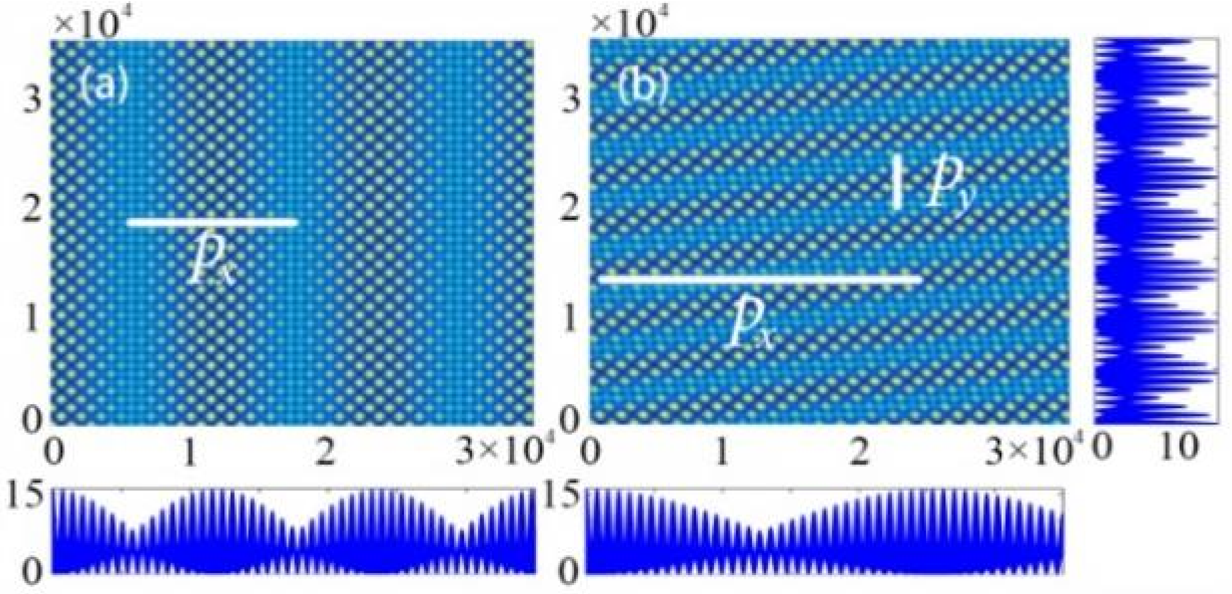


Two versions of optical design and experimental prototype for MBE Chamber



Simulation analysis of the factors to the interference pattern formation

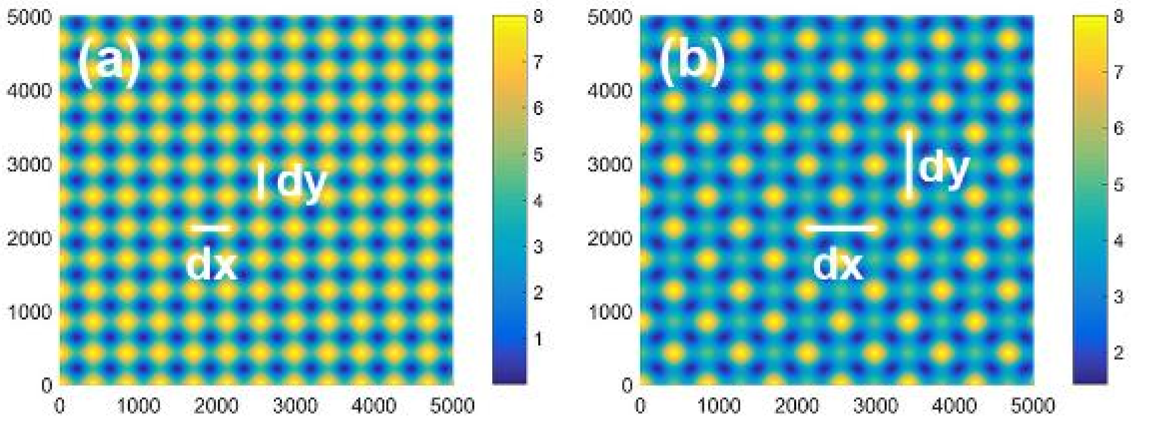
Initial angle offset affects the Four-beam LIL patterns



(a) The incident angle is adjusted a tiny angle offset and the figure below is the intensity profile in the X-direction.

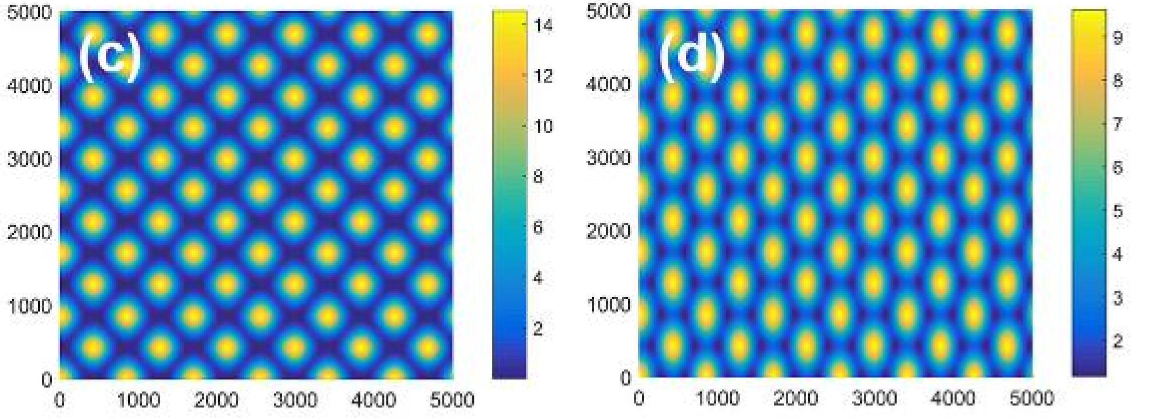
(b) The intensity modulation in two direction due to the tiny azimuth angle offset of one beam)

The effect of Polarization



TE-TE-TE-TE

TM-TM-TM-TM



TE-TE-TM-TM

TE-TE-TE-TM

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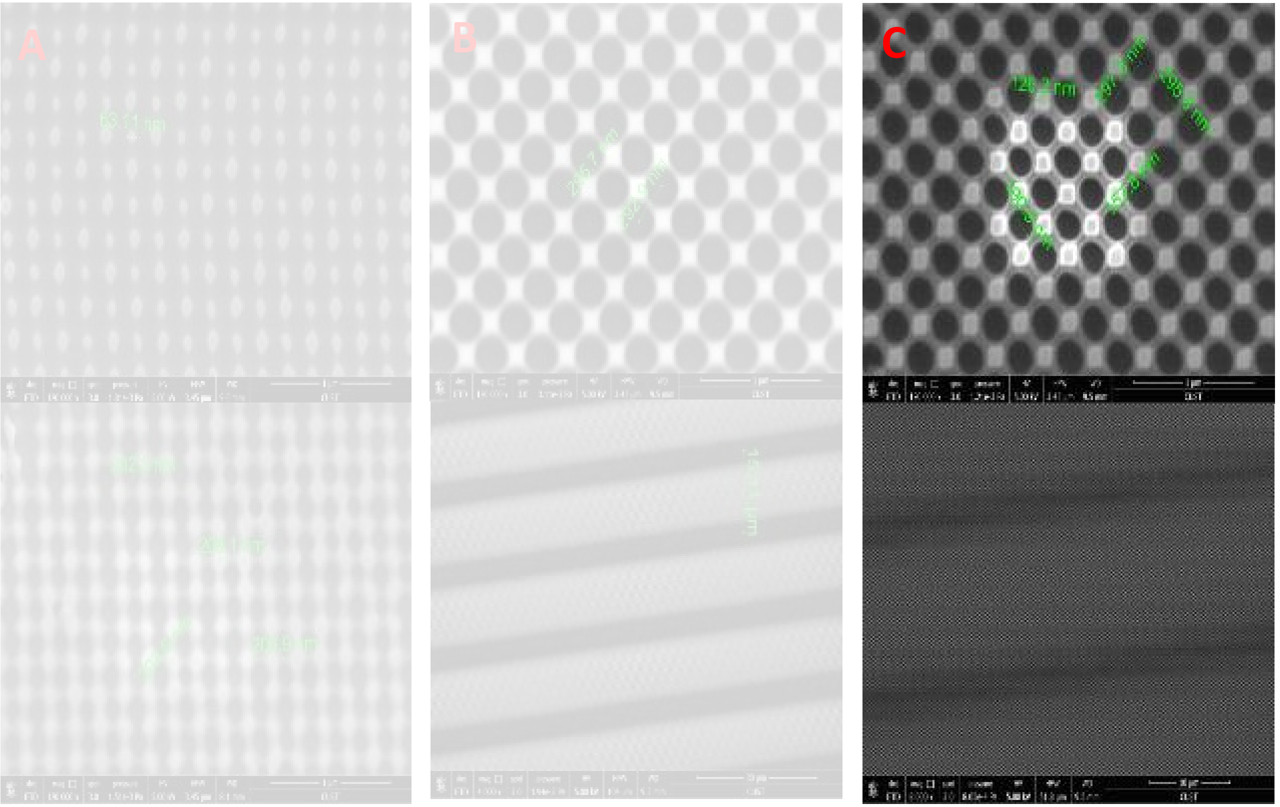
Experimental photoresist tests

The LIL design and examination setup as show in previous slides, the incident angle is 58°. The results are all obtained from positive photoresist.

The TE-TE-TE-TE polarization combination result as show in Figure A, period is about 200nm.

Figure B is the TE-TE-TM-TM combination result. Significant intensity modulation as show below generated by the initial incident and azimuth angle offset in this mode.

Figure C is the TE-TE-TE-TM combination result, this combination could be a good choice for its relatively high contrast and slightly modulation.

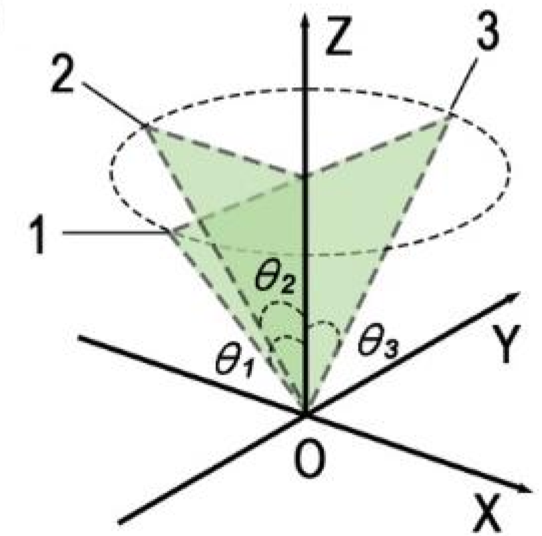


Asymmetric three-beam LIL design and experimental examination

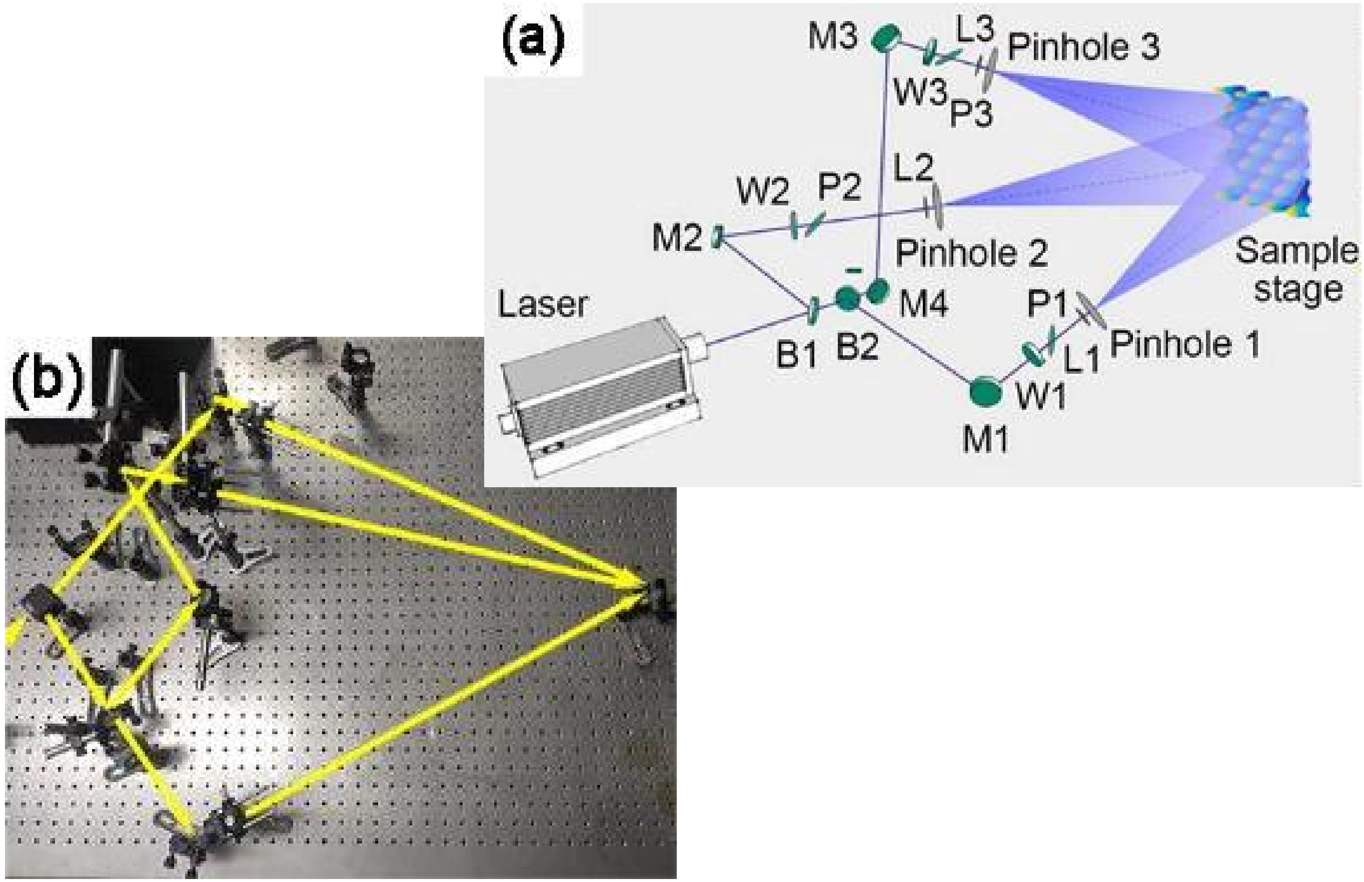
Configurations of the asymmetrical three-beam interference**:**

(a) Azimuthal angles: **0°, 90°, and 180°;**

(b) Polarization mode: **TE-TM-TE** or **TM-TE-TM.**

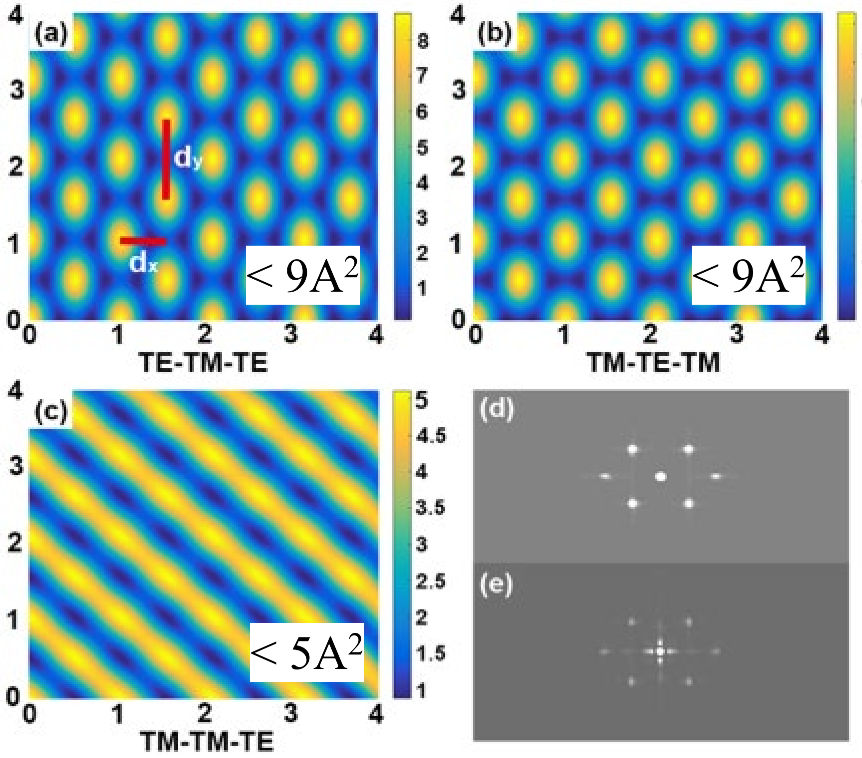


Optical design (a) and asymmetric three-beam LIL system (b)

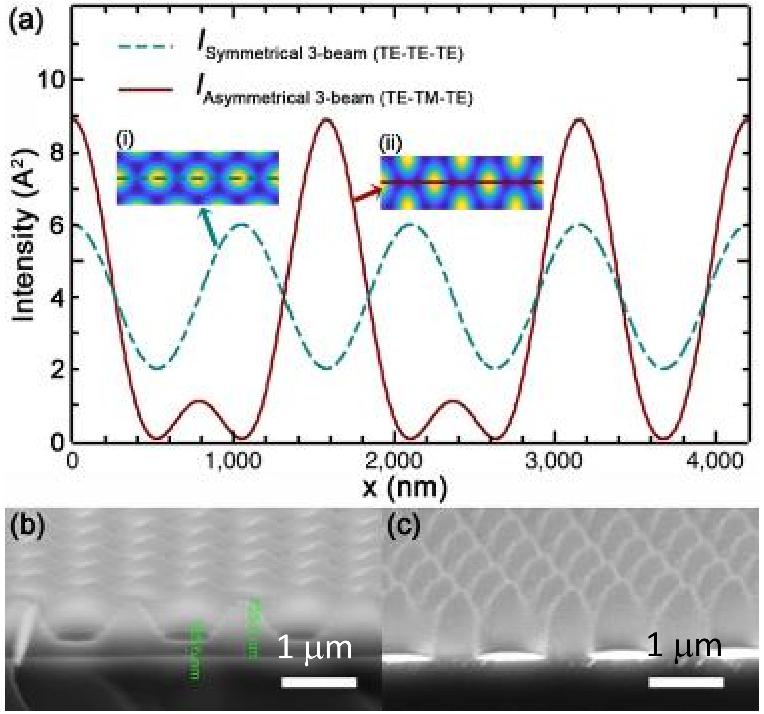


Asymmetric three-beam LIL design and experimental examination

Simulation results



Intensity simulation results (a-c) of the asymmetrical three-beam LIL with different polarization modes in the Z=0 plane. (d) and (e) are the FFT frequency spectra of (a) and (b).



(a) Intensity curves along the corresponding lines in the insets that are optical patterns of the symmetrical three-beam LIL (i) and the asymmetrical three-beam LIL (ii); (b-c) SEM images of the photoresist samples that were generated at the same exposure dose, (b) and (c) correspond to (i) and (ii).

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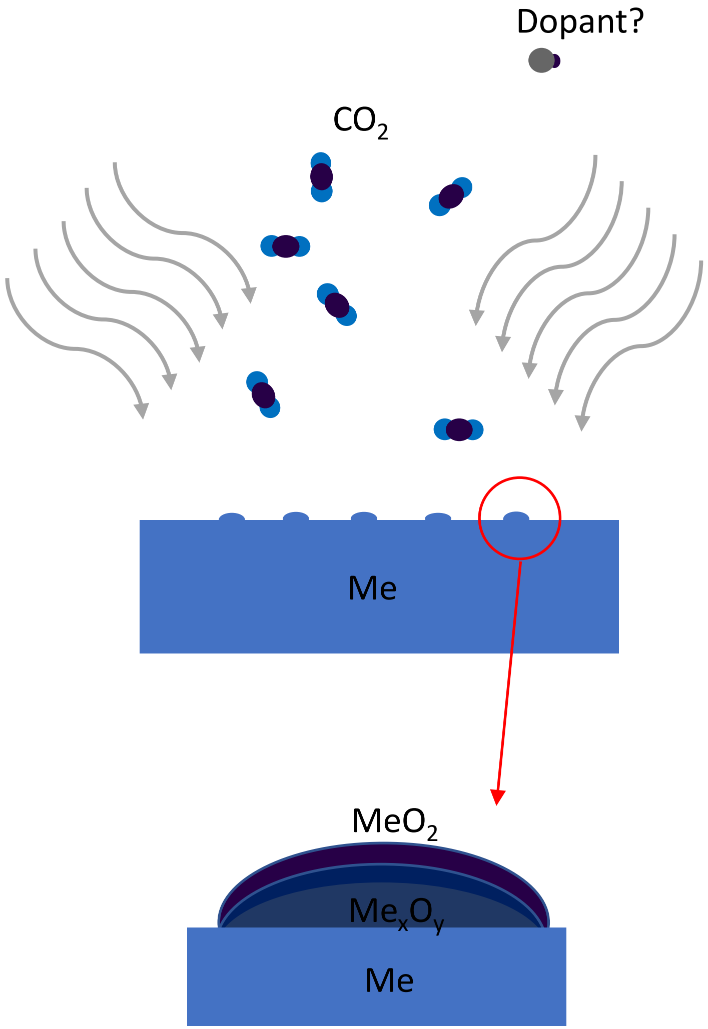
Laser Interference Lithography in $scCO_2$

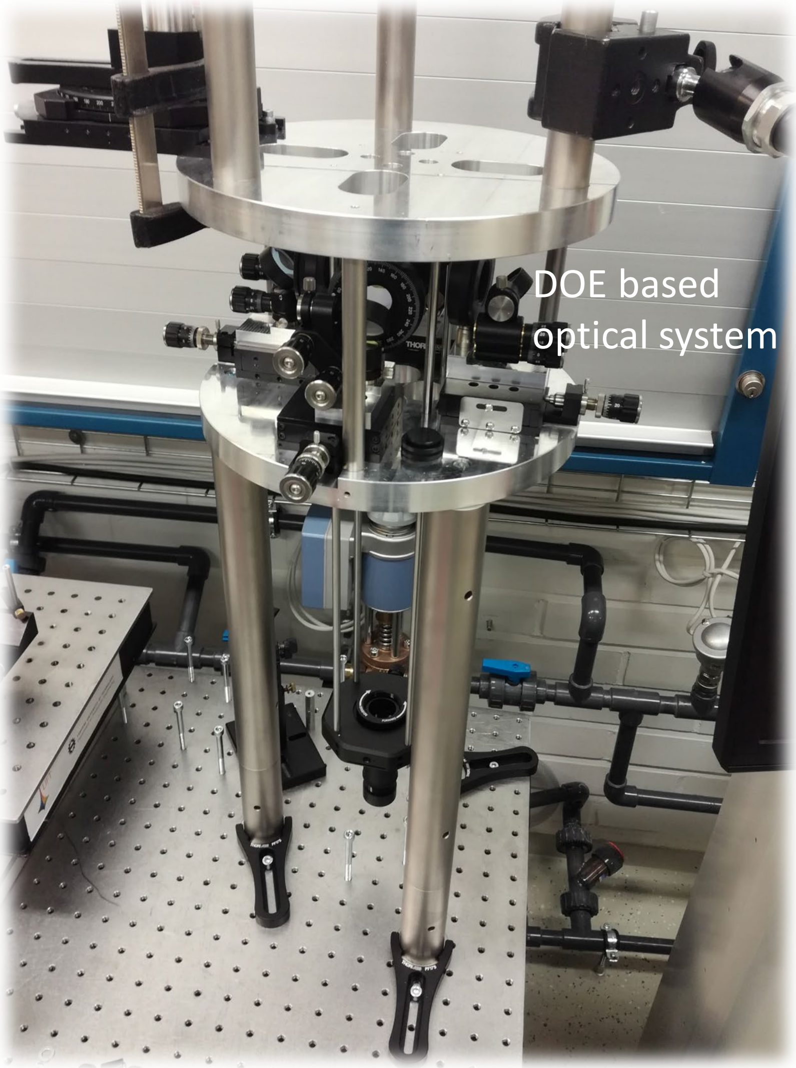
Tampere University
Innolas

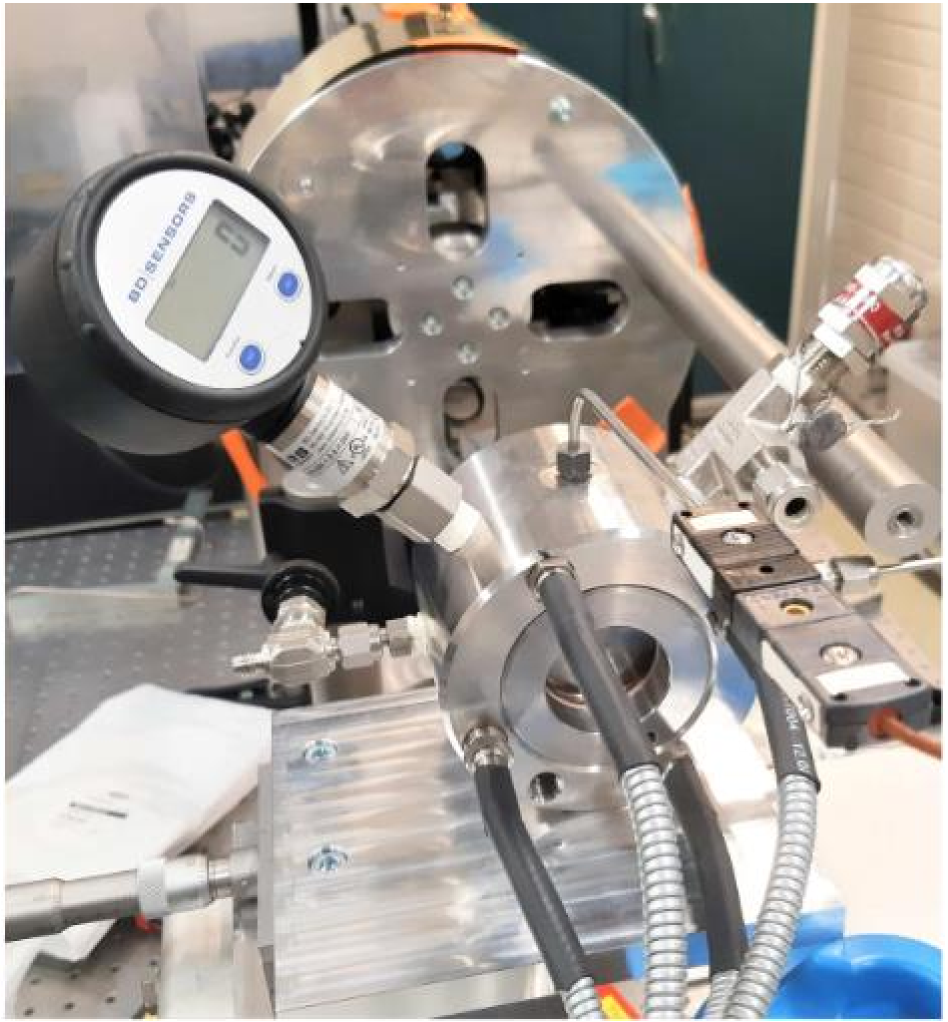
The approach uses super-critical CO_2 (>100 Bar) to achieve controllable localised oxidation of metal films, such as titanium, zinc etc.
Local oxidation occurs only were the pulse(s) hits to substrate

Many parameters/variables need to be explored, including the laser pulse length, number of pulses, laser wavelength, CO_2 pressure etc



$SCCO_2$ optical system and reaction pressure vessel





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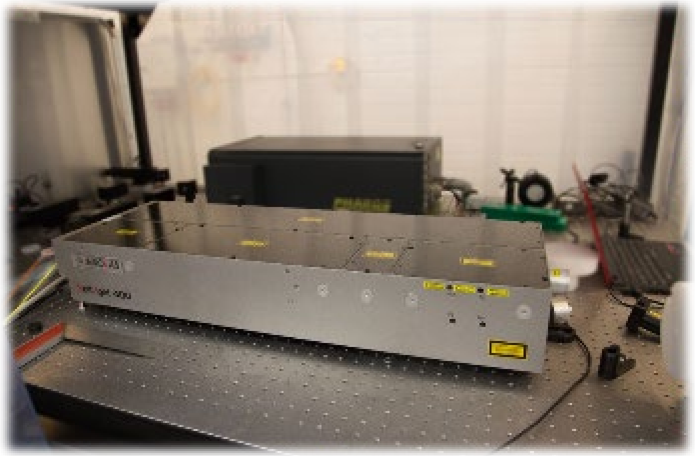
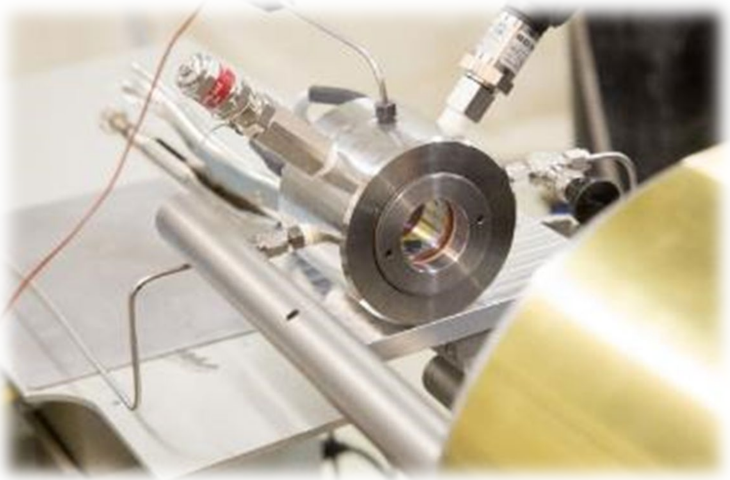
Patterning in SCCO$_2$

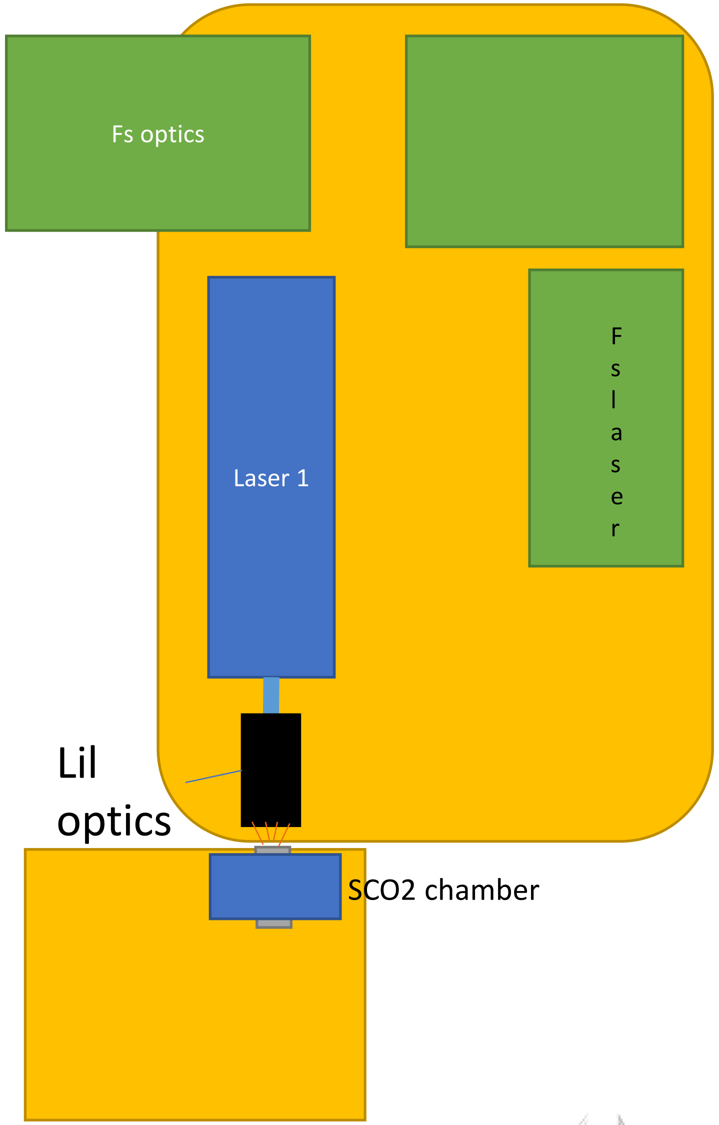
Laser 1 is mounted on the large optical table along with the LIL system
sCO2 Chamber is next to the table on its own separate frame.



4 beams, 0°,180°,90°,270°
1064nm wavelength used
~6mm beam diameter

New chamber with 34mm window was used





Fs optics

Laser 1

Fs laser

Lil optics

SCO2 chamber

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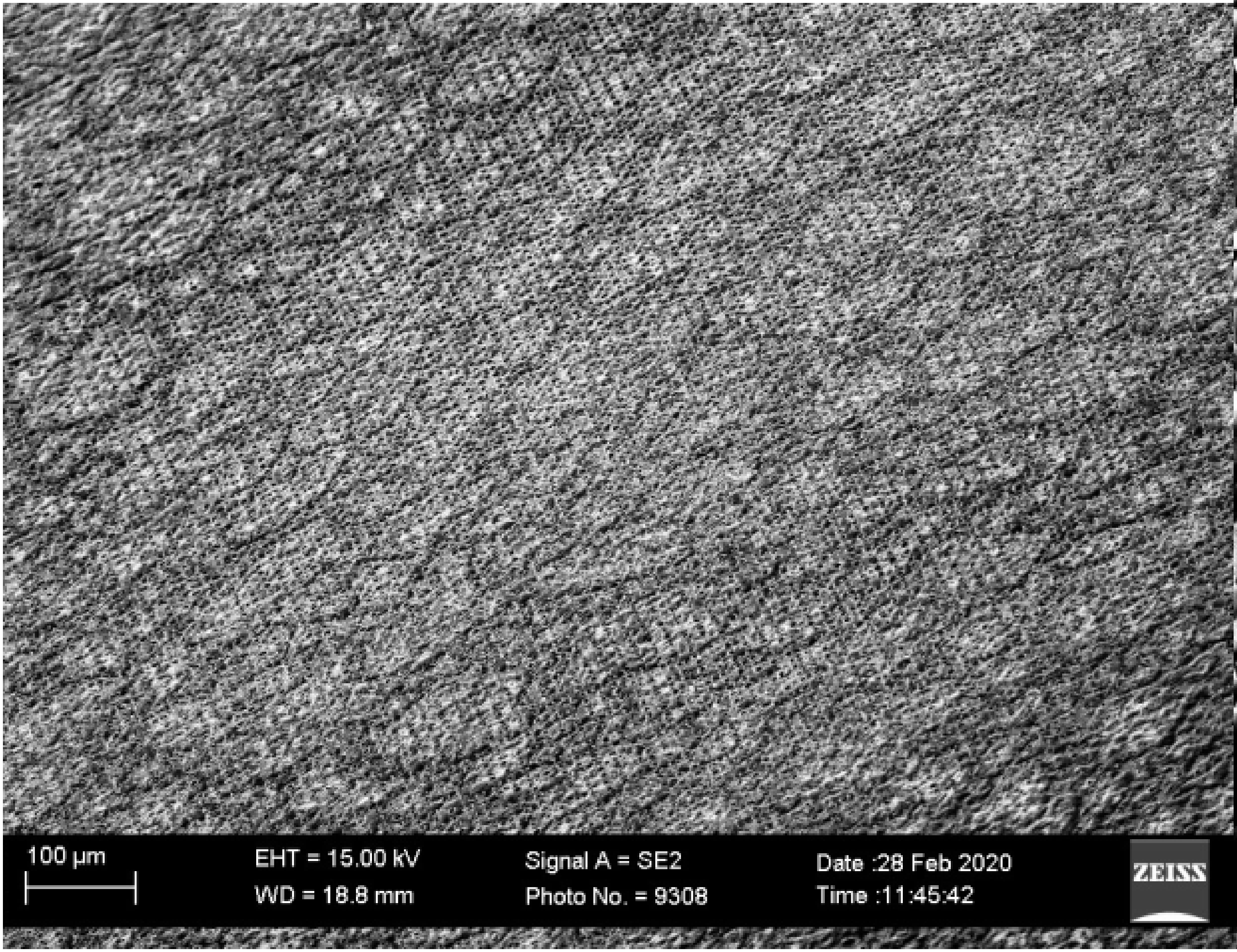
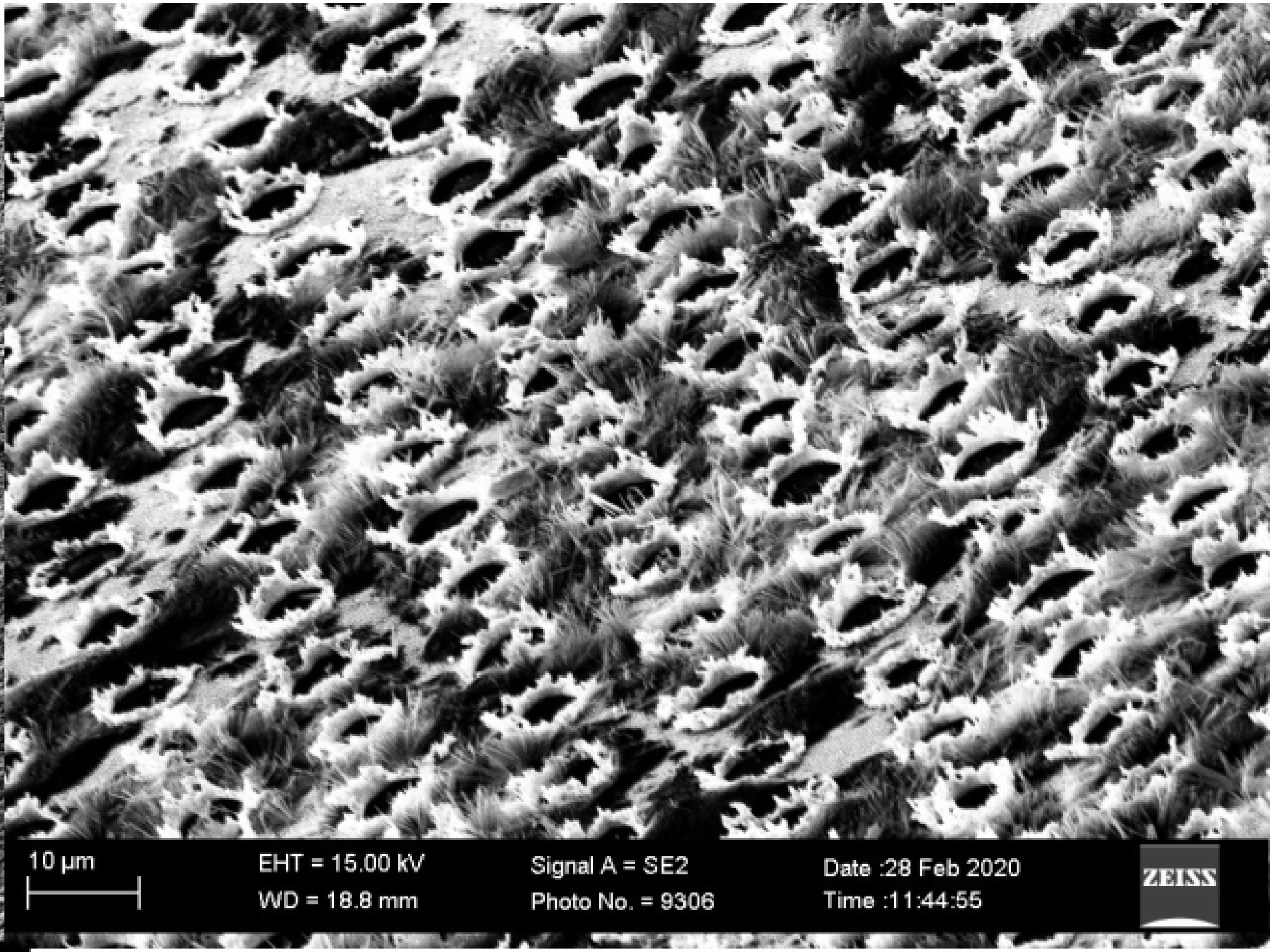
LIL patterning of CO_2 treated Zn surfaces





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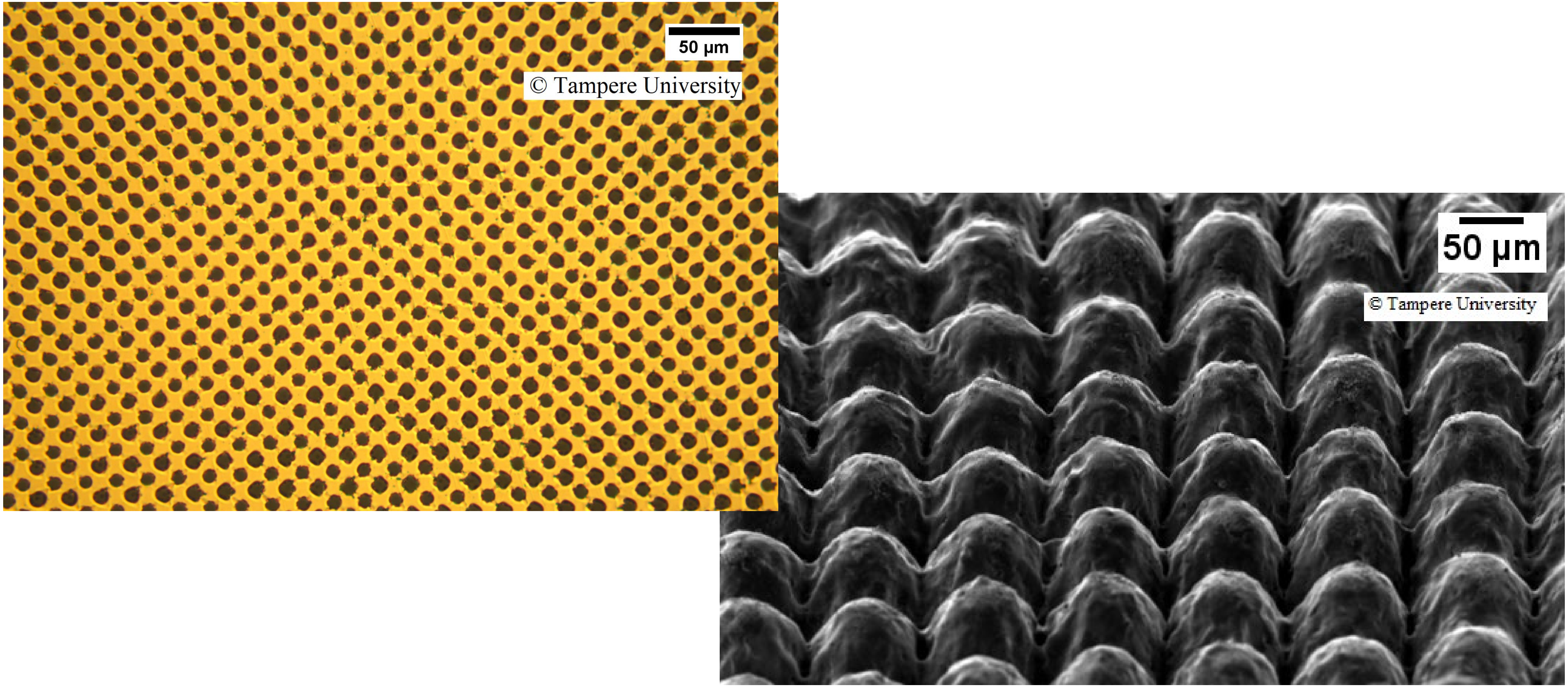
Initial work on Titanium



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Laser Interference Aerosol Assited Chemical Vapor Deposition (LIAACVD)

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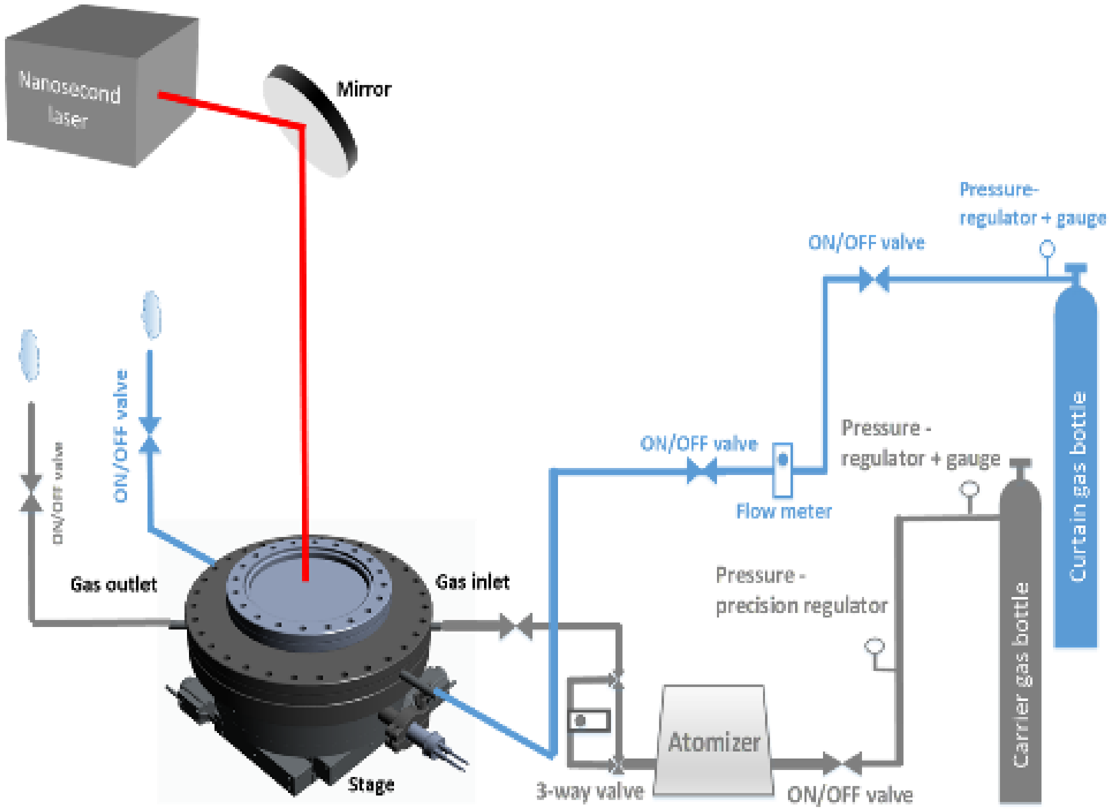
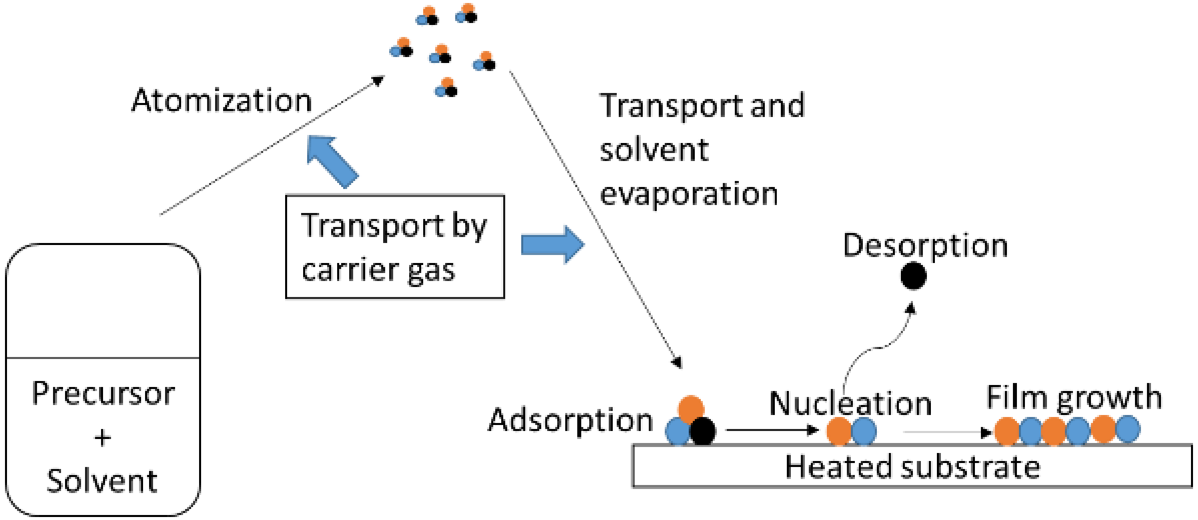
Laser Enhanced Aerosol Assited Chemical Vapor Deposition (LEAACVD)



LEAACVD scheme



Reaction scheme

- Easy delivery and vaporization of a wide range of precursors.
- High deposition rate.
- Low pressure or atmospheric pressure.
- Good stoichiometric control of the reaction

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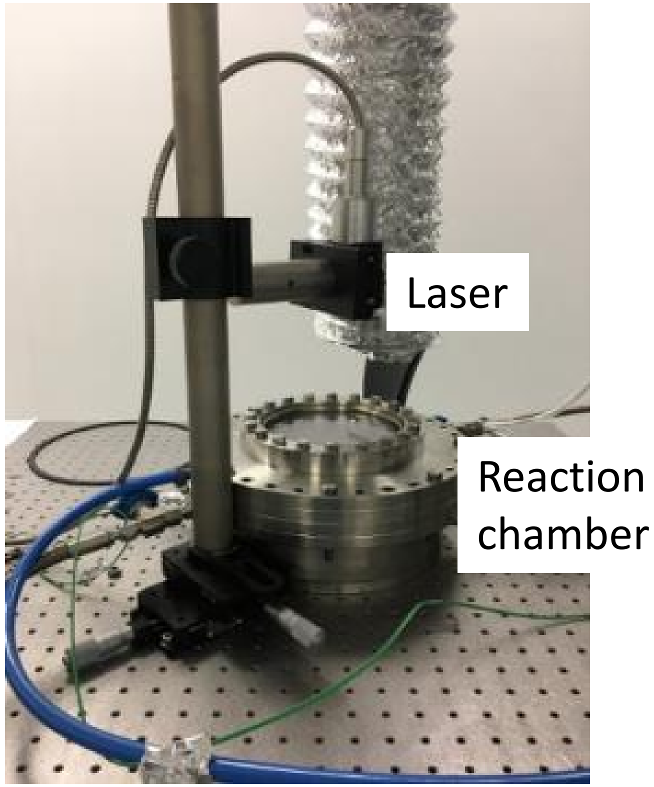
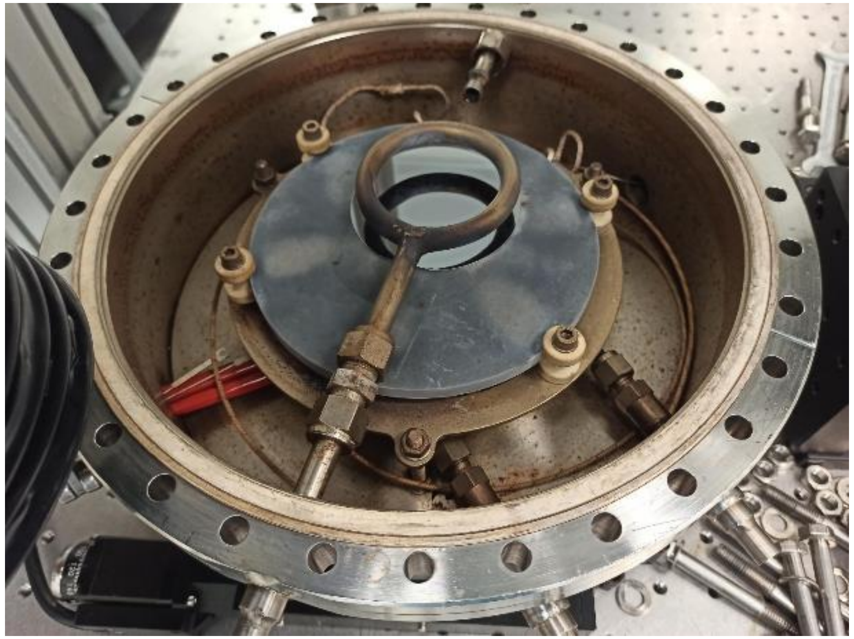
Laser Enhanced Aerosol Assited Chemical Vapor Deposition (LEAACVD)

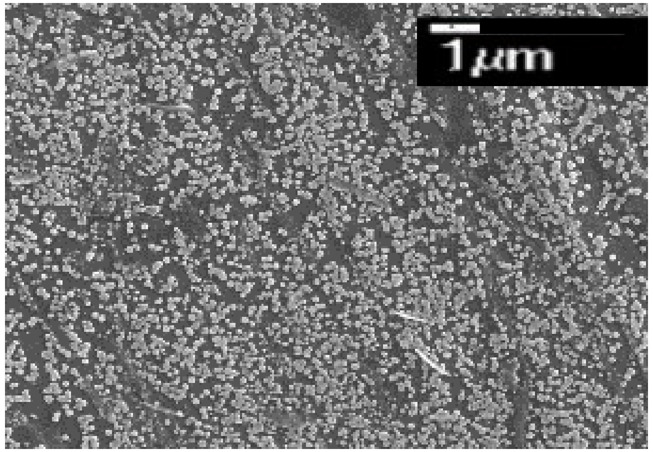
LEAACVD set-up





Reaction chamber

LEAACVD results



t=200 ns T_{heater}=250 °C
6l/min 5.5W 30 min

ZnO thin films grown by LEAACVD onto stainless steel substrates

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Laser Interference Aerosol Assited Chemical Vapor Deposition (LIAACVD)

Maskless method to grow micro/nanostructured thin films

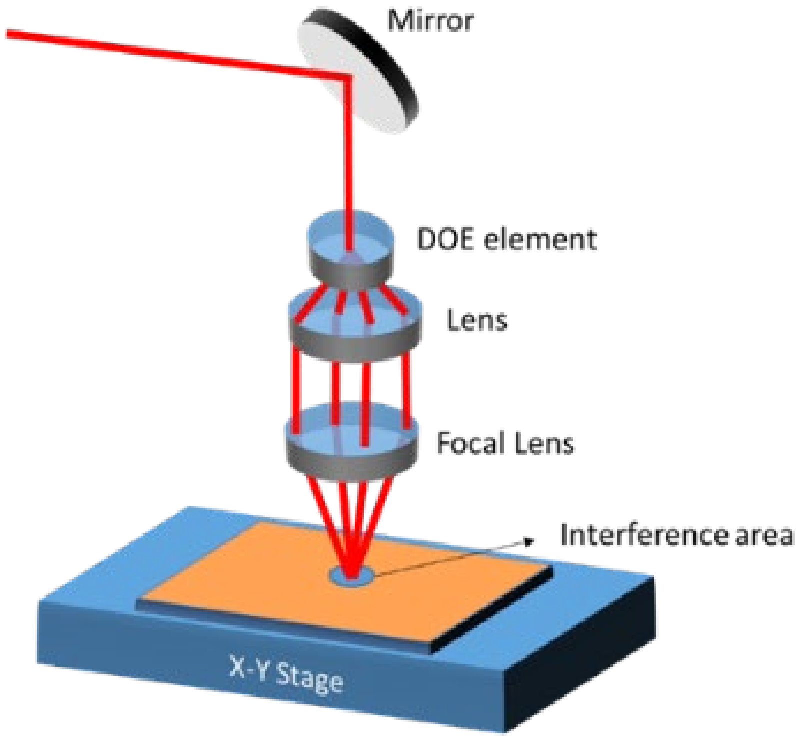
Advantages:

- Direct writing with a laser interference pattern of structures with a resolution of 1 μm
- Only the surface substrate is affected by the temperature deposition
- Geometry and tolerances are not influenced by high temperature conditions

Disadvantages

- Low deposition rates

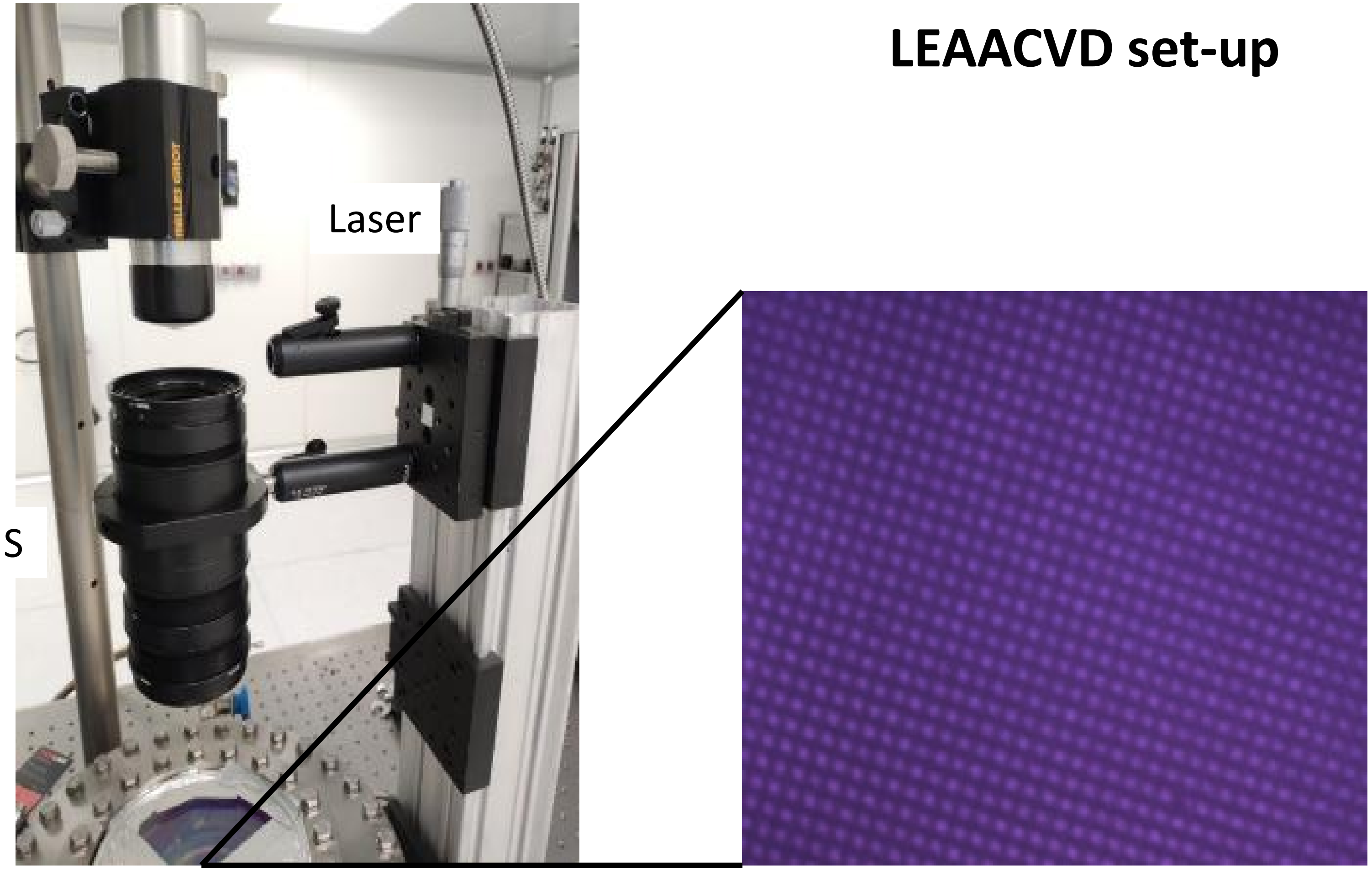
Set-up 3D



LIAACVD scheme

Laser Interference Aerosol Assisted Chemical Vapor Deposition (LIAACVD)

LEAACVD set-up



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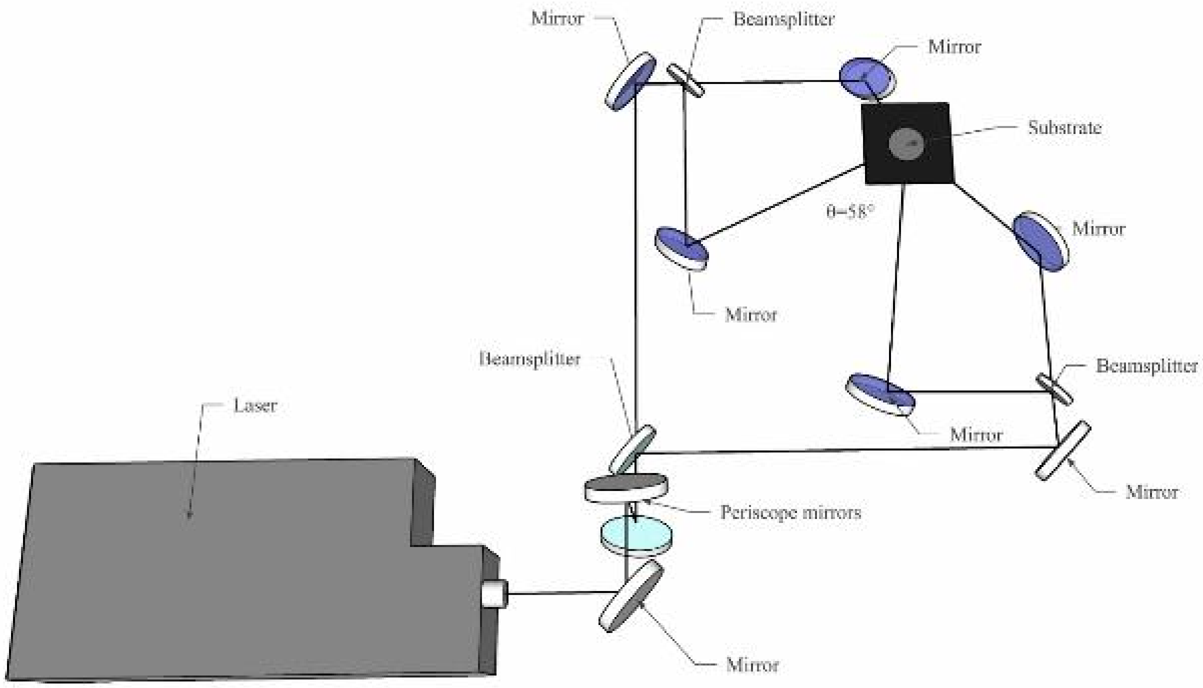
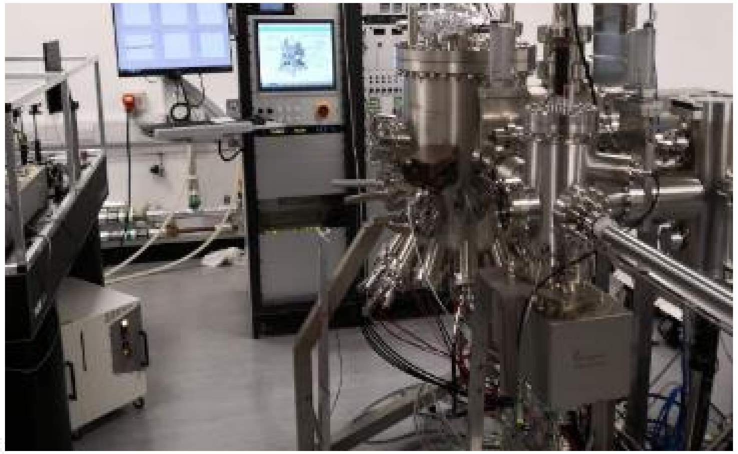
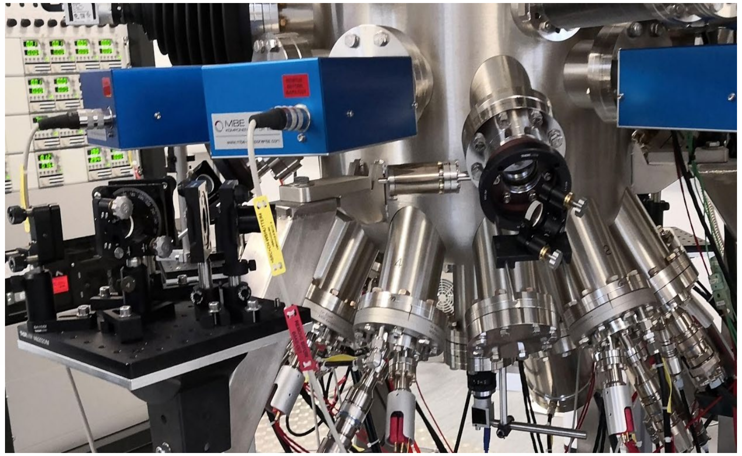
MBE growth of III-V quantum dots

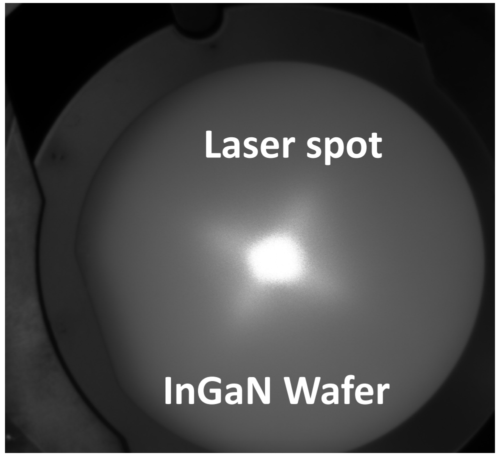
University of Sheffield
Innolas
+ others

MBE-LIP design and setup



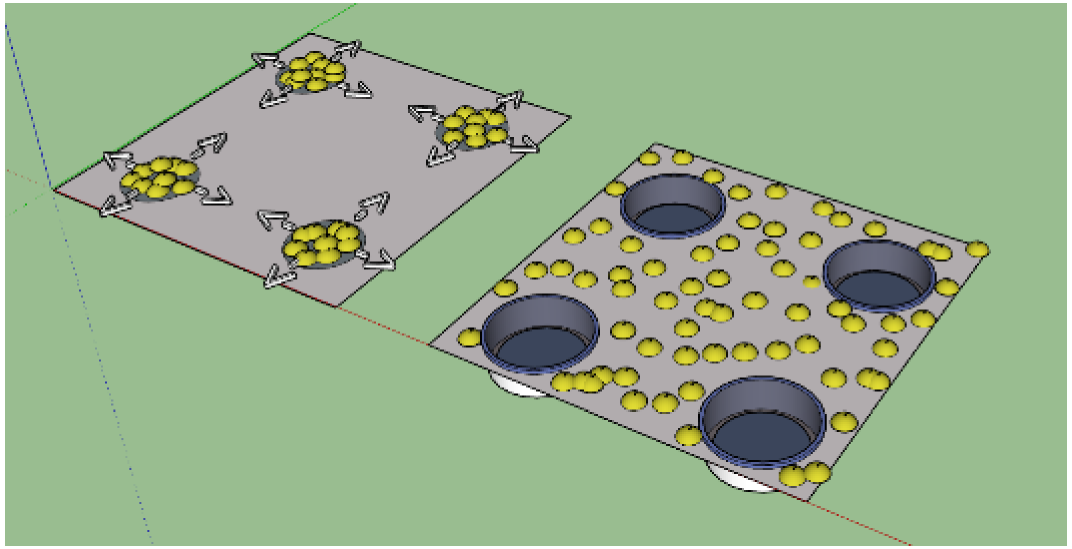




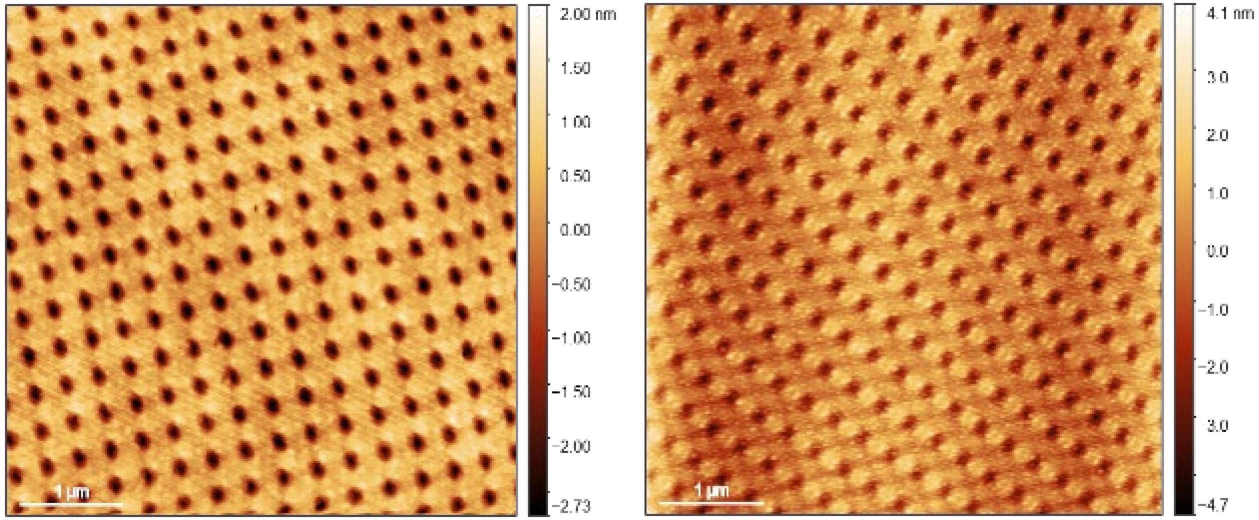


Results - nanoholes

❖ Patterning on GaAs substrates



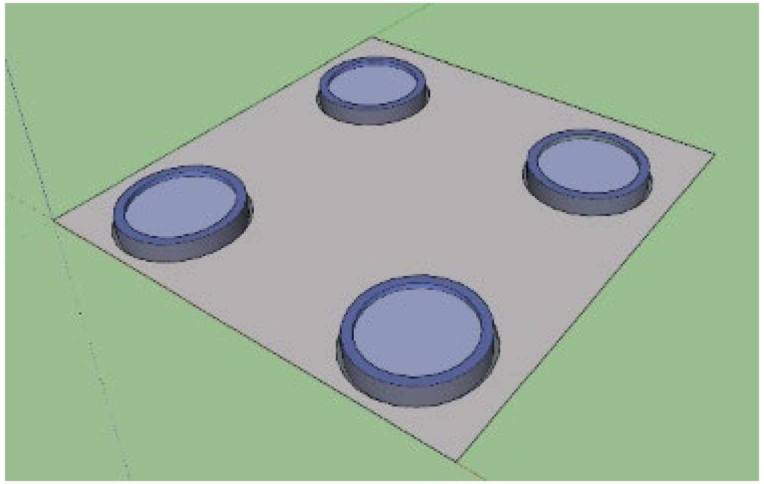
Towards the wafer center, where the beam overlap is the strongest (pulse energy ~30-50 mJ/cm^2)



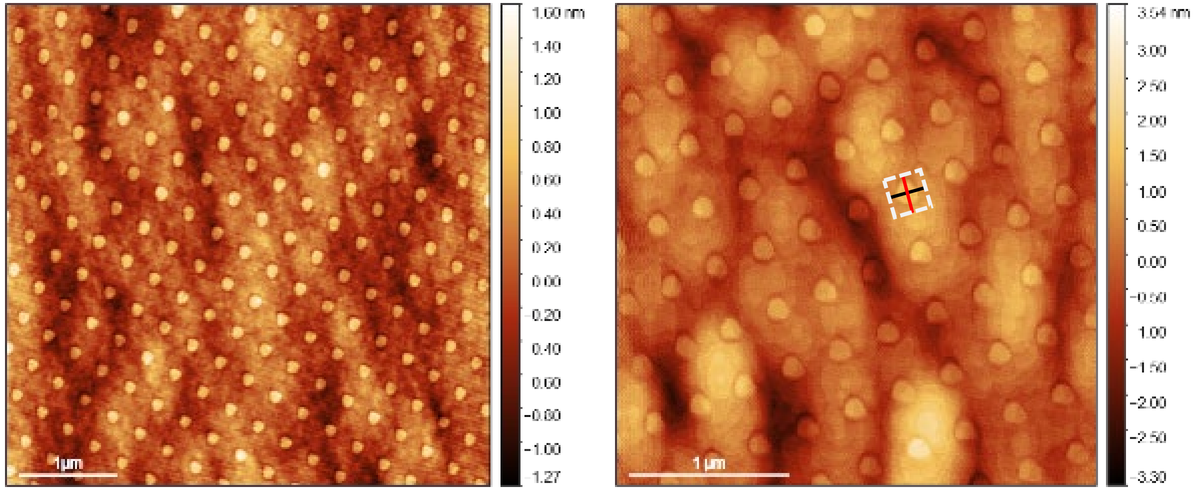
- Surface temperature >650°C
- Arsenic evaporation releasing free Ga
- Migration of Ga droplets to colder regions
- Etching of original surface
- GaAs nanoholes of 60-100nm wide and 2-4nm deep, 300nm pitch

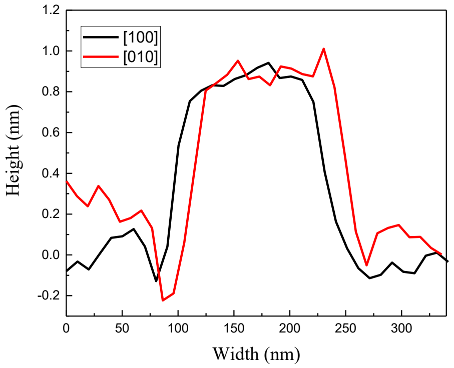
Results - nanoislands

❖ Patterning on GaAs substrates



Towards the edges of the patterned region, where the beam overlap is lower (pulse energy 10-30 mJ/cm^2)

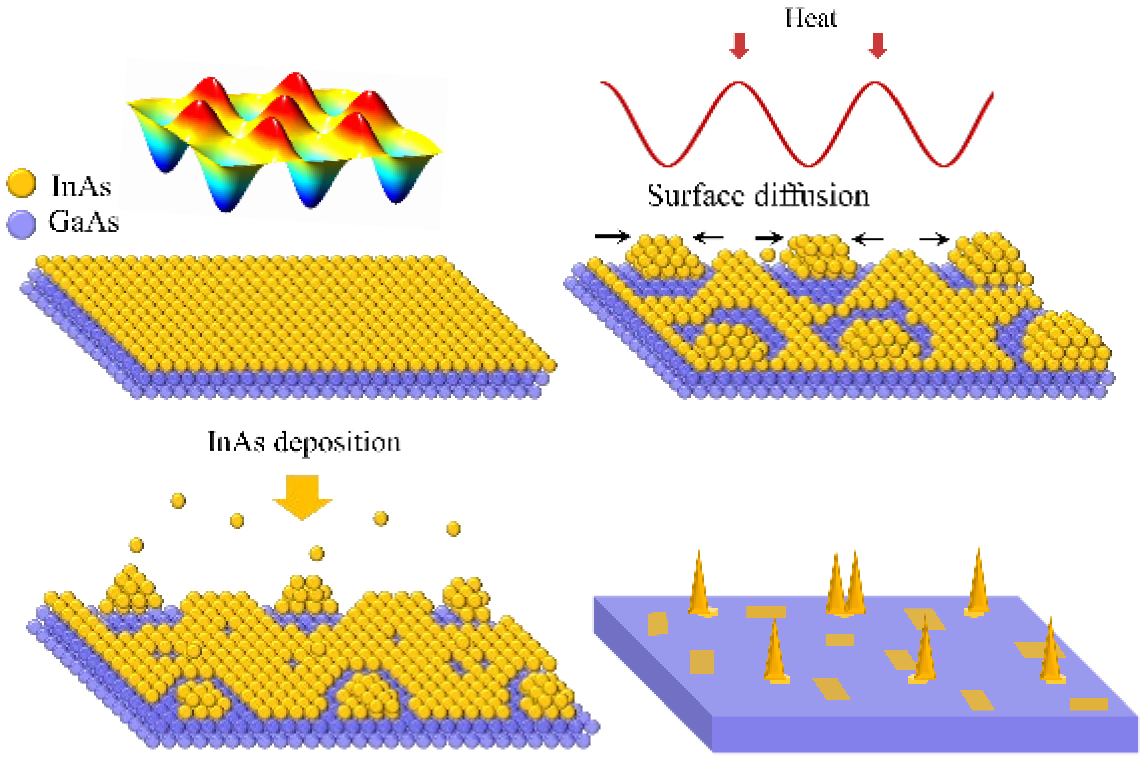


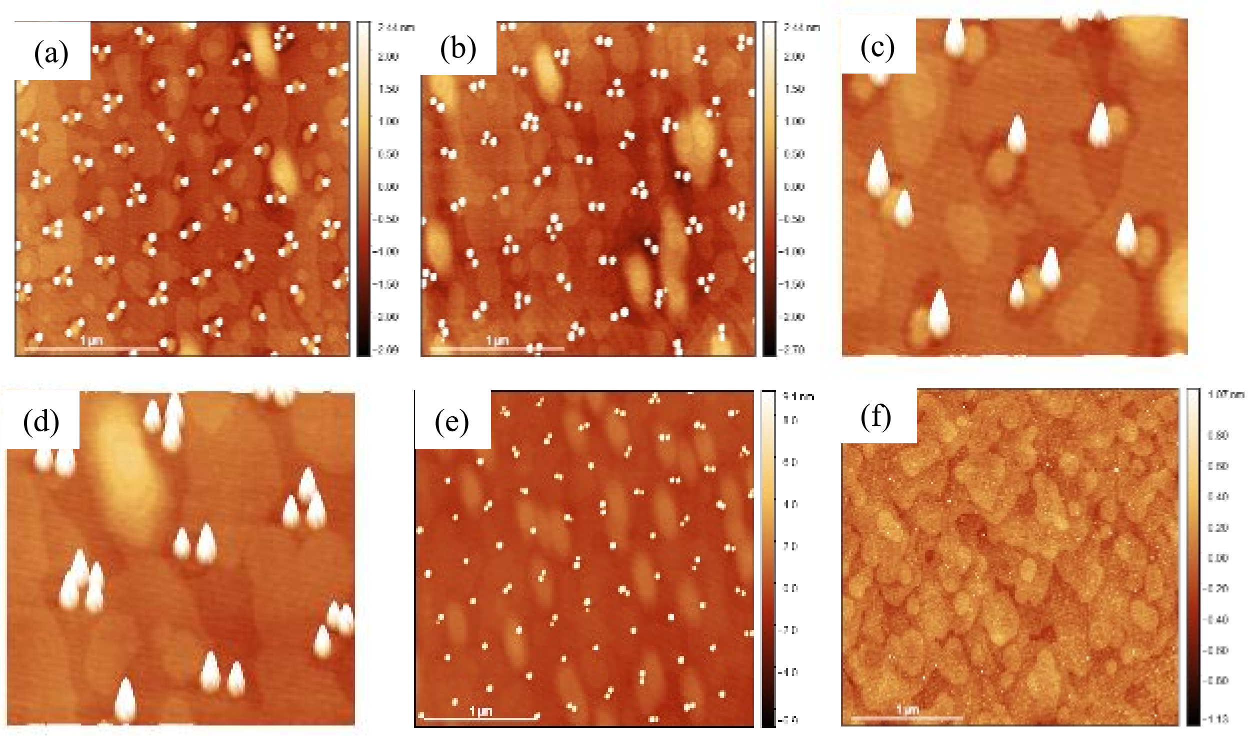


- No droplets, surface very flat apart from the ML islands
- GaAs nanoislands of 80-150nm wide and ~1nm (2-3 ML) high, 300nm pitch
- Diffusion-based mechanism. Ga atoms migrate from ‘hot’ region to ‘cold’ region

Results - Nucleation of quantum dots

❖ Patterning on InAs/GaAs surfaces

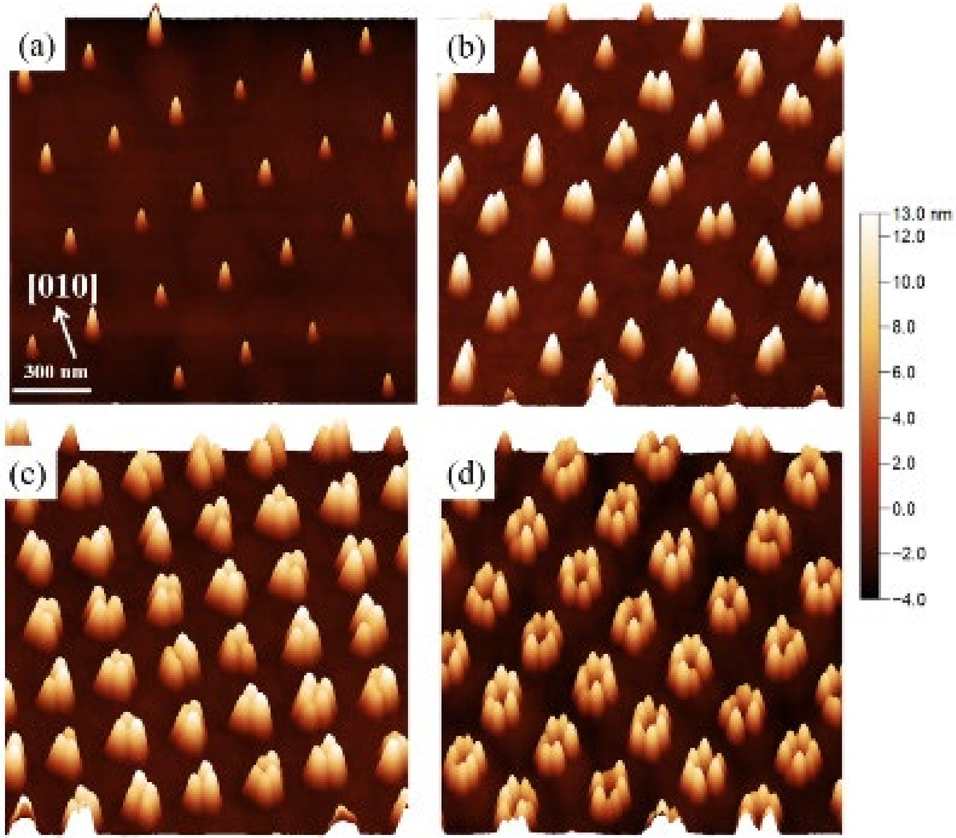




- InAs QDs prefer to nucleate at edge of small nanoislands
- Better uniformity than non-patterned QDs

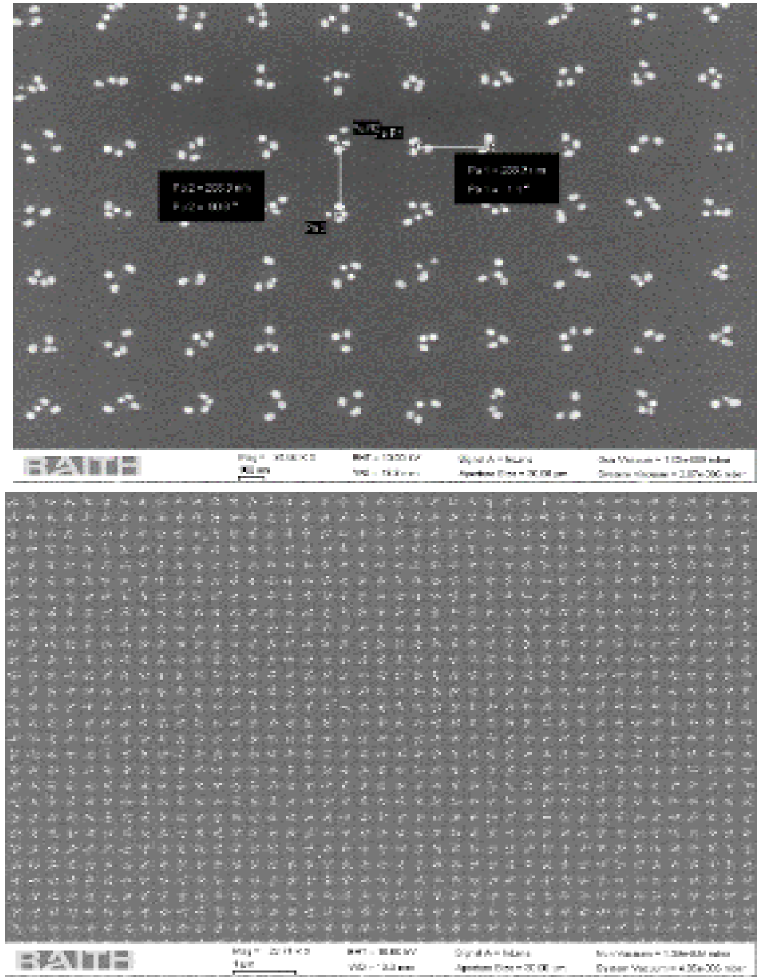
Results – QD/QDM arrays

- ❖ Different InAs coverage of 1.55 ML, 1.6 ML, 1.65 ML, 1.75 ML



With careful control we can achieve one or more quantum dots per site.

- ❖ GaAs droplet epitaxy on Silicon:



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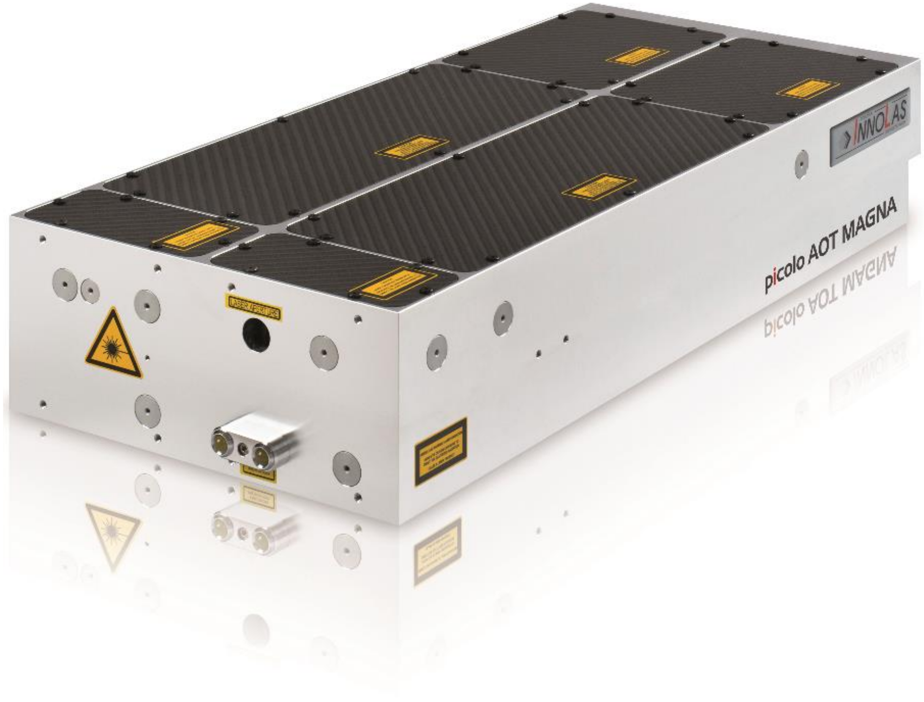
Pulsed Lasers for interference lithography

Innolas Laser
+ others

Laser Development (example)

Standard Specifications in use for MBE and the $scCO_2$ work)

- 1064 nm + 532 nm + 355 nm (priority)
- Pulse duration: 5-7ns
- Repetition: 10Hz
- Polarisation: Linear >100:1
- Bandwidth: As low as possible (injection seeding)
- Energy ~ 100mJ at 355nm

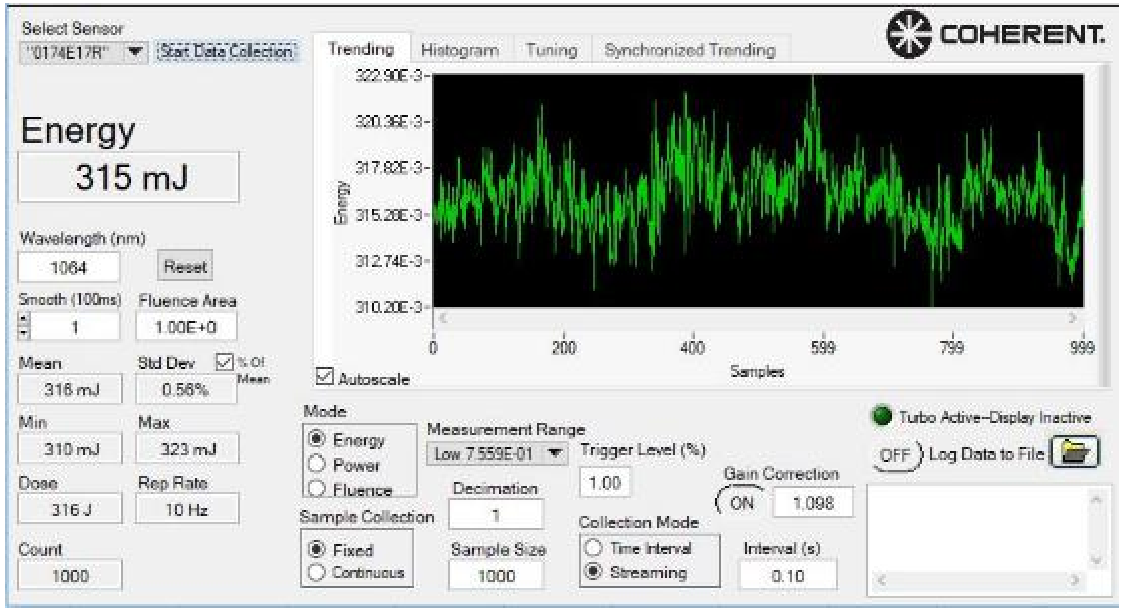


Areas to improve

- Energy stability
- Beam profile
- Wavefront
- Coherence

Performance – Energy / Stability

@1064 nm: <0.6% RMS (below specs 0.7%)



Select Sensor "0174E17R"

Energy 315 mJ

Wavelength (nm) 1064

Smooth (100ms) 1

Fluence Area 1.00E+0

Mean 316 mJ

Std Dev 0.56% ☑ % Of Mean

Min 310 mJ

Max 323 mJ

Dose 316 J

Rep Rate 10 Hz

Count 1000

☑ Autoscale

Mode ● Energy ○ Power ○ Fluence

Measurement Range Low 7.559E-01

Trigger Level (%) 1.00

Decimation 1

Gain Correction ON 1.098

Sample Collection ● Fixed ○ Continuous

Sample Size 1000

Collection Mode ○ Time Interval ● Streaming

Interval (s) 0.10

@355 nm: <0.6% RMS (below specs 0.7%)

Select Sensor "0174E17R"

Energy 89.8 mJ

Wavelength (nm) 355

Smooth (100ms) 1

Fluence Area 1.00E+0

Mean 90.1 mJ

Std Dev 0.59% ☑ % Of Mean

Min 88.6 mJ

Max 91.9 mJ

Dose 90.1 J

Rep Rate 10 Hz

Count 1000

☑ Autoscale

Mode ● Energy ○ Power ○ Fluence

Measurement Range Low 9.430E-01

Trigger Level (%) 5.00

Decimation 1

Gain Correction ON 1.123

Sample Collection ● Fixed ○ Continuous

Sample Size 1000

Collection Mode ○ Time Interval ● Streaming

Interval (s) 0.10

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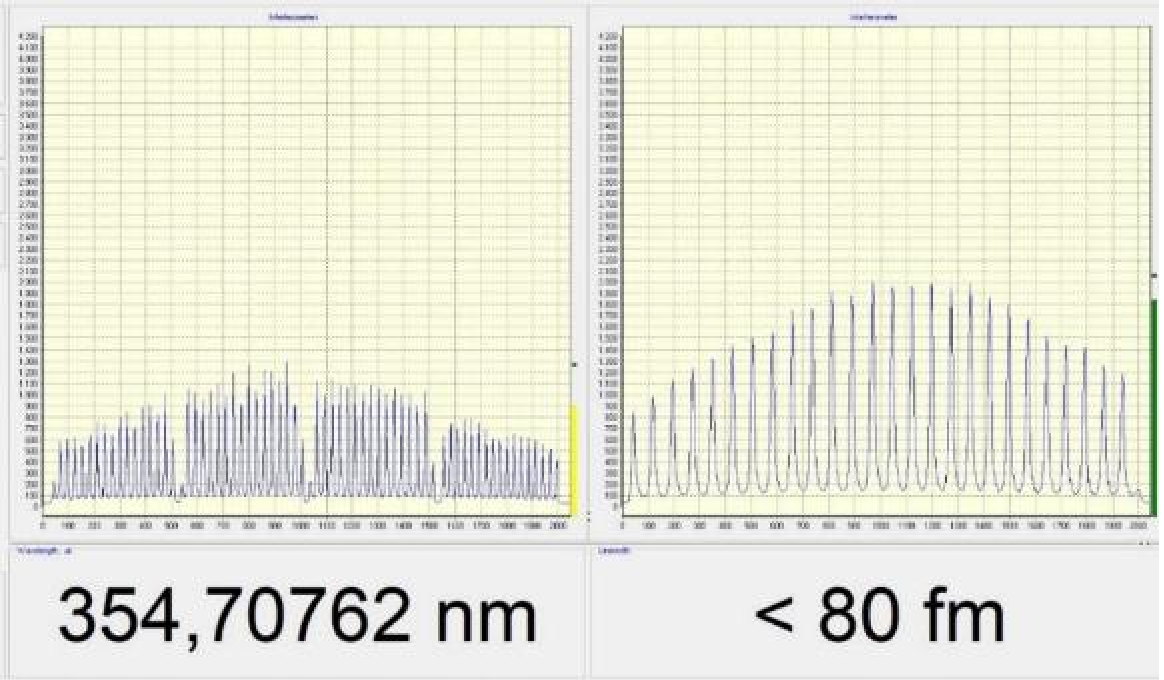
Performance – Coherence

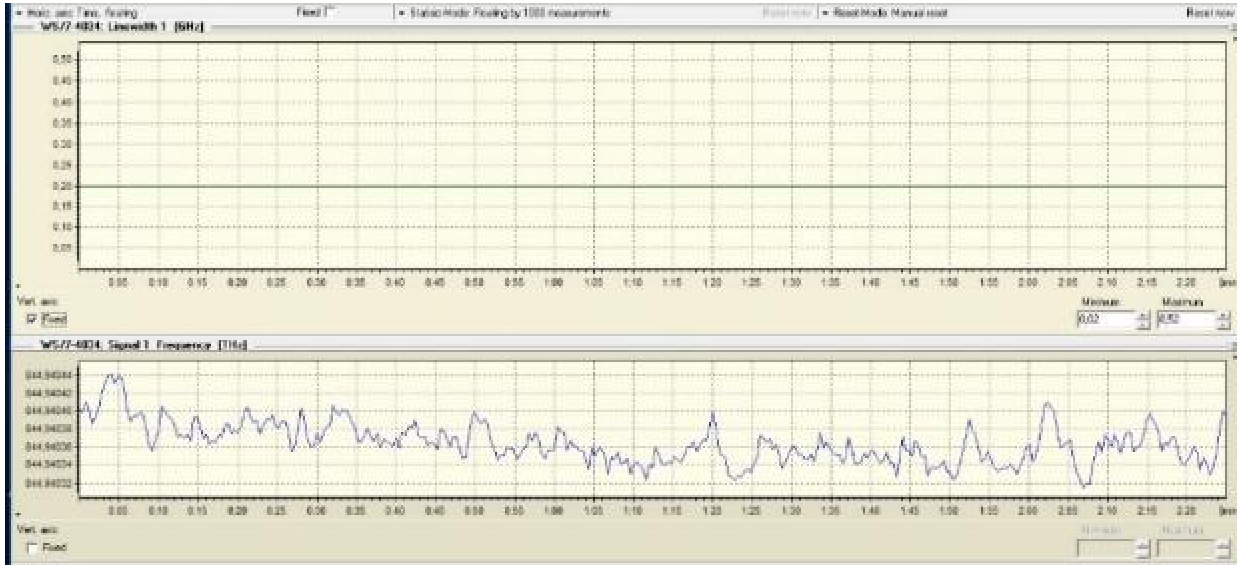
355 nm:

Δλ = << 80 fm; Δf = << 200 MHz → Coherence Length >> 1.2 meter



354,70762 nm

< 80 fm



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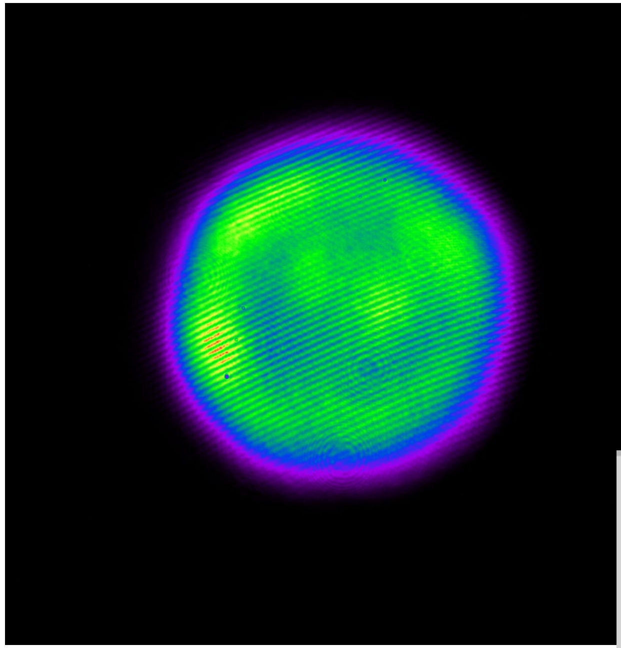
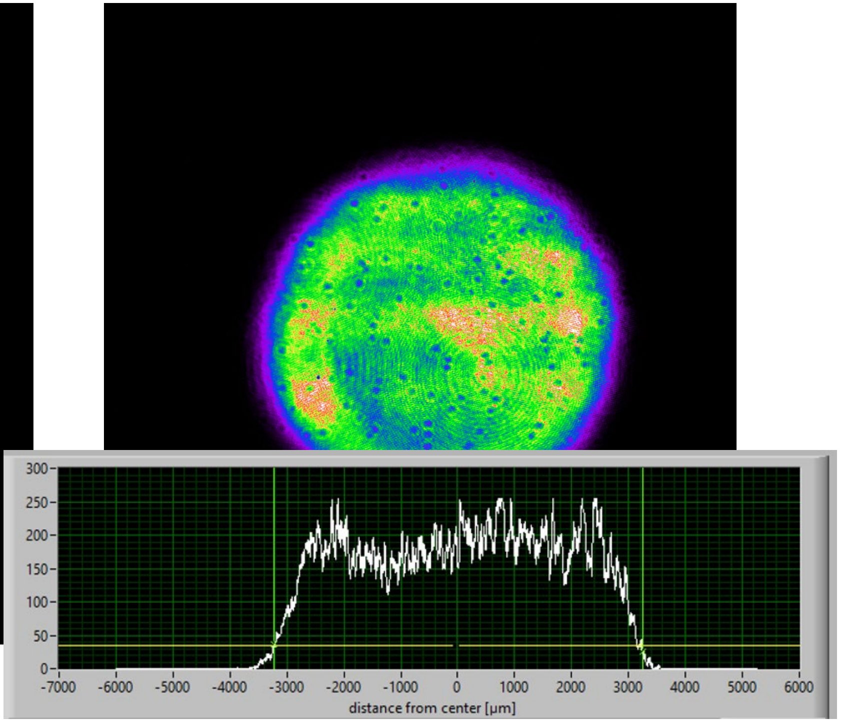
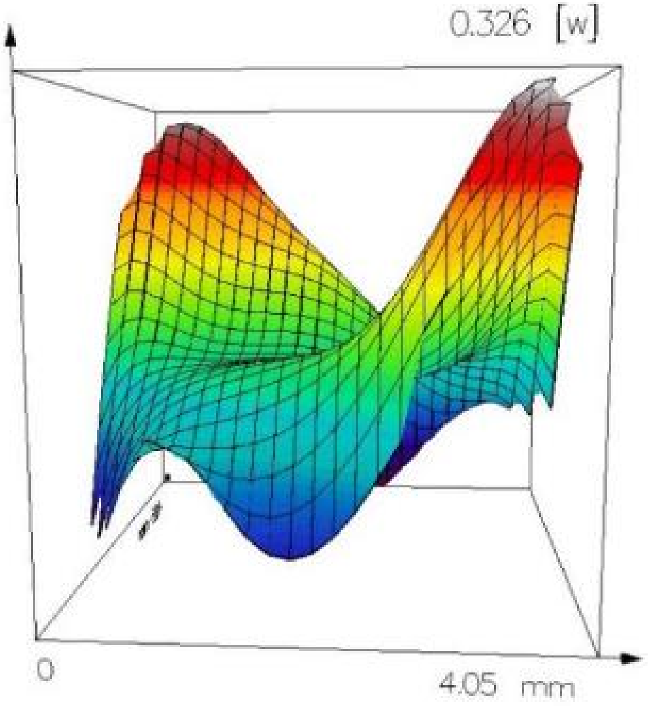
Performance – Beam profile and wavefront



1064 nm Near field



355 nm Near field



355 nm Near Field
P-V = 0.3 λ

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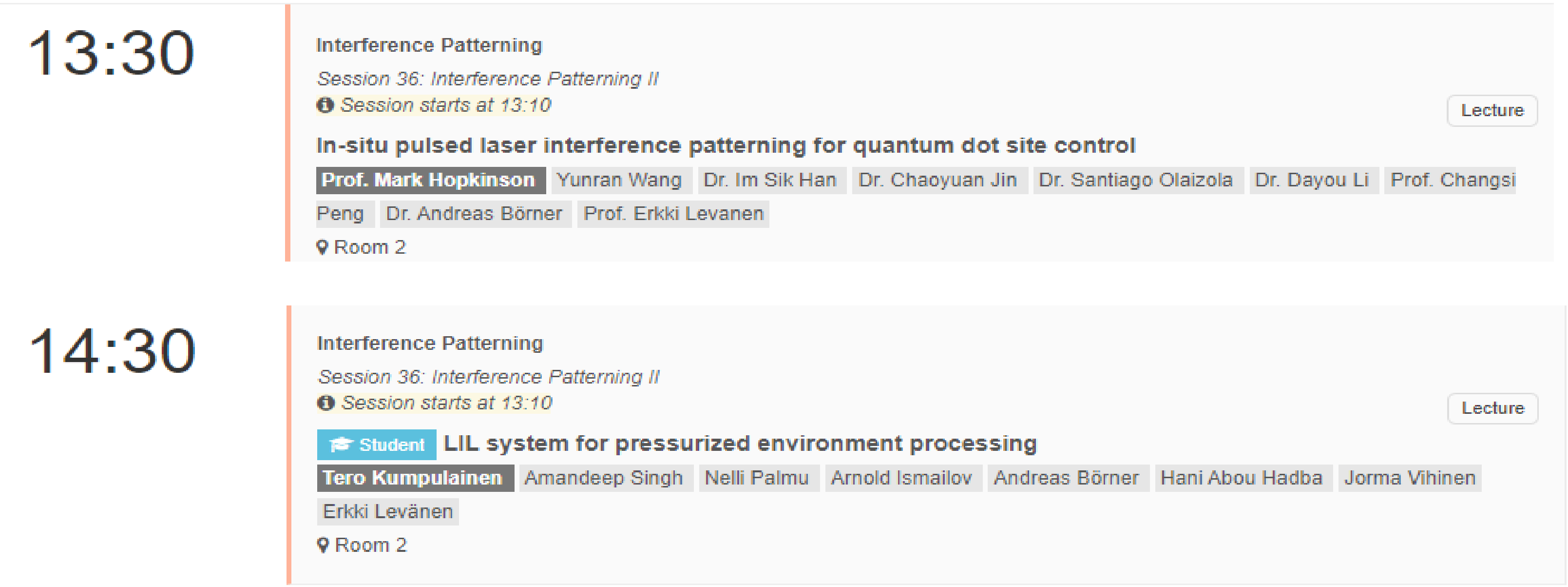
Thank you for listening

More detailed talks follow later today



13:30

Interference Patterning

Session 36: Interference Patterning II

Session starts at 13:10

Lecture

In-situ pulsed laser interference patterning for quantum dot site control

Prof. Mark Hopkinson Yunran Wang Dr. Im Sik Han Dr. Chaoyuan Jin Dr. Santiago Olaizola Dr. Dayou Li Prof. Changsi Peng Dr. Andreas Börner Prof. Erkki Levanen

Room 2

14:30

Interference Patterning

Session 36: Interference Patterning II

Session starts at 13:10

Lecture

Student **LIL system for pressurized environment processing**

Tero Kumpulainen Amandeep Singh Nelli Palmu Arnold Ismailov Andreas Börner Hani Abou Hadba Jorma Vihinen Erkki Levänen

Room 2

Please feel free to talk with us at the Innolas stand

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