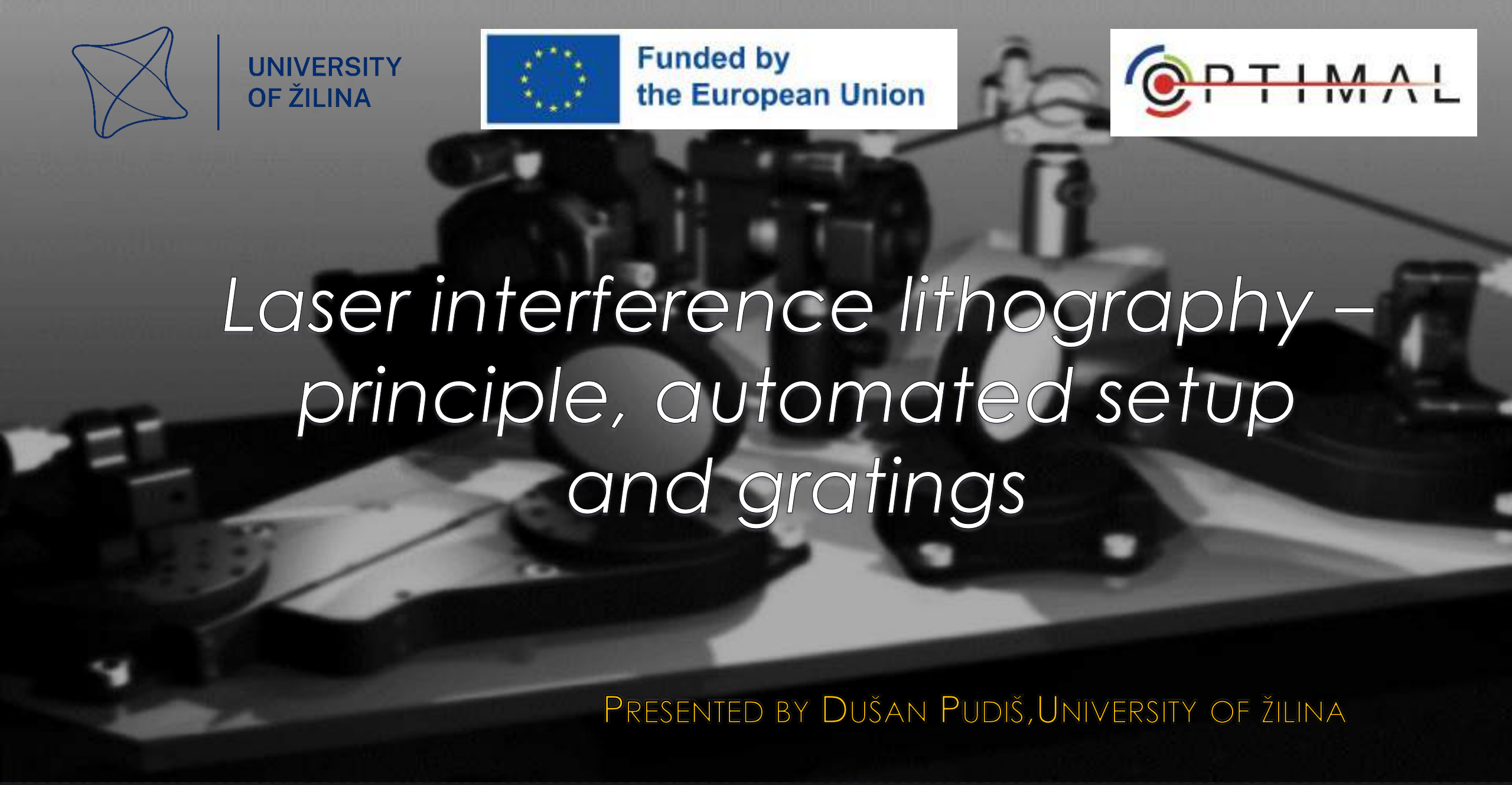


UNIVERSITY OF ŽILINA

Funded by the European Union

OPTIMAL

# Laser interference lithography – principle, automated setup and gratings

PRESENTED BY DUŠAN PUDIŠ, UNIVERSITY OF ŽILINA



KIA motors

Peter
**Sagan**

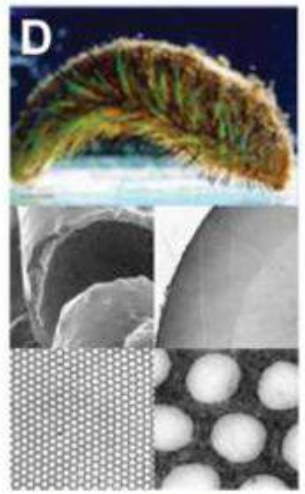
**UNIZA - 7 faculties**
*124 Study programs (43 Bc / 51 MSc / 30 PhD)*
*Students (6835 int / 550 ext)*

**Faculty of Electrical Engineering and Information Technology**
*22 Study programs*
*Students (1028 int / 29 ext)*

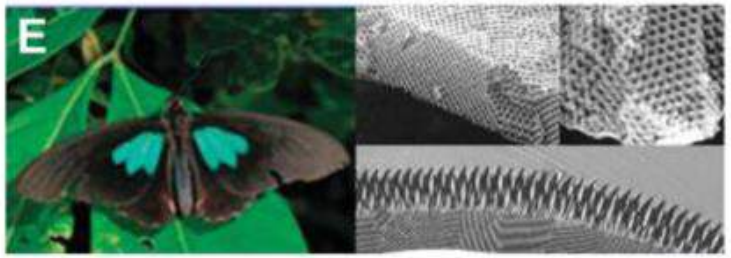
*University of Žilina (UNIZA)*

# Gratings inspired by nature

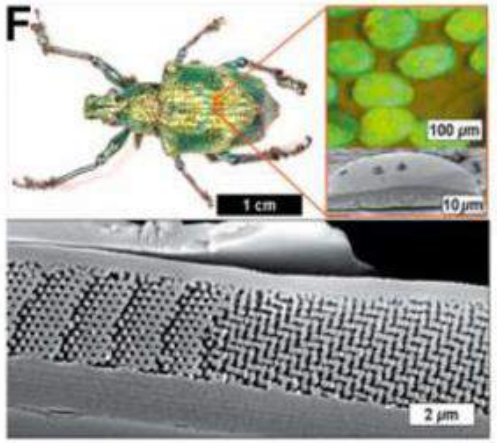
...waau, photonics on the wings



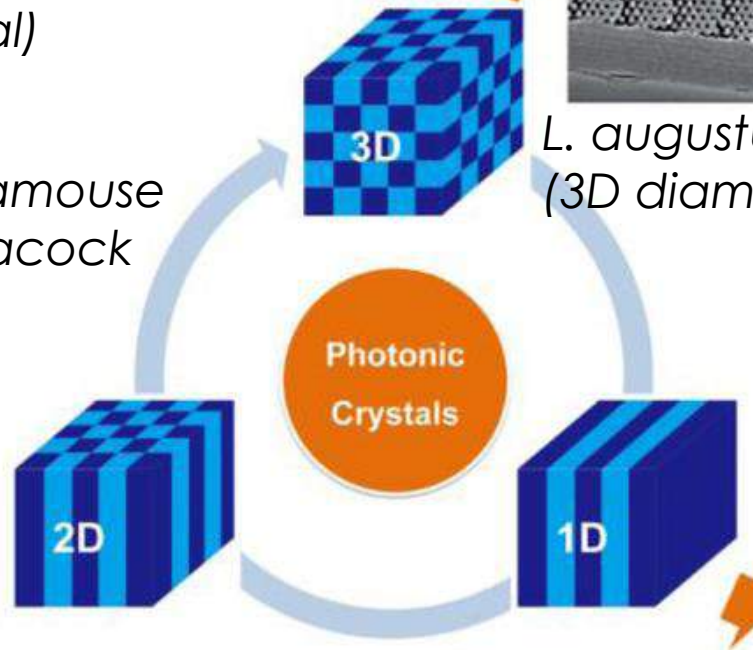

Seamouse
Peacock

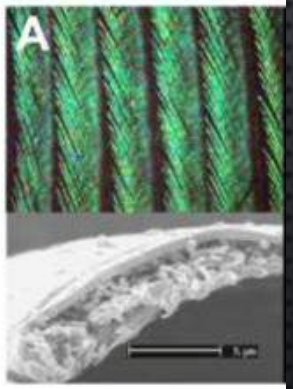


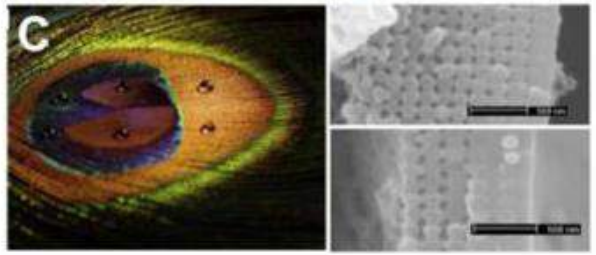

*Parides sesostris*
*(3D inverse opal)*



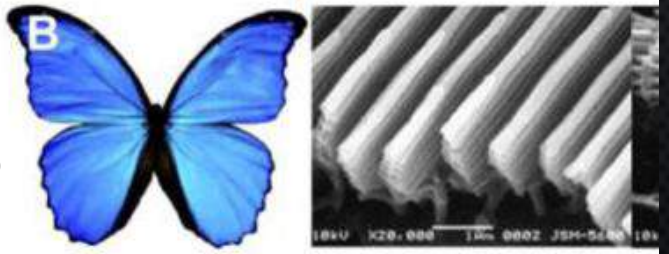

*L. augustus*
*(3D diamond structure)*



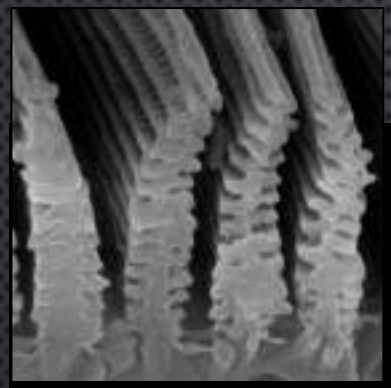

Morpho



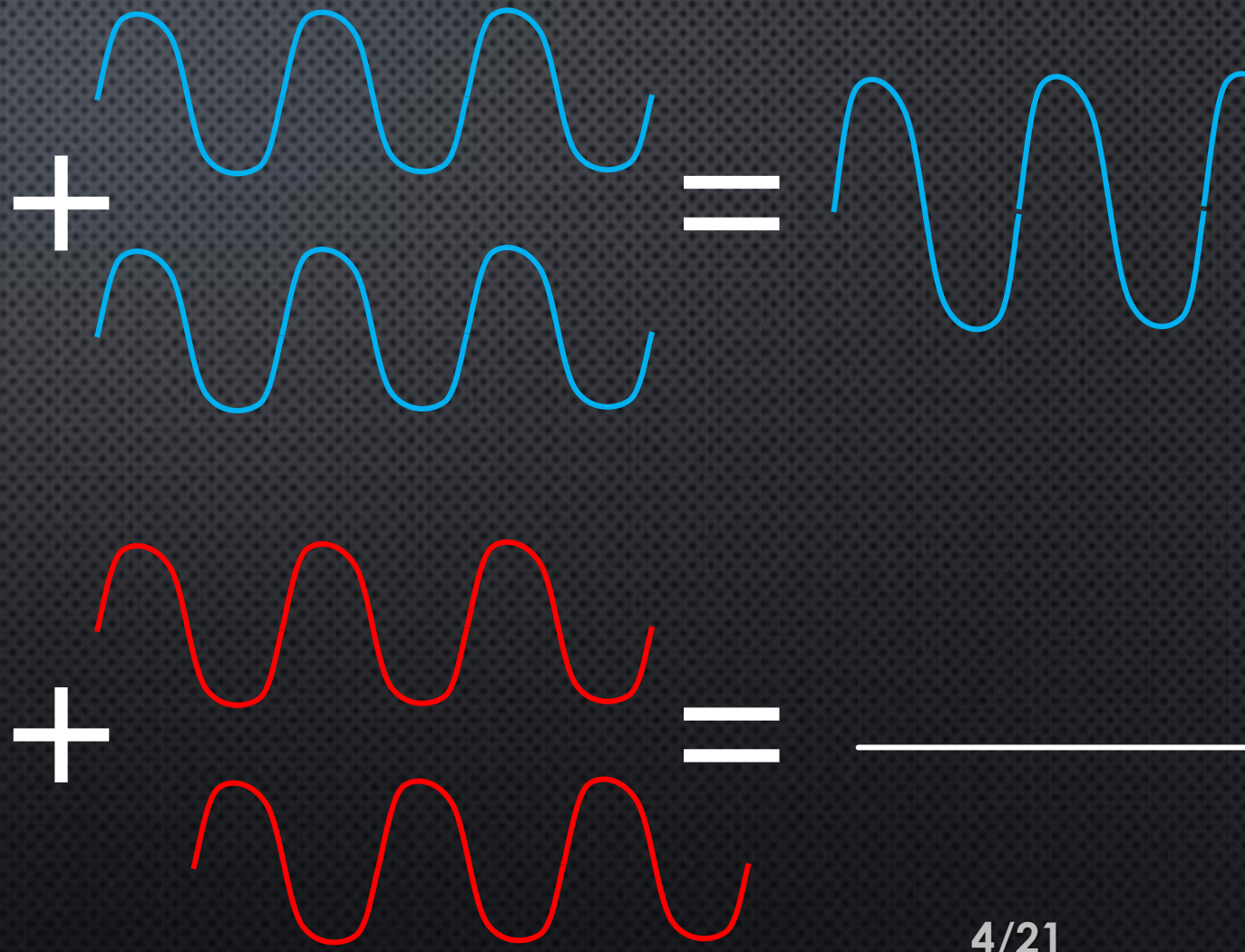

*Apatura iris*

*Tmesisternus isabellae (wet/dry)*

# How it works?

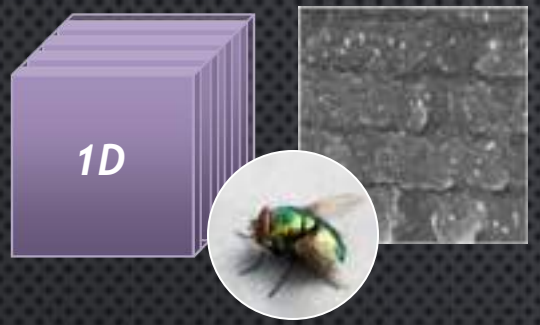



Incident
white light
Reflected
blue light
Just blue wavelength
corresponds to
the distance
of the layers

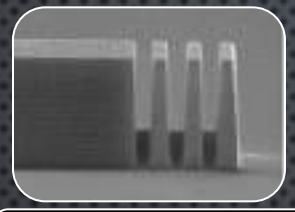


# From nature to technology

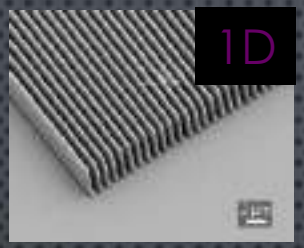
*Nature* *Technology*

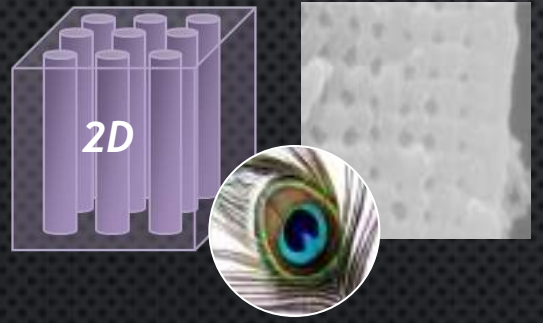




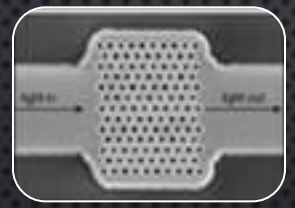



Bragg reflector

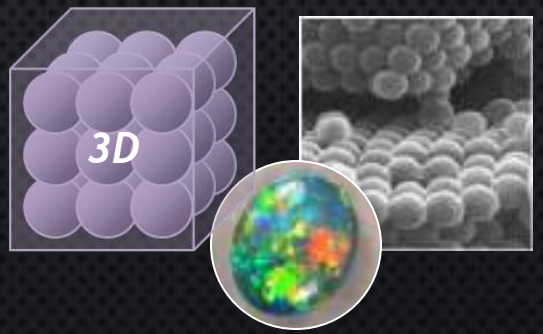


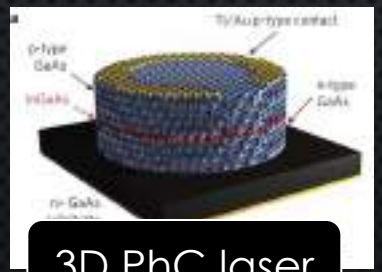


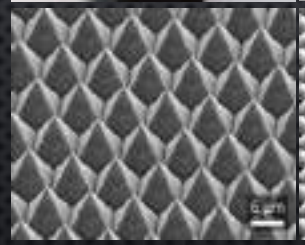
PhC slabs

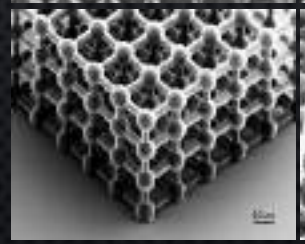





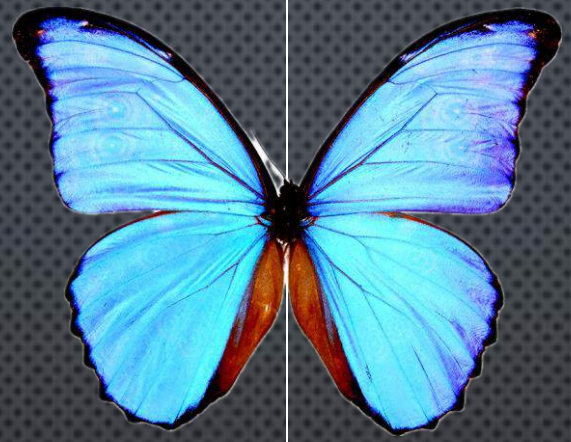
3D PhC laser



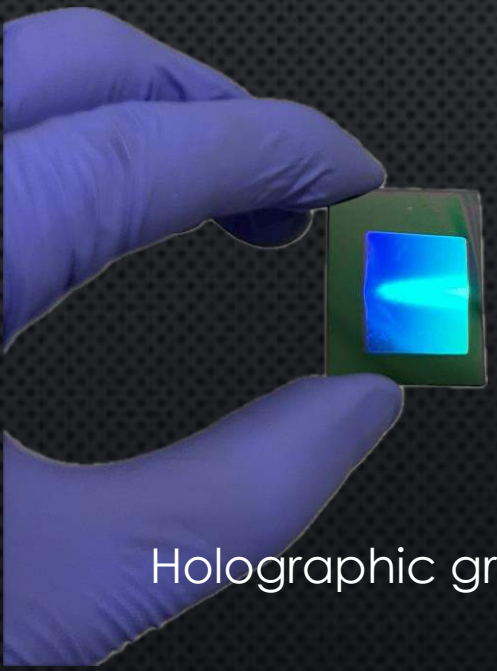



# Interference Lithography | Holographic gratings

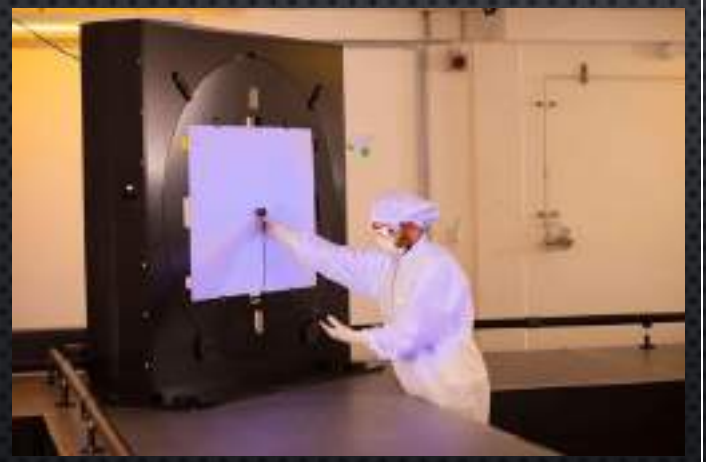
- **Large area patterning**
- **Customizability**
- **Rapid prototyping**
- Sub-micron resolution
- Non-contact fabrication

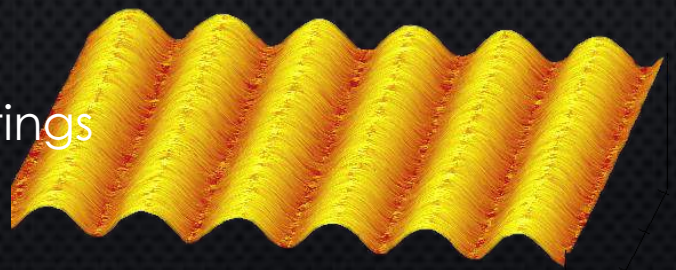


- **Laser systems**
- **Sensing**
- **Filters**
- **Optical communications**



Holographic gratings





Grooved gratings

# Laser interference lithography - single exposure

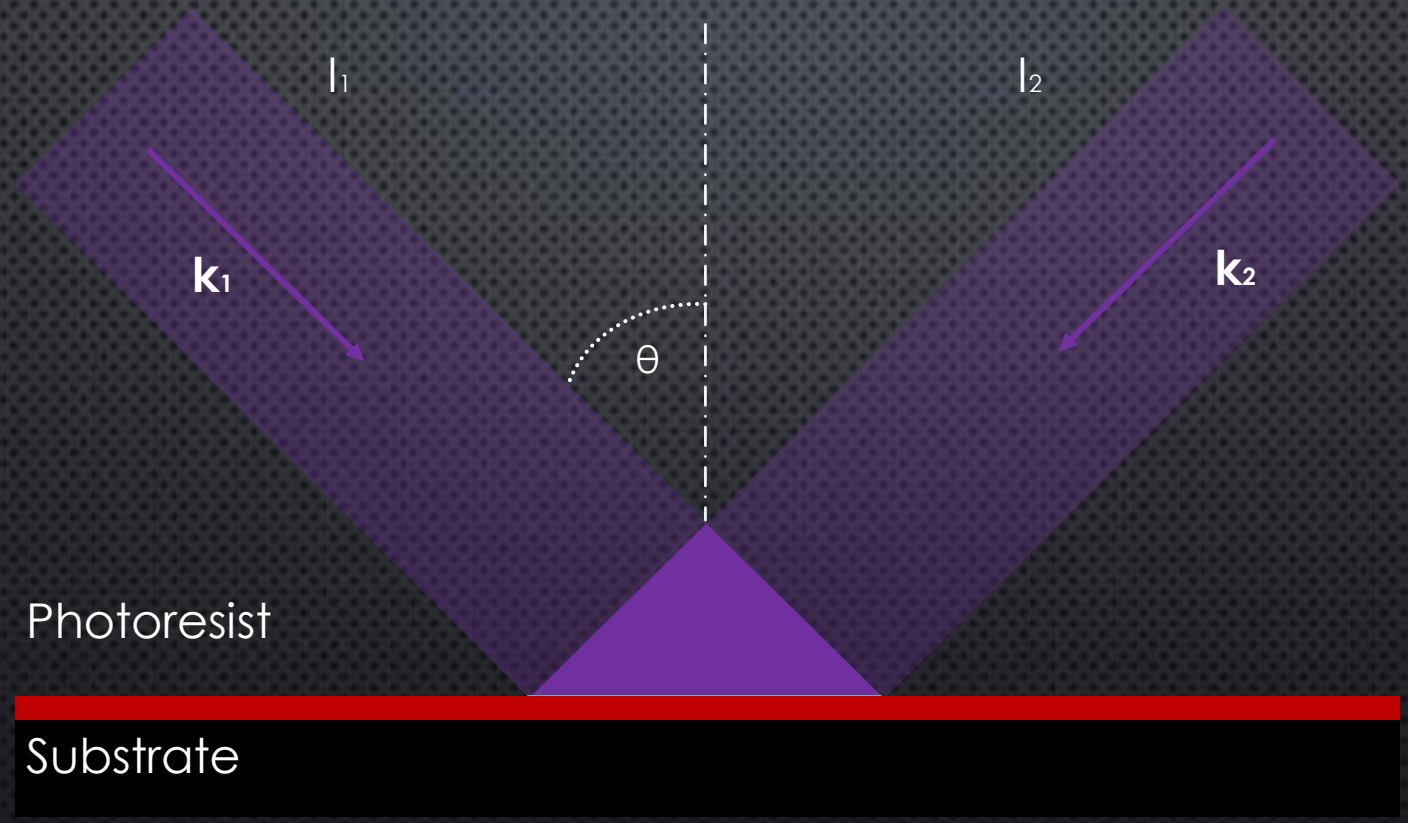
$$E_1 = E_{10}e^{i(\omega t + \boldsymbol{k}_1 \cdot \boldsymbol{r})} = E_{10}e^{i\varphi_1}$$

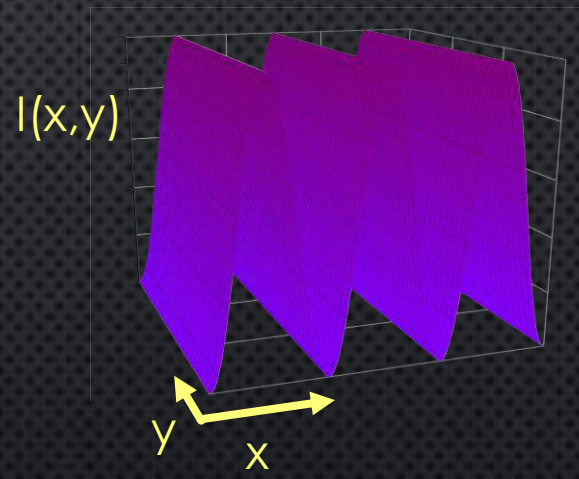
$$E_2 = E_{20}e^{i(\omega t + \boldsymbol{k}_2 \cdot \boldsymbol{r})} = E_{20}e^{i\varphi_2}$$

$$\Lambda = \frac{\lambda}{2\sin\theta}$$

| | | |
|---|---|---|
| 8° | ⇔ | 1500 nm |
| 12° | ⇔ | 1000 nm |
| 24° | ⇔ | 500 nm |
| 54° | ⇔ | 250 nm |

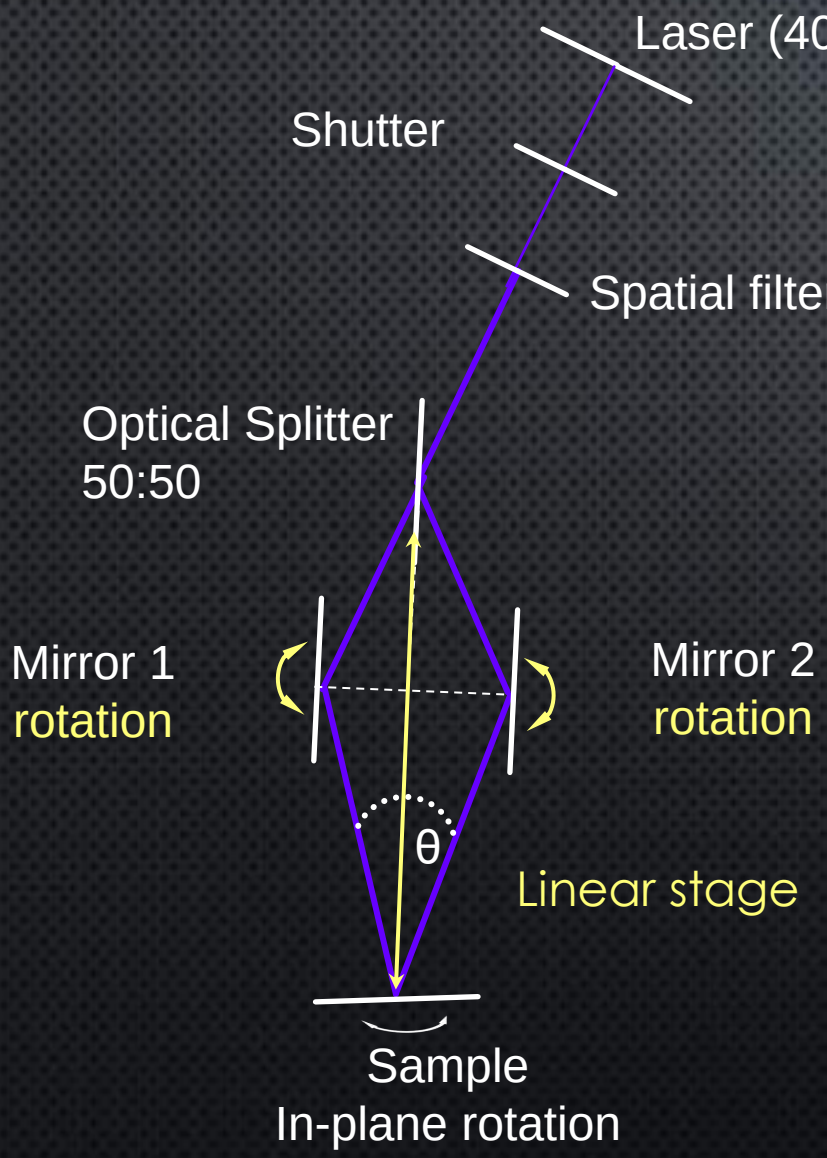
405 nm Laser

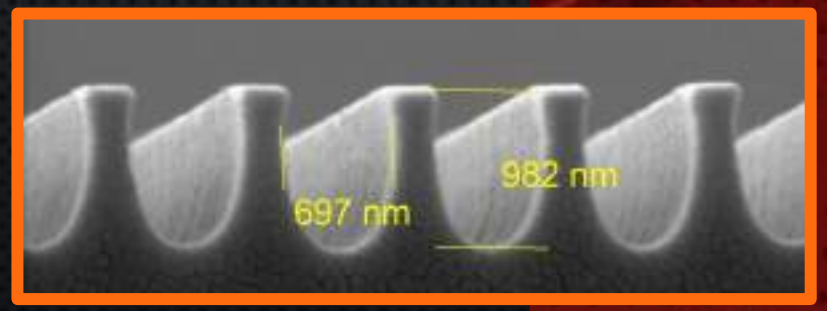


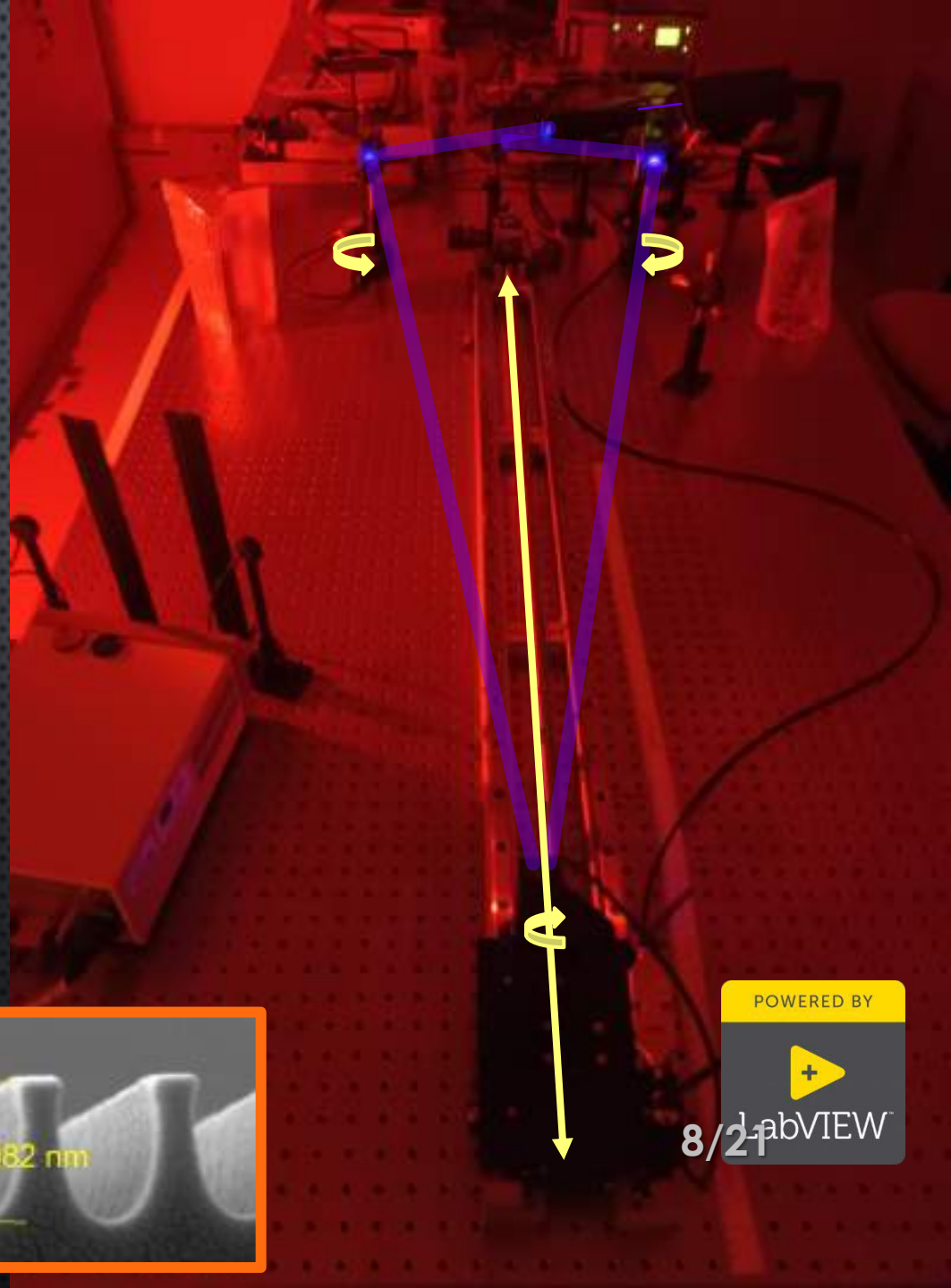




$$I = \sum_{i=1}^{n} I_i = 4\sum_{i=1}^{n} E_{0i}^2 [\cos(kx\sin\theta)(x\sin\alpha_i + y\cos\alpha_i)]^2$$

# Experimental setup of interference lithography



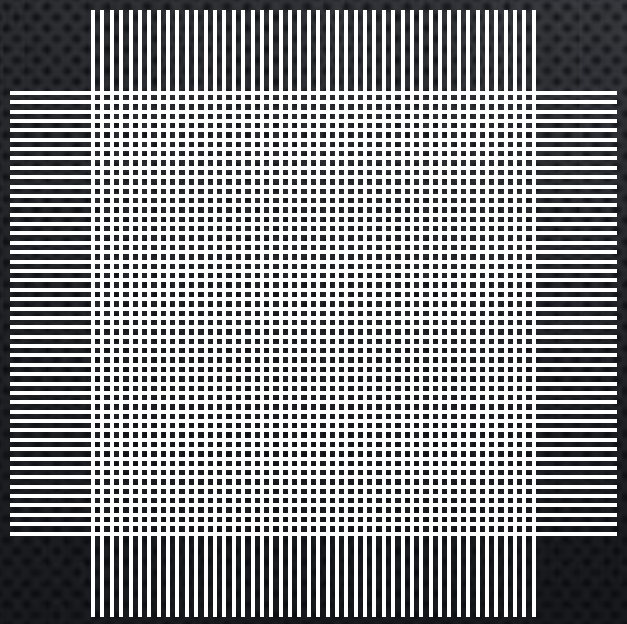



# Laser interference lithography – multiple exposure

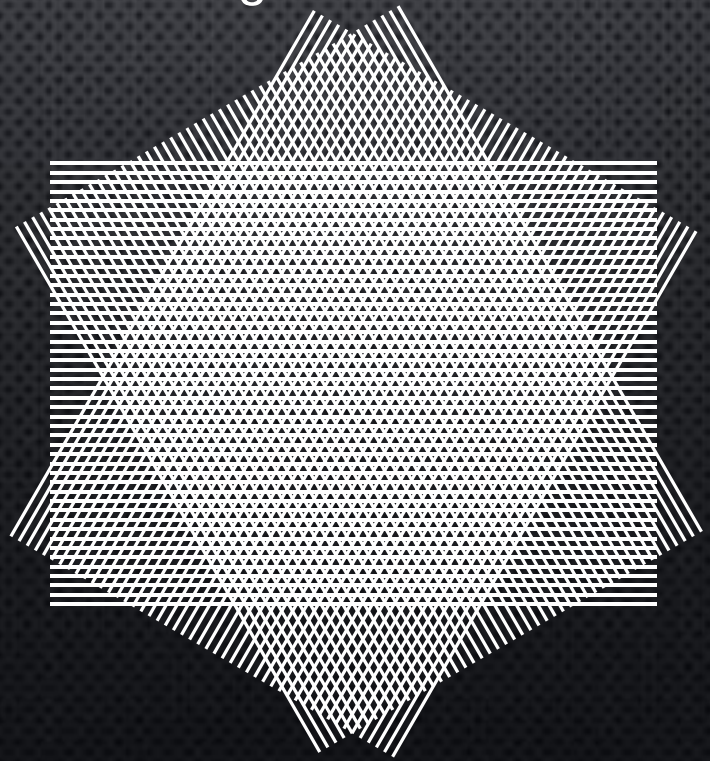
Rotation and cumulation of exposure doses

- 2D structures
- Moiré effect

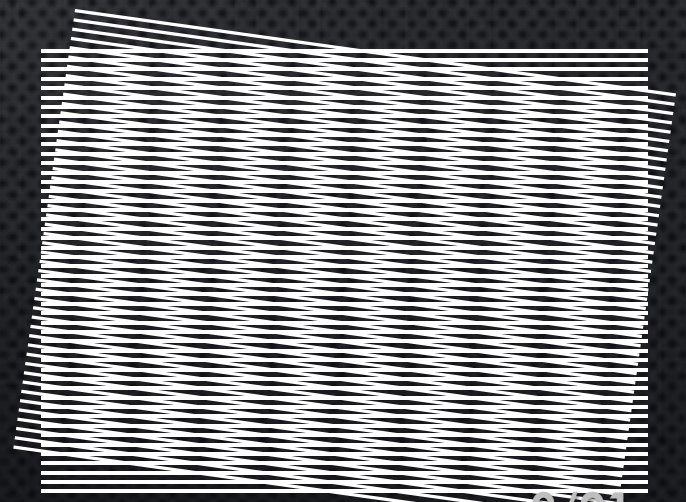
2D square lattice



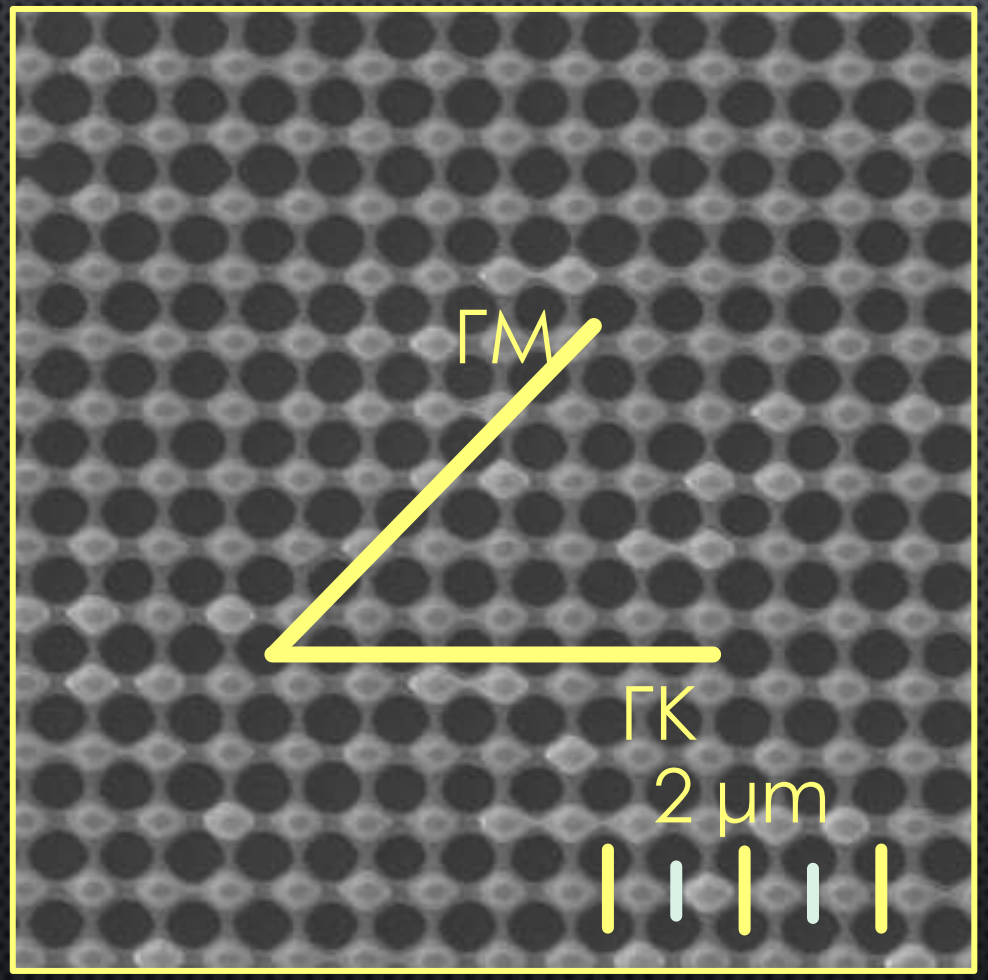
2D triangular lattice



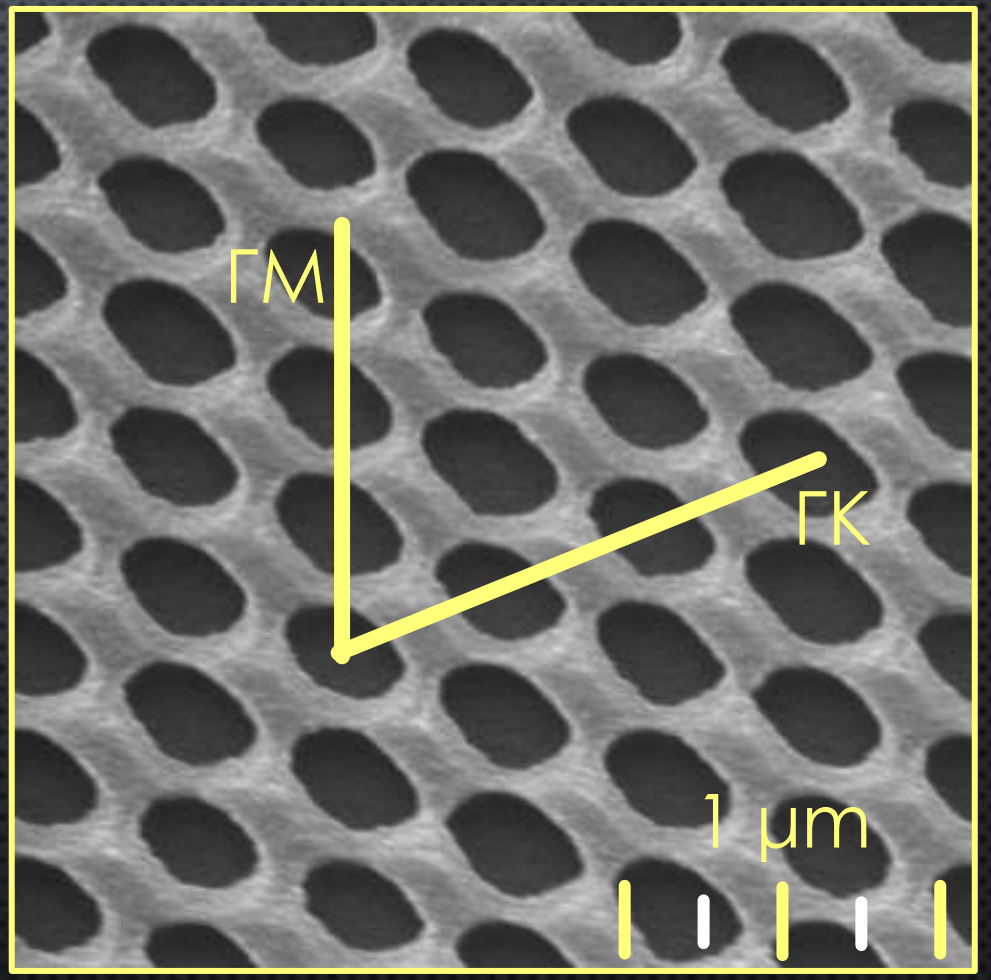
Moiré effect



# Laser interference lithography – multiple exposure




Λ = 500 nm




Λ = 600 nm

# Ultra wide range of periods

**250 nm ↔ 250 000 nm**
**(λ/2) (infinity)**

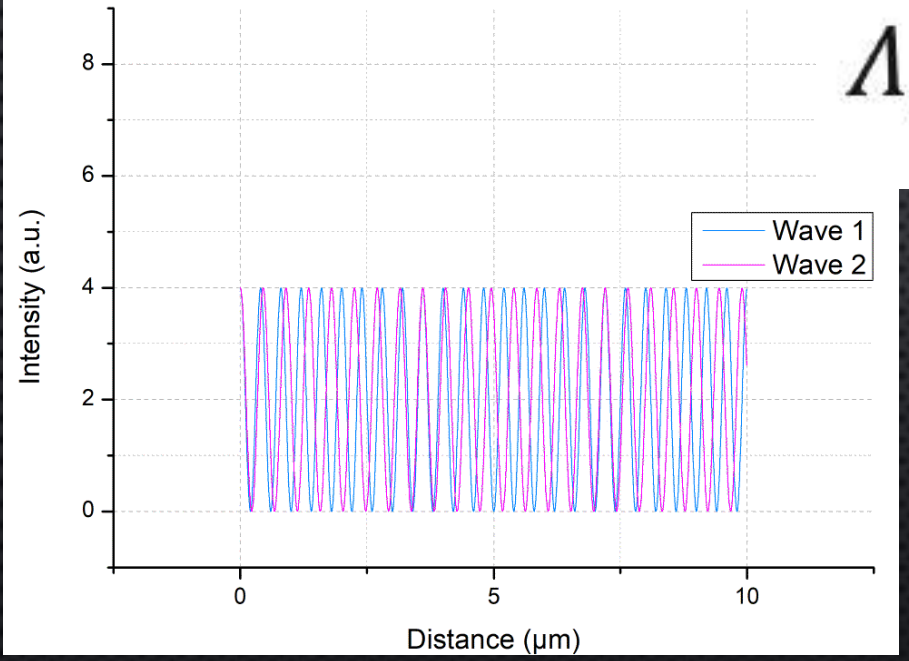
# Period mixing principle – multiple exposures

$$I = I_1 + I_2$$

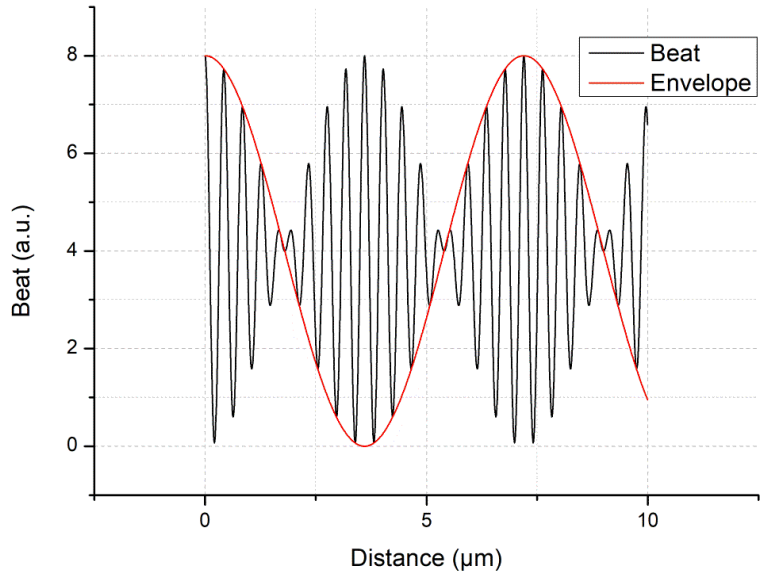
$$I = 4E_0^2 \left[\cos^2\left(\frac{\pi}{\Lambda_1}x\right) + \cos^2\left(\frac{\pi}{\Lambda_2}x\right)\right]$$

$$I = 4E_0^2 + 4E_0^2 \cos\left(\pi\frac{\Lambda_1 + \Lambda_2}{\Lambda_1\Lambda_2}x\right)\cos\left(\pi\frac{\Lambda_2 - \Lambda_1}{\Lambda_1\Lambda_2}x\right)$$

$$\Lambda_{env} = \frac{\Lambda_1\Lambda_2}{\Lambda_2 - \Lambda_1}$$



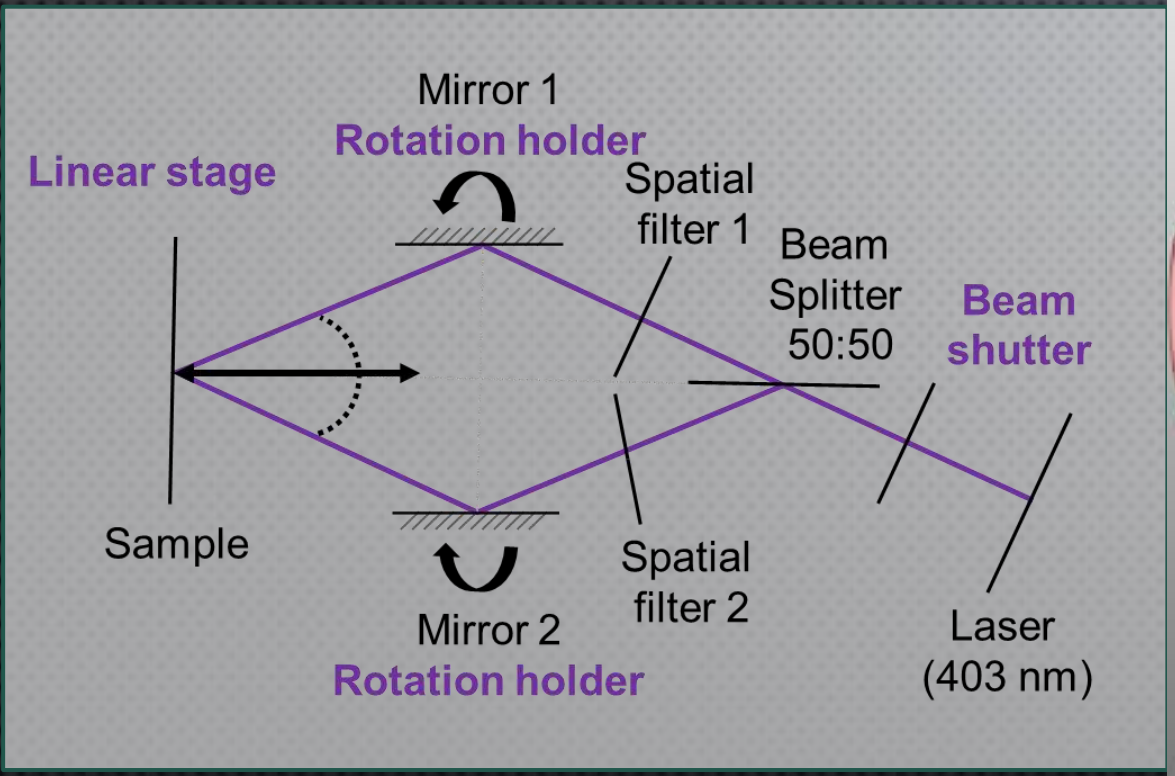

Wave 1 & Wave 2



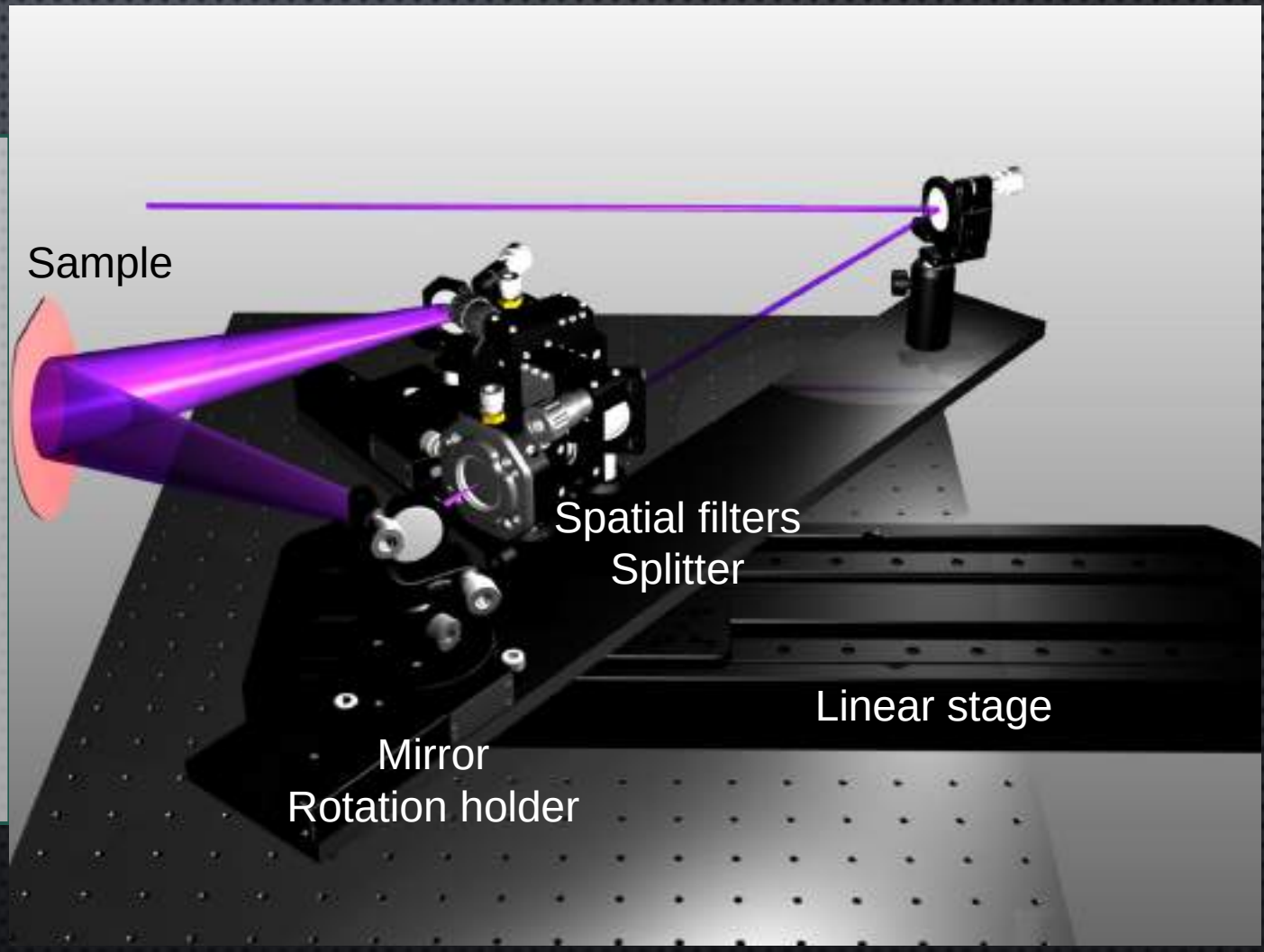

Resulting field

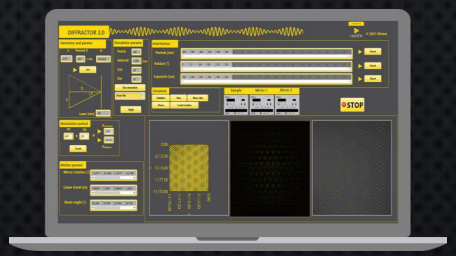
# Period mixing: setup design

## Moving sample, static optics



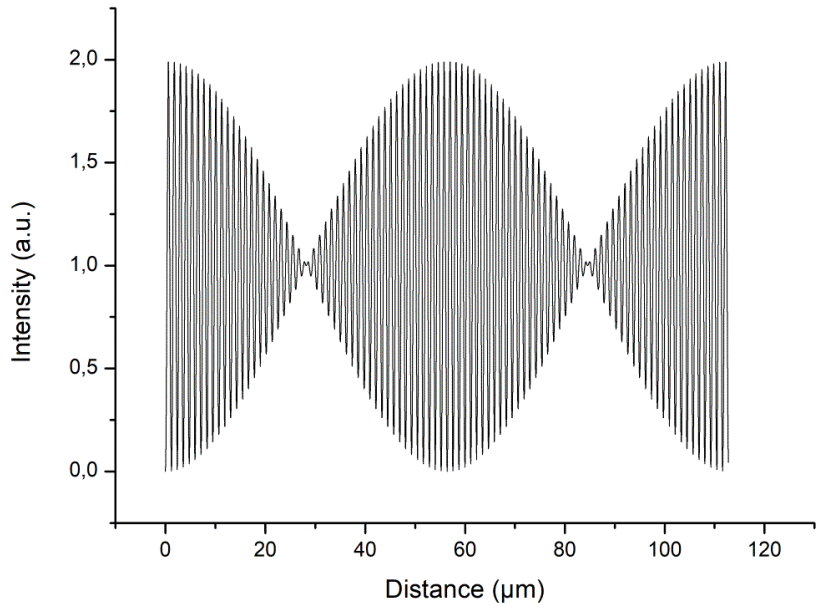

## Static sample, moving optics

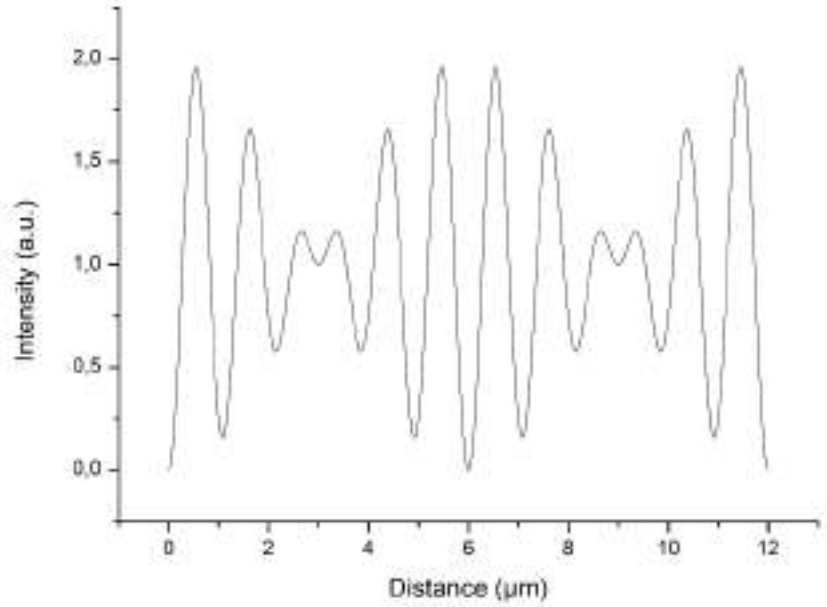


**LabVIEW controlled and fully automated**

# Period mixing: structures design and simulation



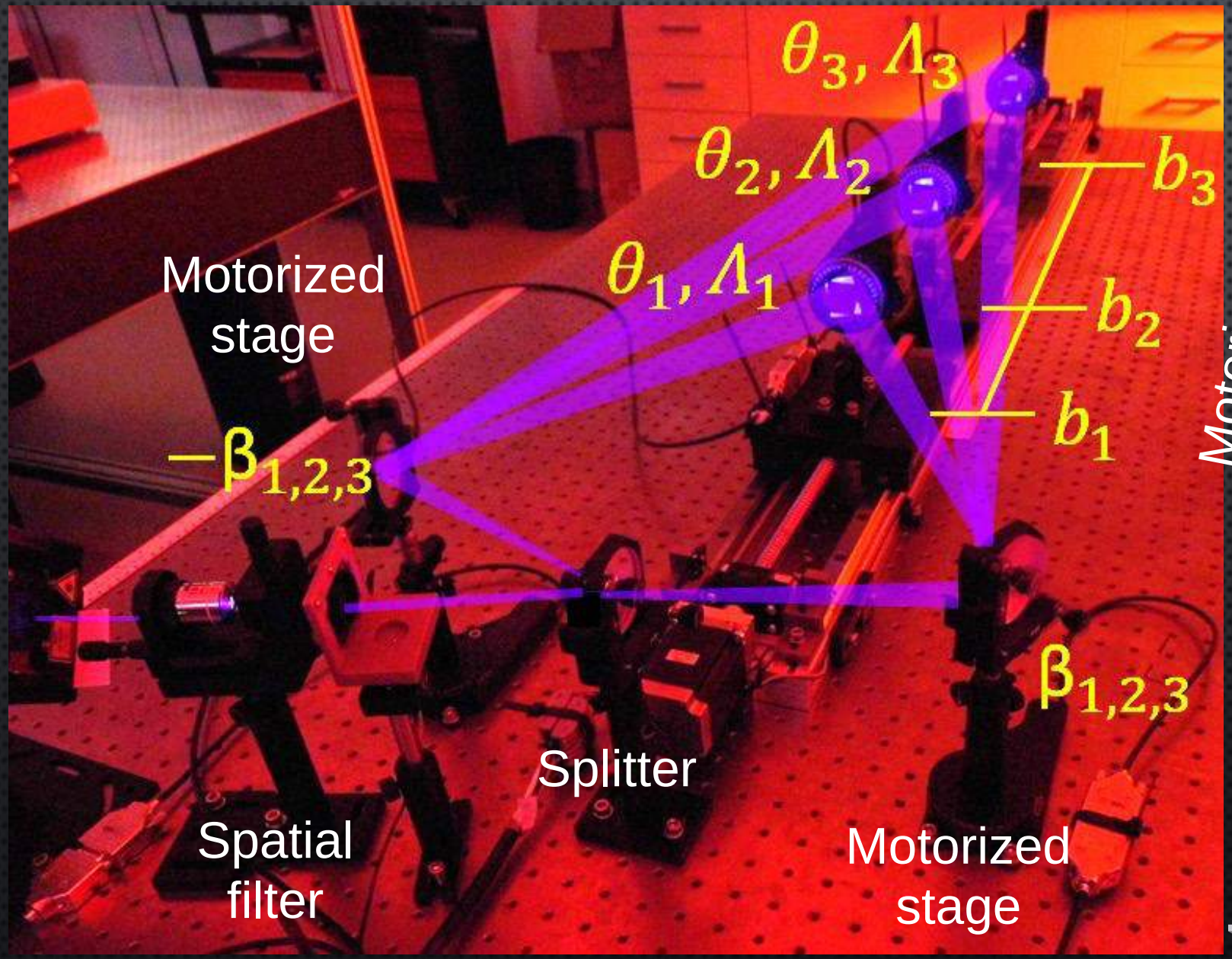




**Small period difference = Large period Grating**

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Wave 1 [μm] | 1.200 | 1.200 | 1.200 | 1.200 |
| Wave 2 [μm] | 1.195 | 1.175 | 1.100 | 1.000 |
| Λ diff. [μm] | 0.005 | 0.025 | 0.100 | 0.200 |
| Envelope [μm] | 287 | 56 | 13 | 6 |
| Internal [μm] | 1.197 | 1.187 | 1.148 | 1.091 |

**Large period difference = Small period Grating**

# Laser interference lithography experimental setup




Motorized stage

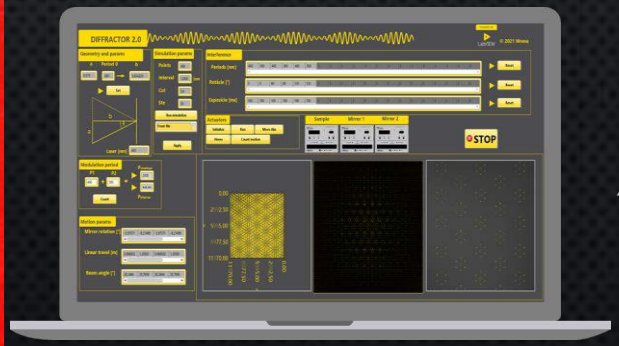
Single exposure:
250 – 1000 nm

Period mixing:
250 – 250 000 nm

**Exposure dose**

**Period tuning**

**Sample rotation**



## Small period difference = Large period Grating

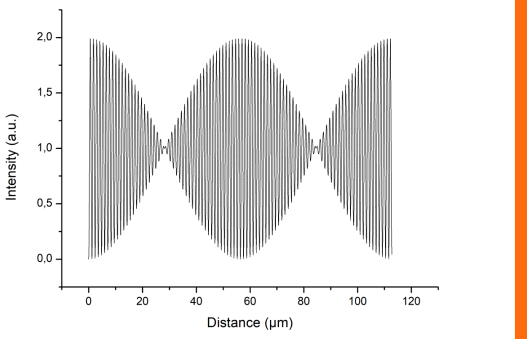
**Period 1:** 1200 nm

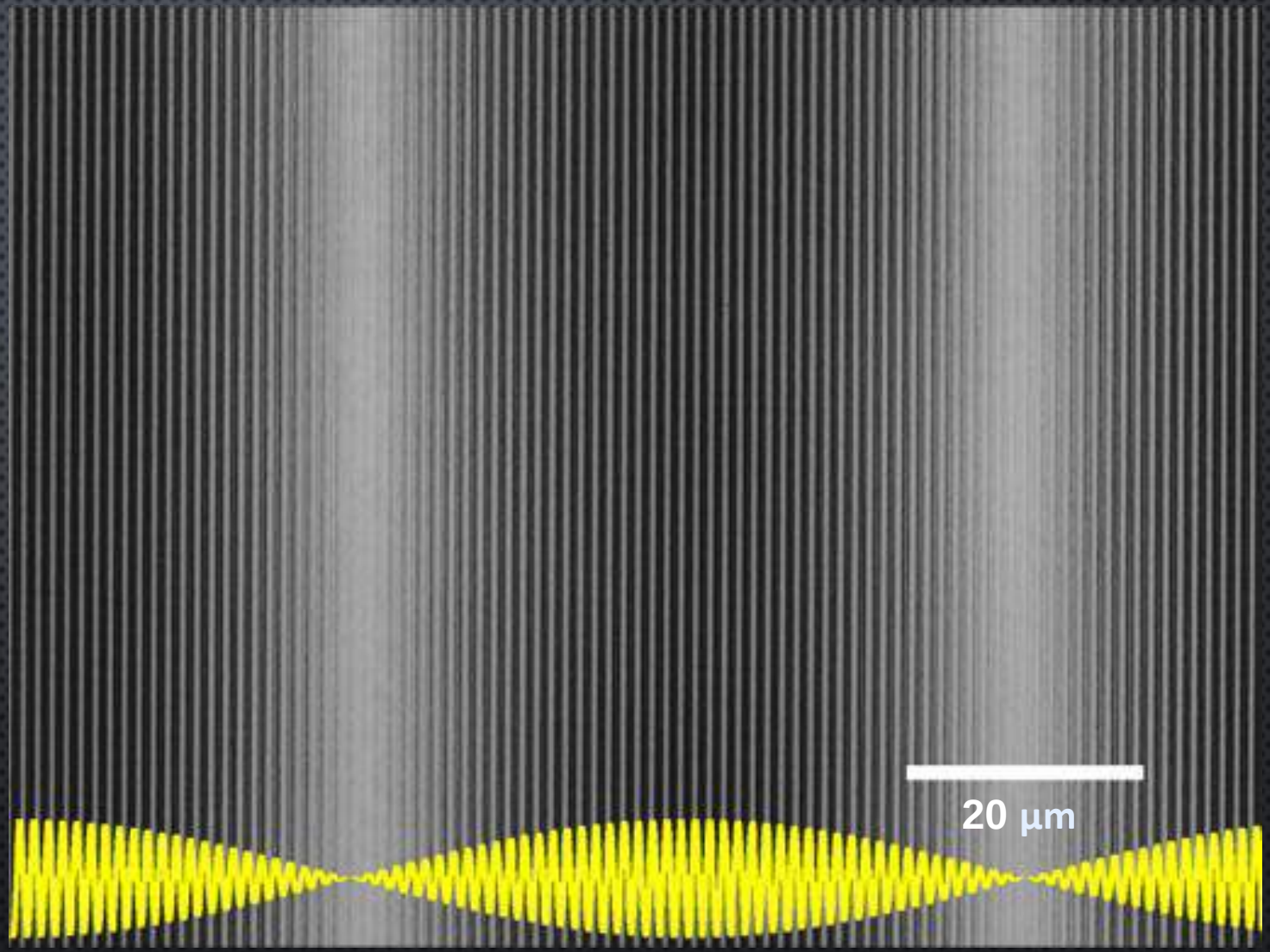
**Period 2:** 1175 nm

**Period diff:** 25 nm

**Envelope:** 56 000 nm

**Internal:** 1187 nm



## Large period difference = Small period Grating

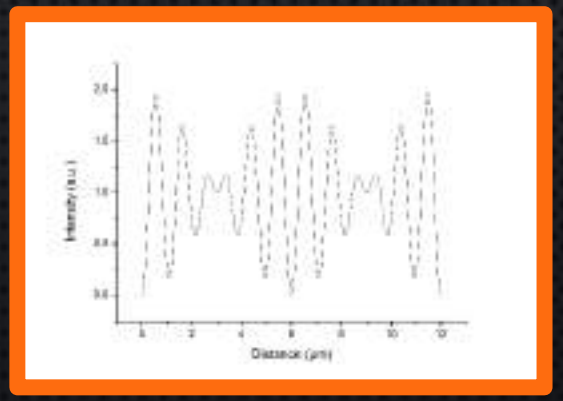
**Period 1:** 1200 nm

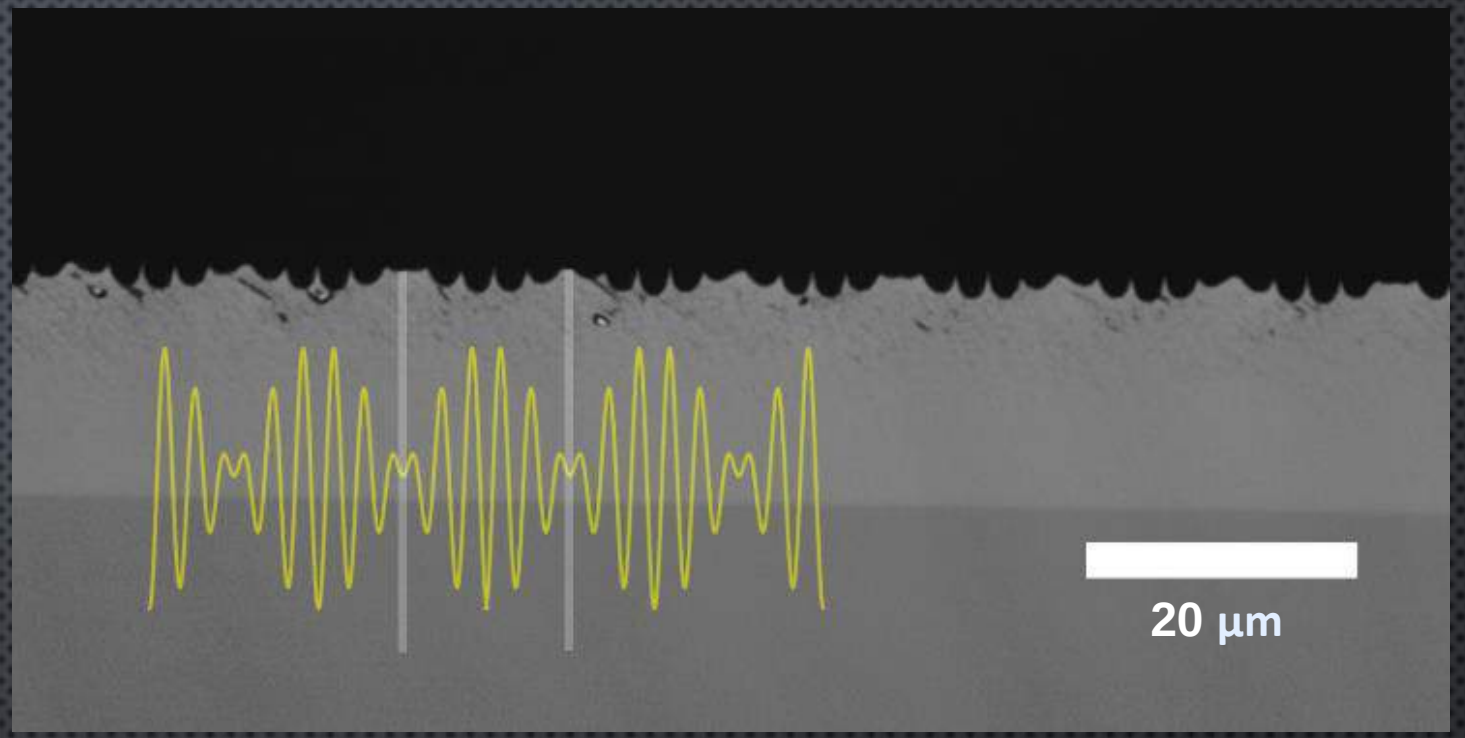
**Period 2:** 1000 nm

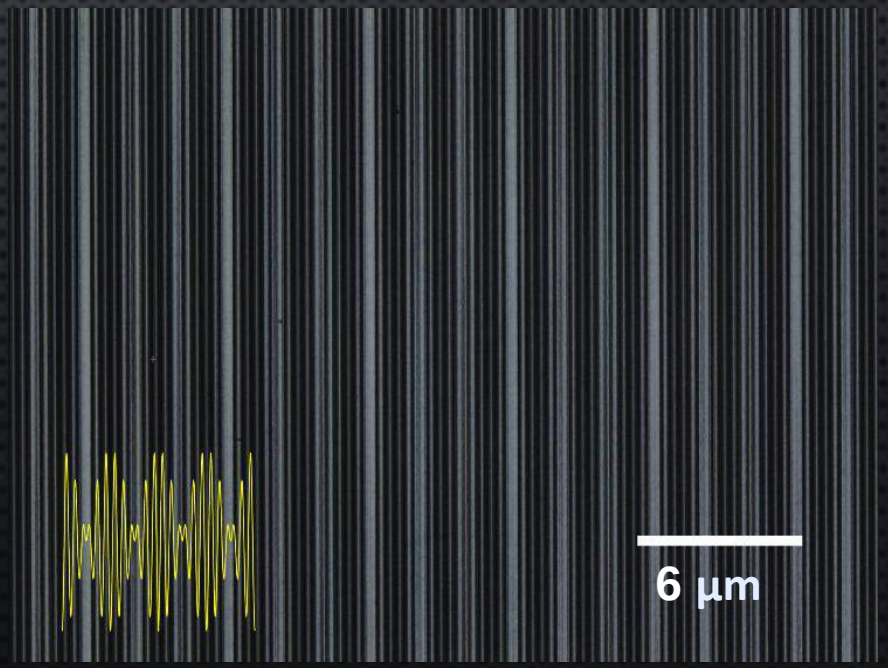
**Period diff:** 200 nm

**Envelope:** 6000 nm

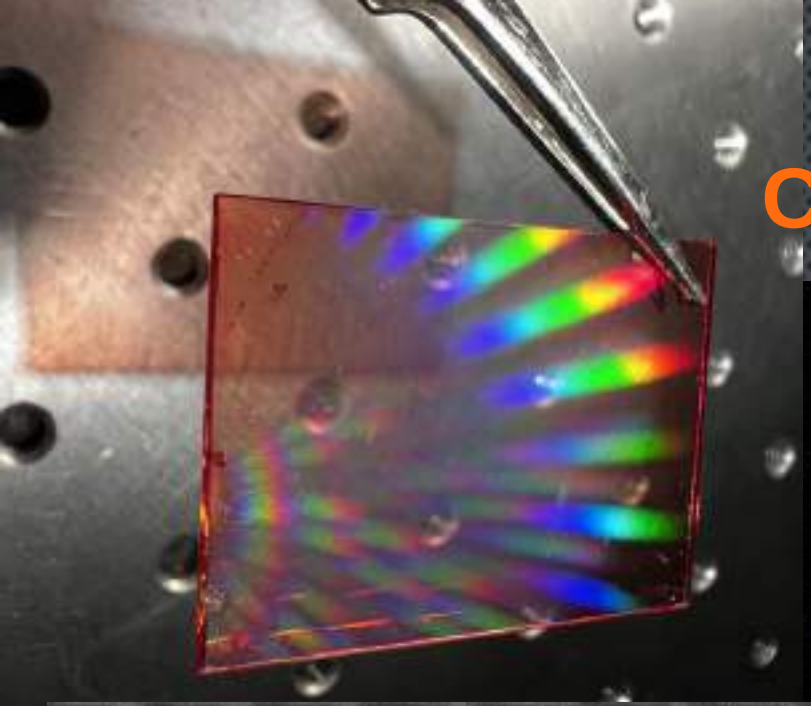
**Internal:** 1091 nm

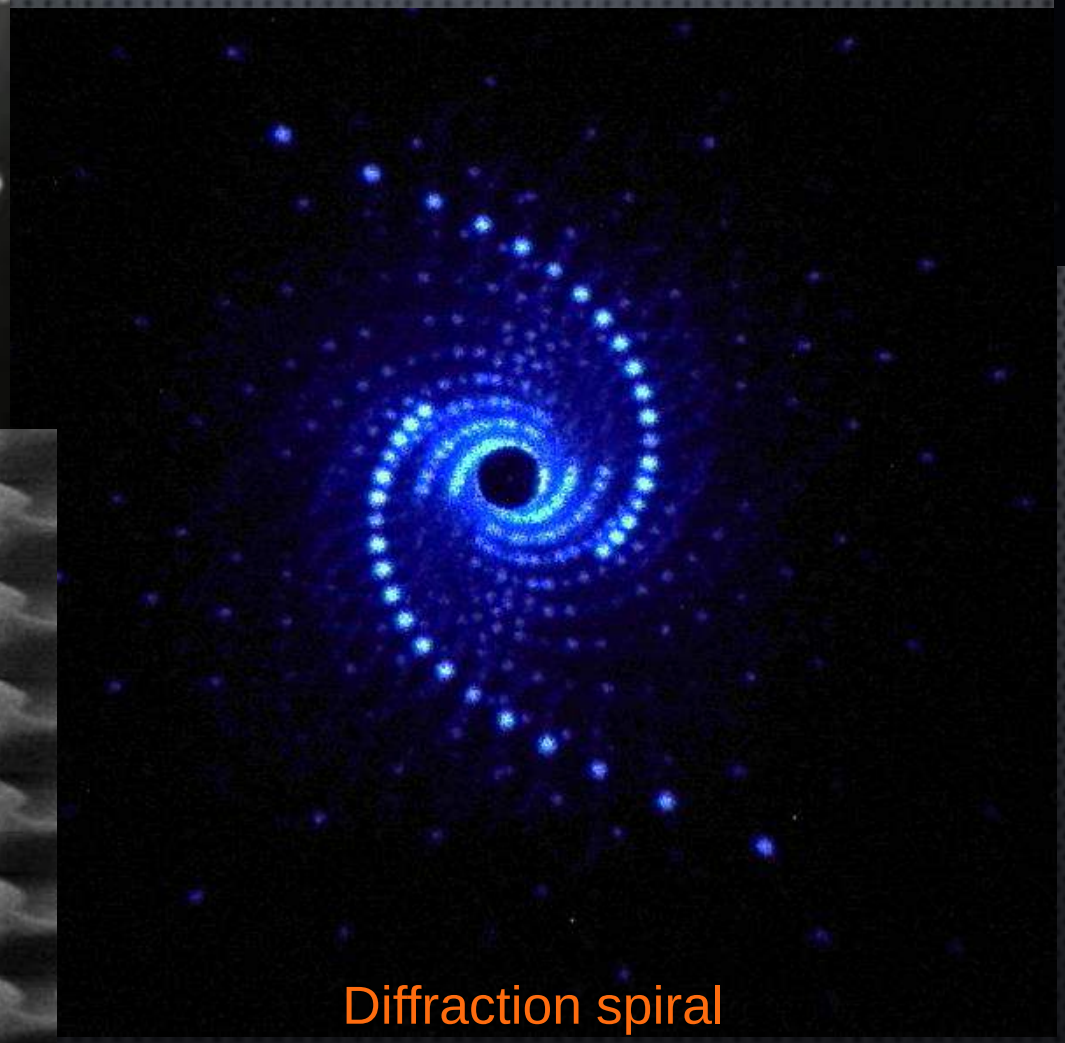


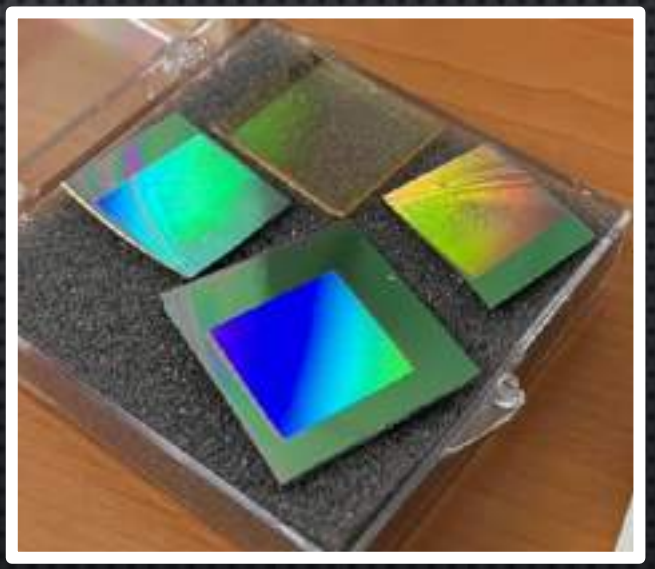


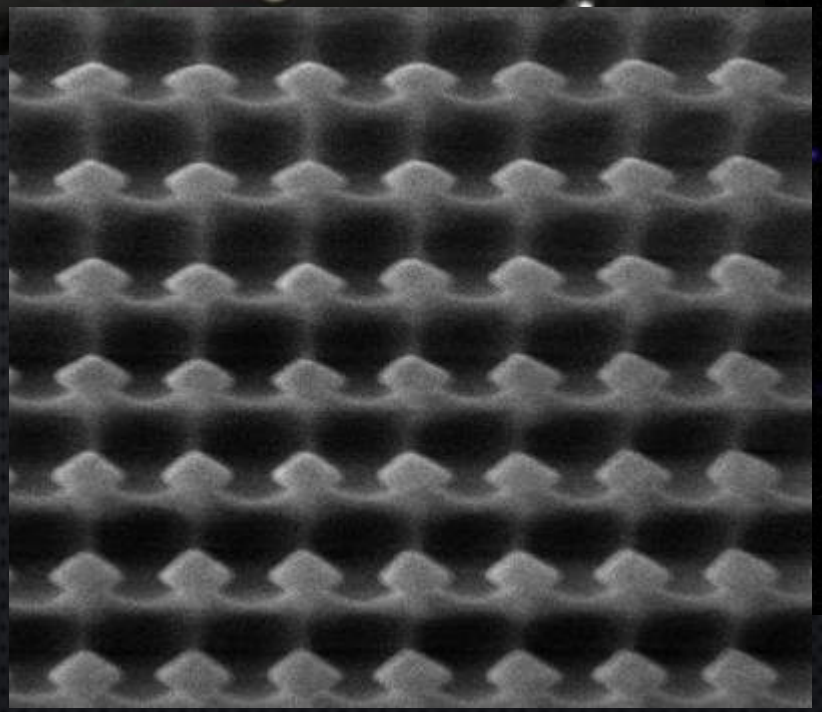



# Complicated symmetries
# Change of period & rotation





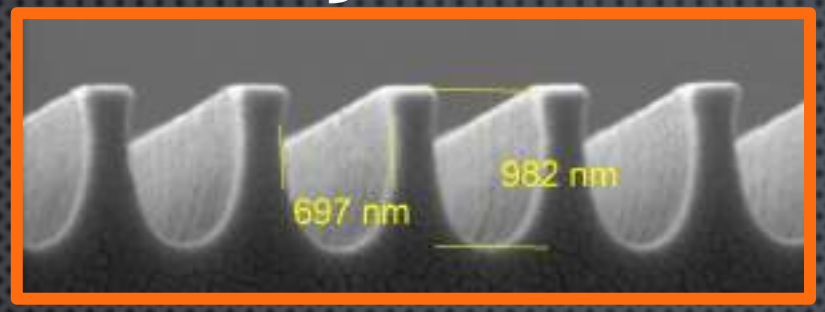


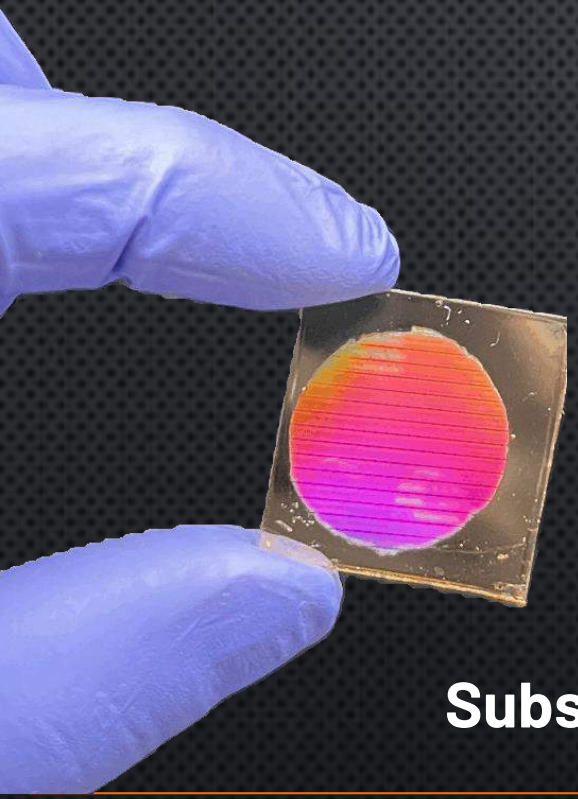


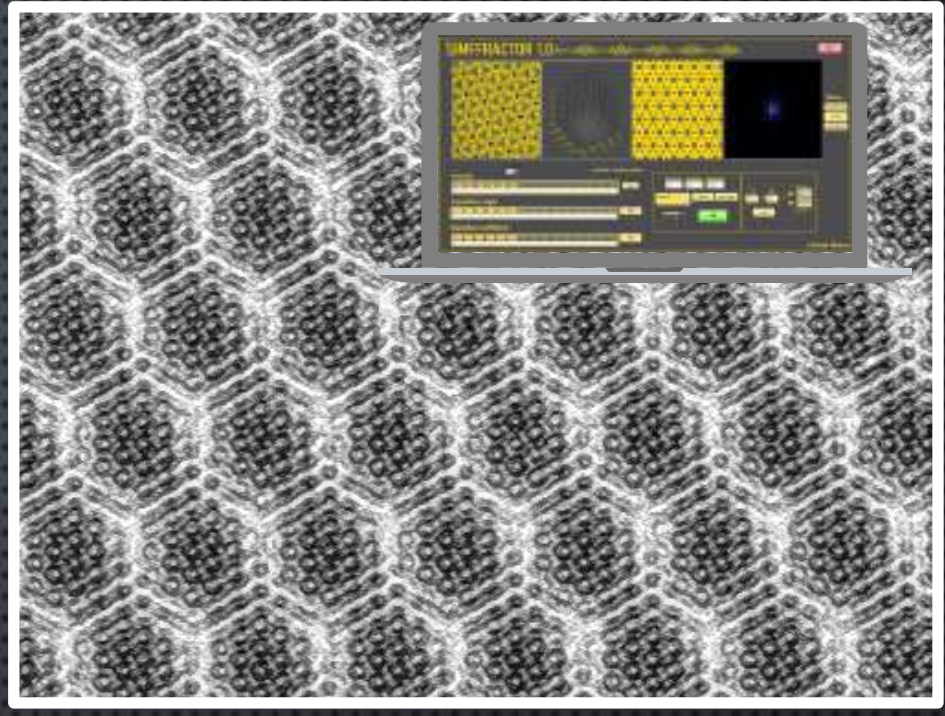
Diffraction spiral
(20 periods mixed)

# Thank you for your attention

High aspect ratio



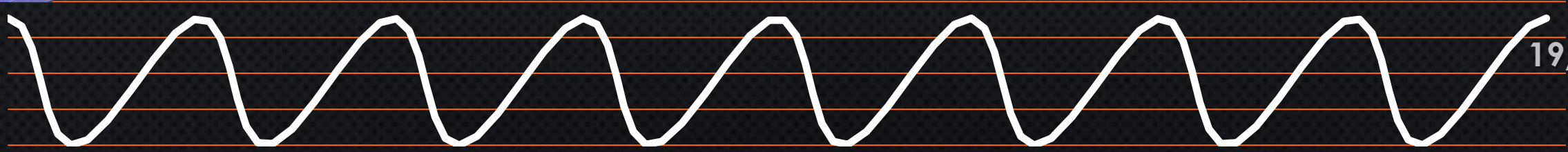


Moiré structures

250 nm ↔ 250 000 nm

Substrates: glass, silica, other

Tilted blazed structures



# THANK YOU FOR YOUR ATTENTION!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UNIVERSITY OF ŽILINA

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OPTIMAL

# Partners' logos

- To be used in the slides