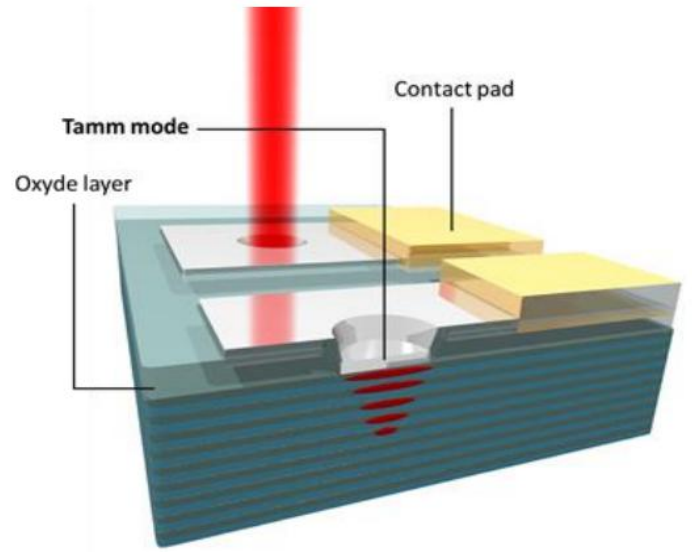


Electrically Excited Tamm Laser Sources: Lasers and Addressable Laser Arrays

Maël LAUPRETRE



Materials Nanostructures and Photonics Team (MNP) – ILM

PhD supervisor: BELLESSA Joël

PhD co-supervisor : BENOIT Jean-Michel

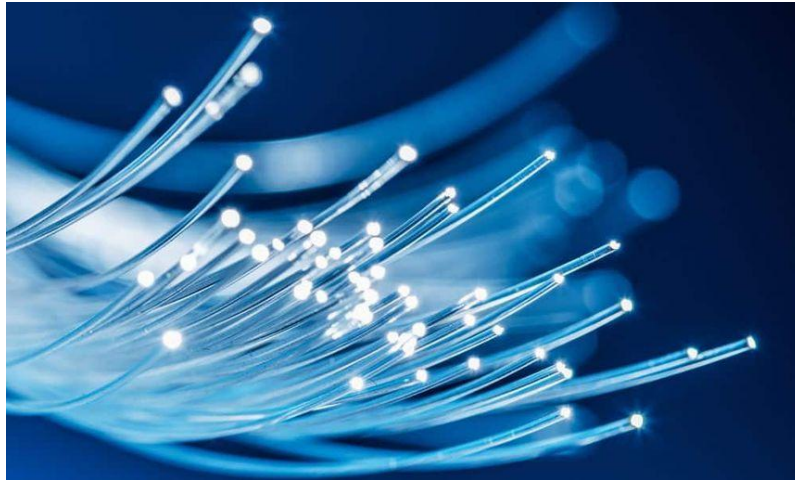
SYMONDS Clémentine

Semiconductor Lasers in Everyday Applications

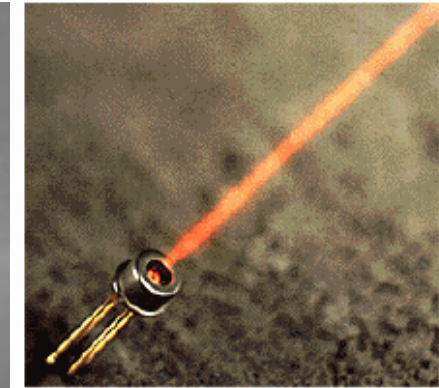
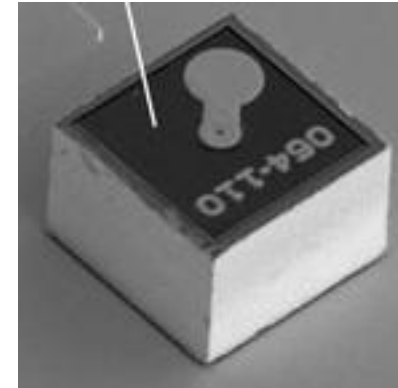
As physicists, you've encountered **lasers** in the lab — for spectroscopy, excitation, or measurements.

But outside the lab, lasers are everywhere. They need to be:

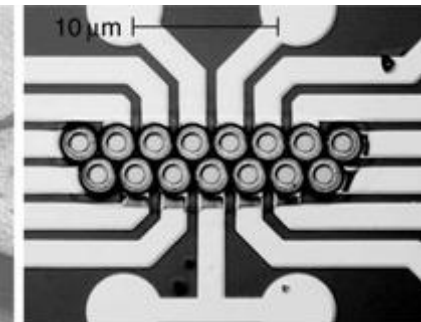
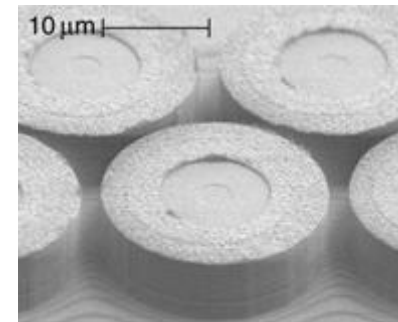
- Compact
- Efficient
- Controllable
- Integrable



<https://www.arroyoinstruments.com/blog/the-importance-of-laser-diodes-in-fiber-optic-communications/>

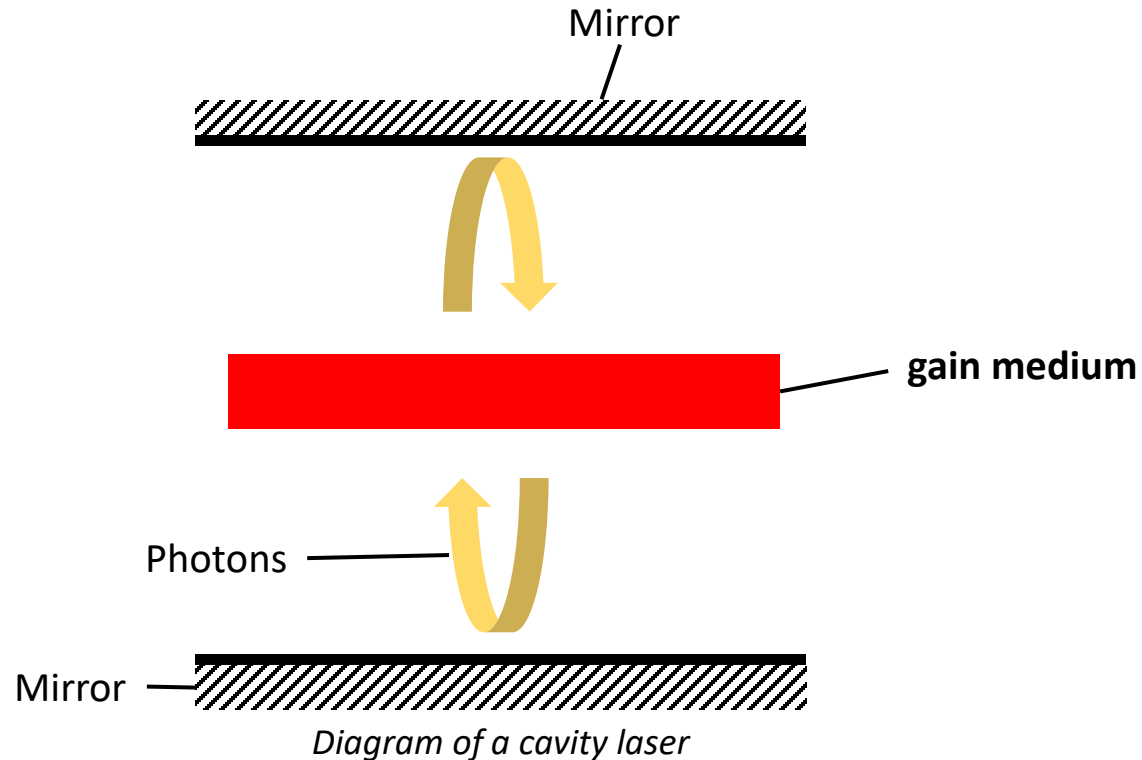


<https://www.fiberoptics4sale.com/blogs/archive-posts/95051078-vcSEL-laser-the-advantages-of-vcSEL>



That's why most lasers used today are **semiconductors** lasers

“How Does a Lasers Work?”

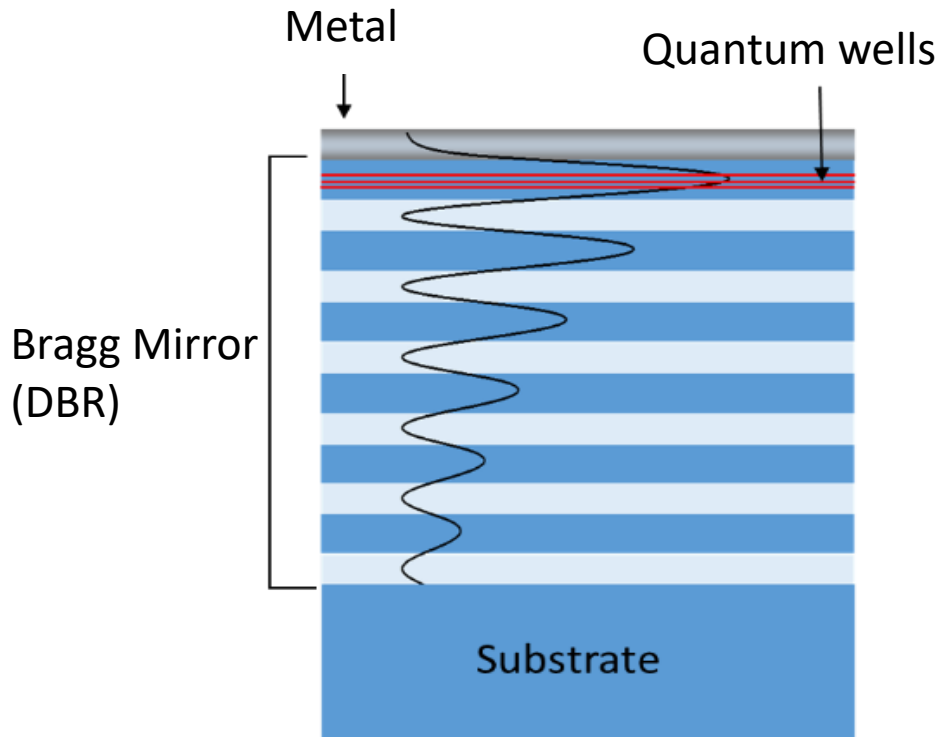


3 keys elements :

- Gain medium ➡ material that amplifies light
 - An optical cavity ➡ 2 mirrors that confines photons
 - Pumping ➡ external energy provides to the system
- ➡ The gain medium is located **at the center** of the cavity

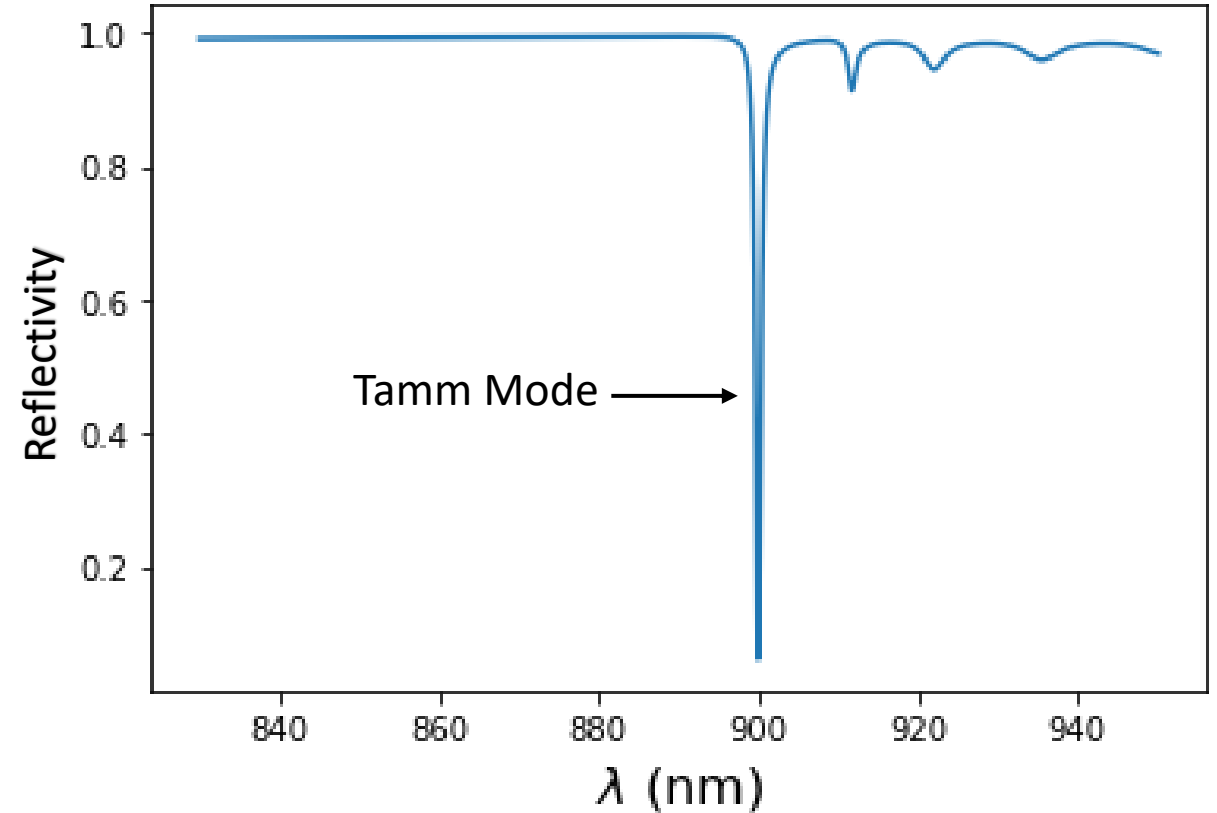
Laser occurs when **Gain > Losses**

Tamm Mode



E field associated with the Tamm mode in the structure

- ➔ Tamm mode **at the interface** of a Bragg mirror and a metal
- ➔ Tamm mode = **Surface mode**



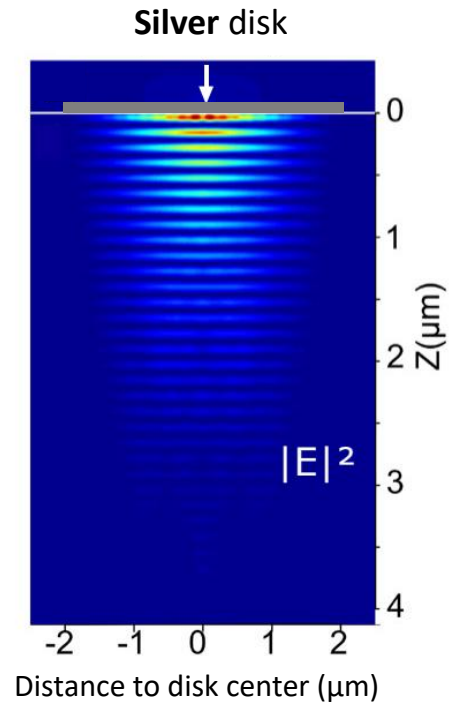
$$\text{Quality factor } Q = \frac{\lambda}{\Delta\lambda}$$

- ➔ Gives information about the **losses** of the mode
-> Tamm modes : 1000 to 4000

Laser condition : Gain > Losses

The benefits of Tamm laser diodes

Confined Tamm mode

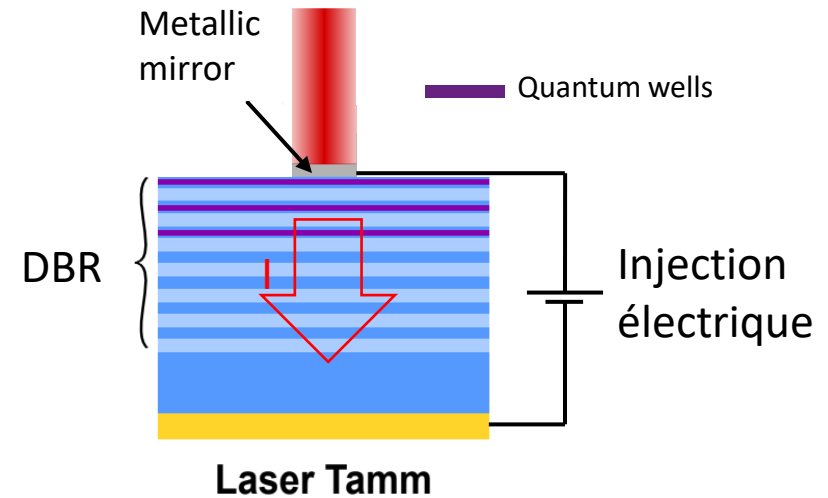


- ▶ Tamm mode **confined laterally** by metal
- ▶ Discretization of the mode

➔ **Properties control** by structuring the **metal only**

➔ **Easy fabrication and optical versatility**

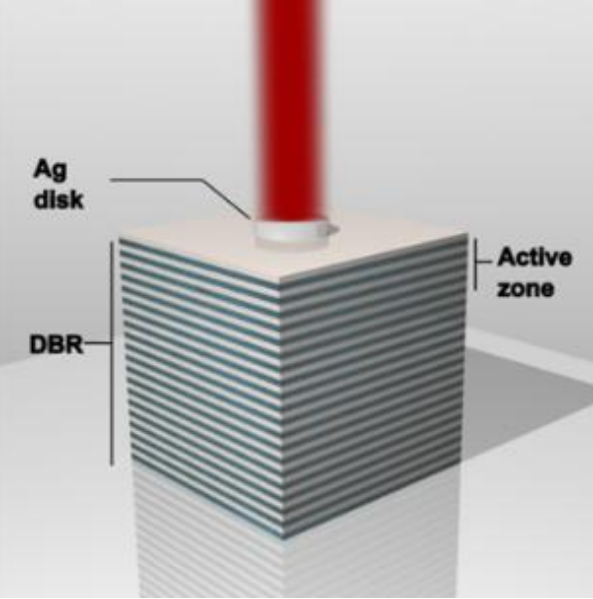
Charge carriers injection



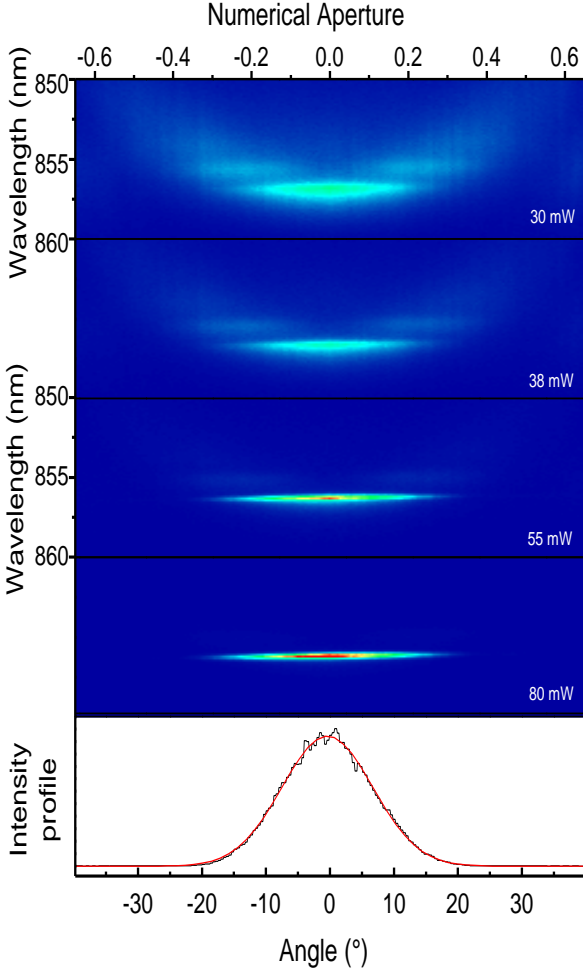
➔ Injection of charge carriers **through the metal disk** at the QW

Demonstration of Tamm Lasing under Optical Pumping

Pulsed optical pumping ($785\text{ nm} - 300\text{ fs} - 80\text{ MHz}$)
Low temperature (77K)



➔ Confined Tamm states

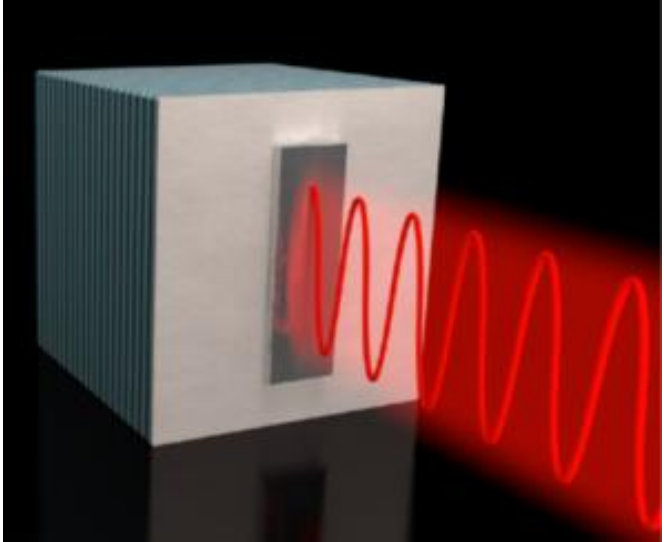


➔ **Laser effect** (fundamental mode)

C. Symonds et al., Nano Lett. 13 3179 (2013)

➔ **Room temperature lasing**

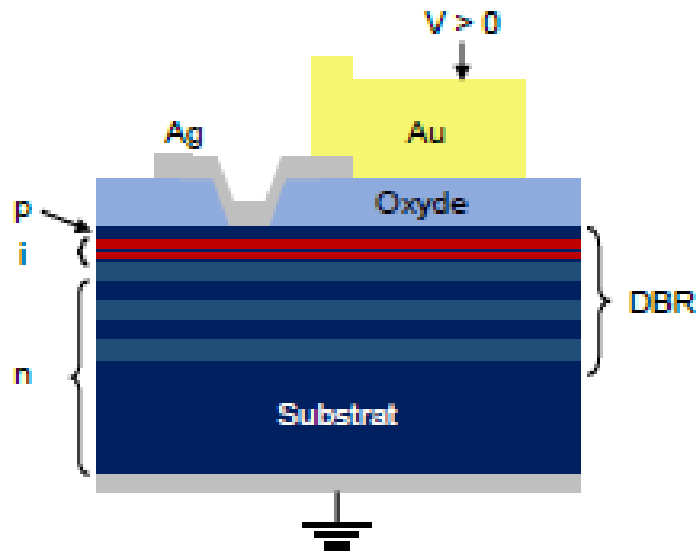
V. Toanen et al., ACS Photonics 7 2952 (2020)



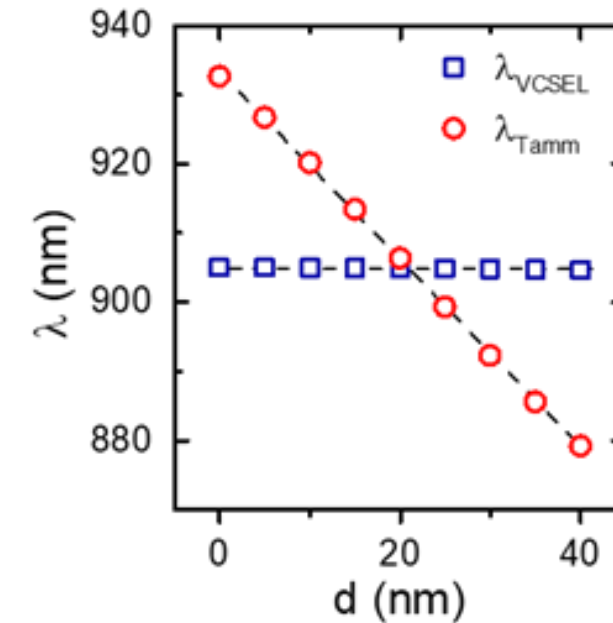
G. Lheureux et al., ACS Photon. (2015)

➔ **Controlled-polarization emission**

Electrically excited Tamm laser diodes



- ▶ Metal disk
 - ▶ Insulated layer
 - ▶ Gold pads
 - ▶ Quantum wells
 - ▶ DBR GaAs/AlAs
- MBE at C2N by
Aristide LEMAITRE



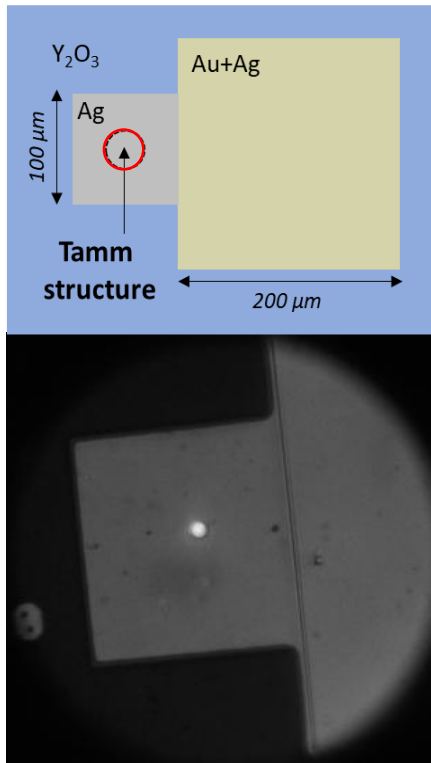
➔ Tamm position is very **sensitive** to the thickness of the **top DBR layer**

Usual process ➔ **degradation** of the first nanometers

Demonstration of the laser effect

T = 95K

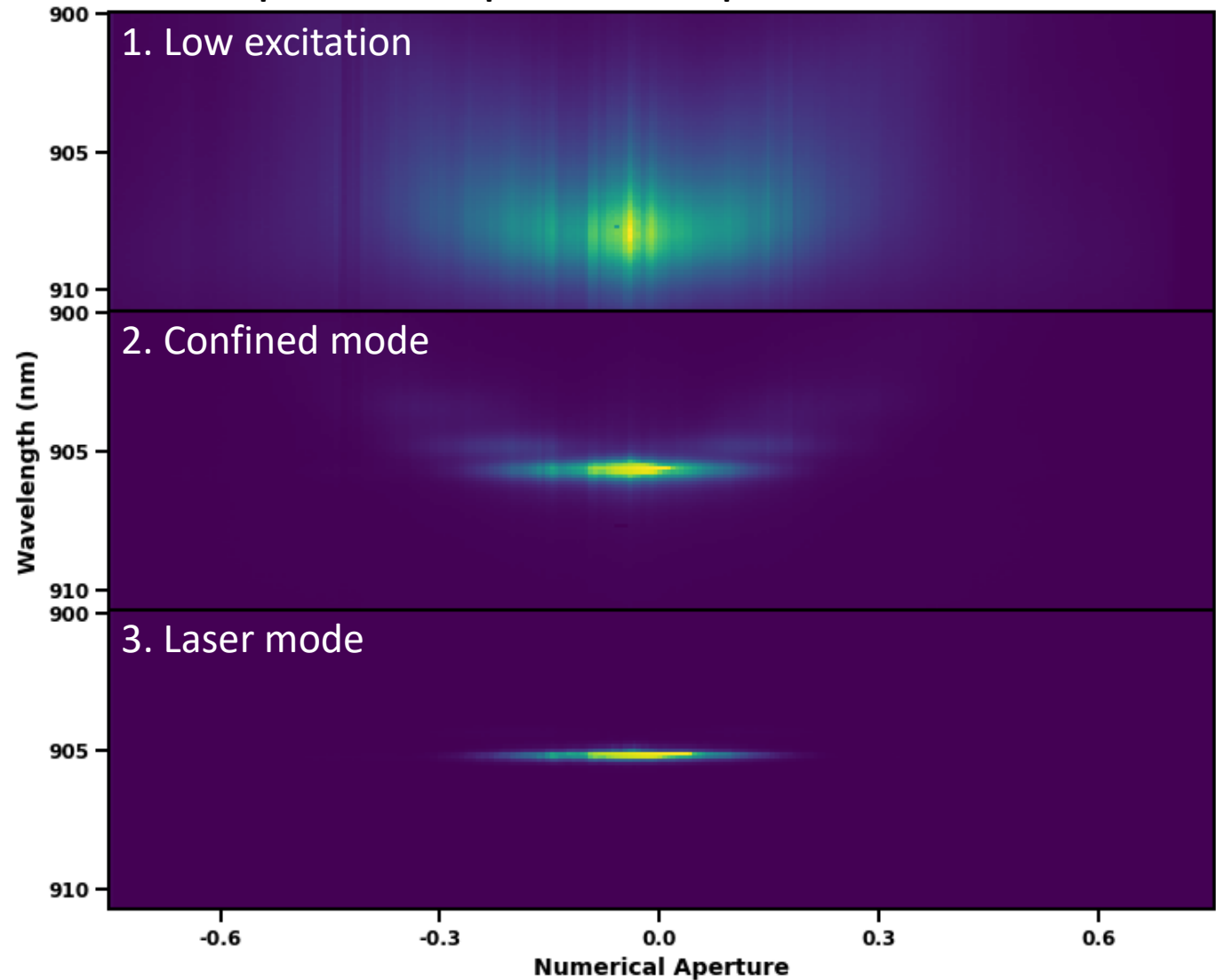
DC electrical excitation



Direct image of Tamm structure emission

- ➔ Emission line **sharpening**
- ➔ Emission **concentration** in the **fundamental mode**

Experimental dispersions of a $6\ \mu m$ Tamm sources



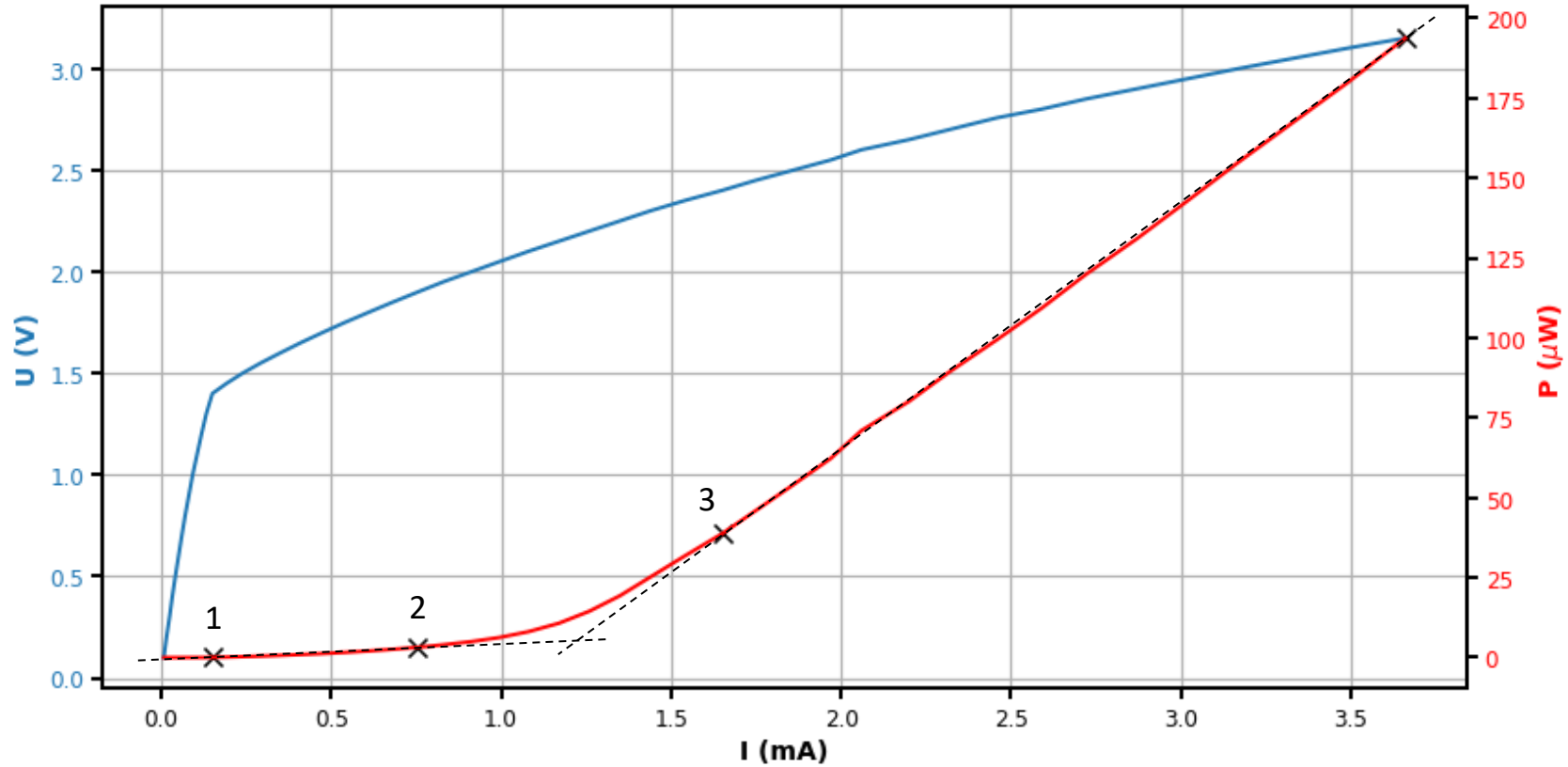
M. Lauprete et al., *Phys. Lett.* 127, 151104 (2025)

Laser emission characteristics

T = 95K

Diameter = 6 μm

DC electrical excitation



Position of dispersion relations on $P(I)$:

1. Low excitation
2. Before laser threshold
3. Laser mode

Maximal measured power = 200 μW

➡ Power density: $P_S = 700 \text{ W/cm}^2$

Conclusion

▶ **Tamm modes benefits:**

Optical confinement and electrical excitation through the same metallic patch

- ↳ Easy control of the mode properties
 - ➡ **Technological and optical versatility**

▶ **Tamm modes make possible a novel type of surface mode laser**

▶ **1st demonstration of Tamm laser sources by electrical excitation**

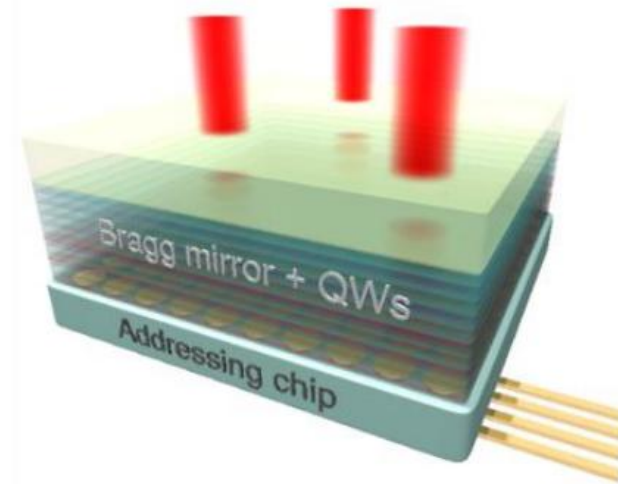
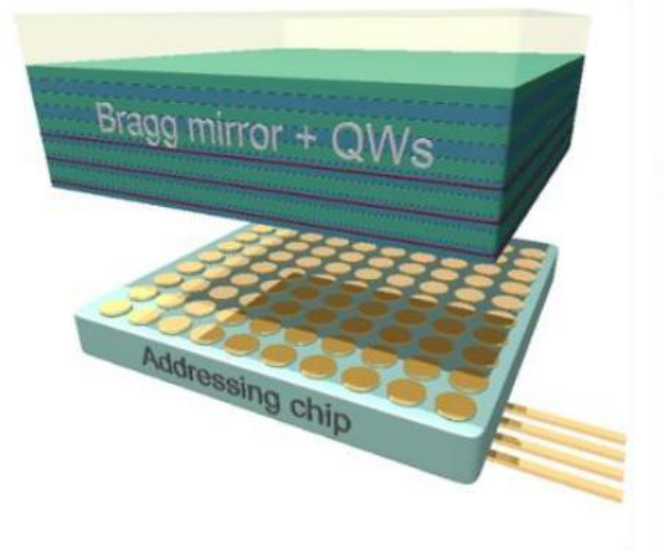
- ↳ Power up to 200 μW
- ↳ Power density $P_s = 700 \text{ W/cm}^2$

Perspectives :

- ➡ Room temperature lasing by improving quality factor
- ➡ New laser diode geometries for polarisation
- ➡ Multilaser behaviour

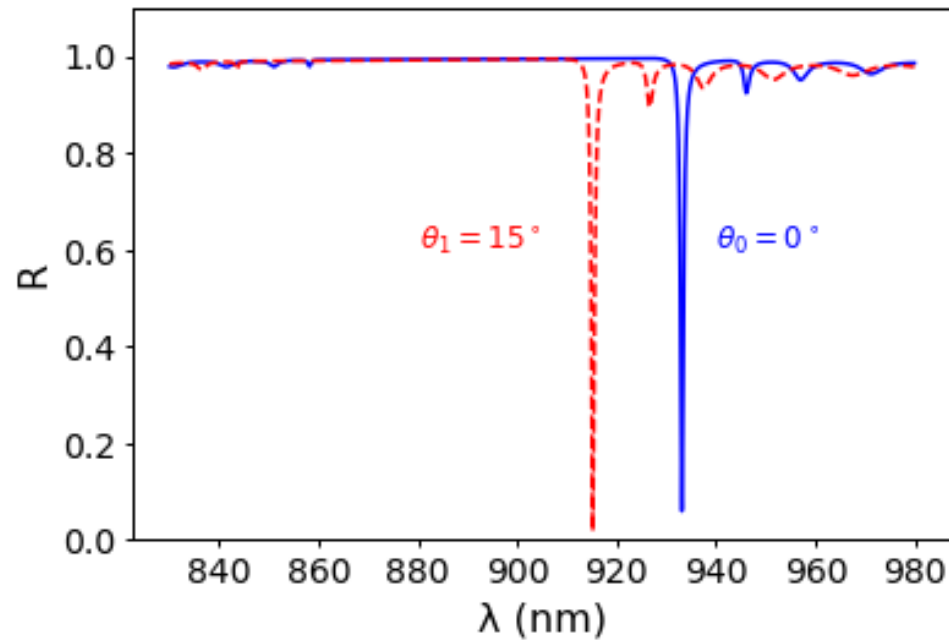
Futures directions

➔ Development of large-scale adressable laser arrays :

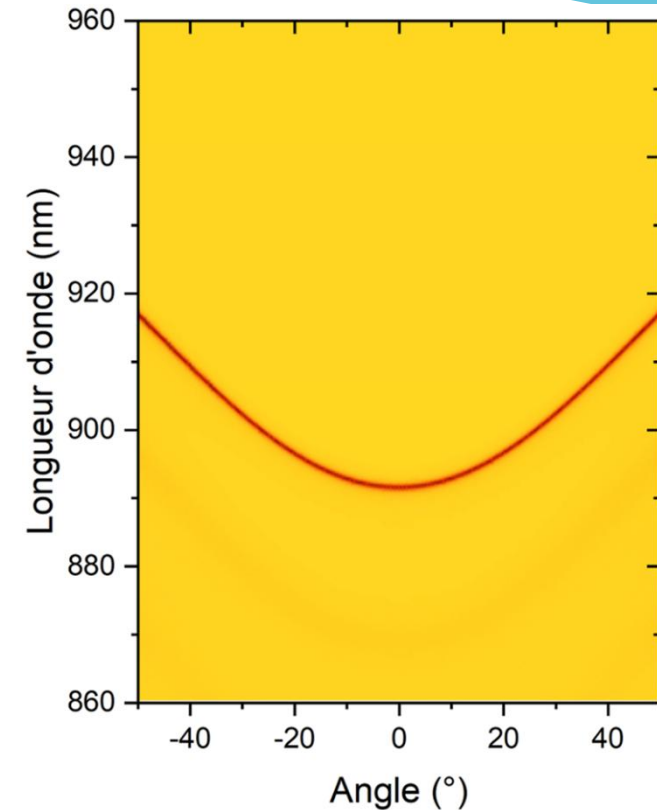


➔ Achieving a **directional** and **coherent** beam via electrical excitation

Dispersion relation



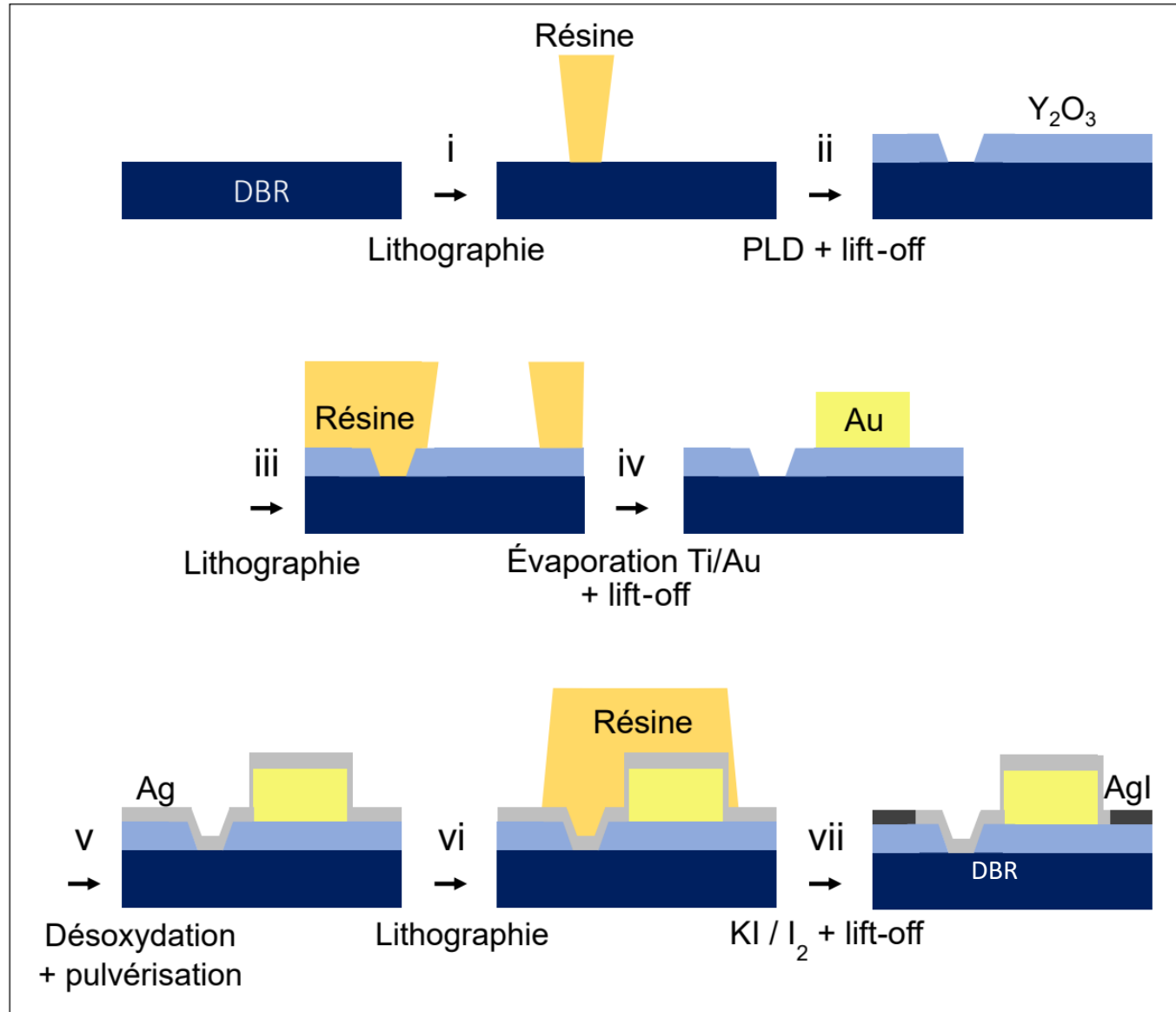
➔ The wavelength λ_T of the Tamm mode **depend on θ**



Experimental dispersion relations :

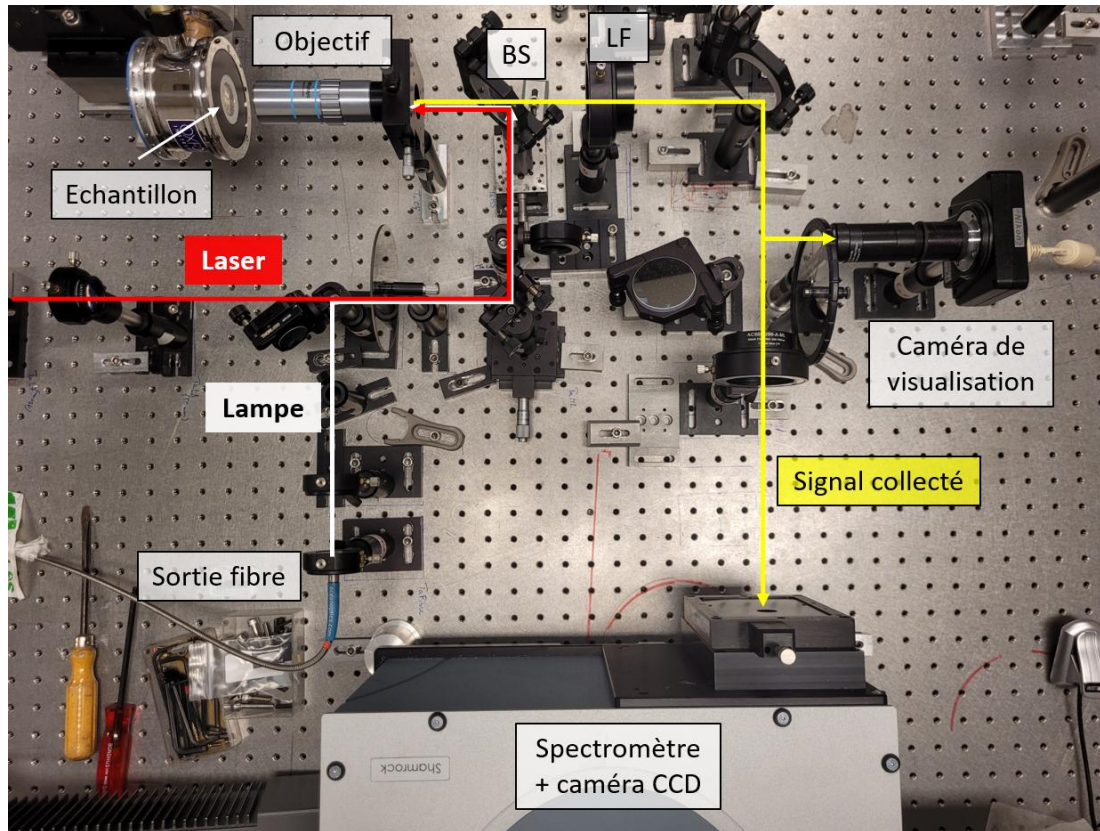
- ▶ **identify modes**
- ▶ **Detailed understanding of mode emission**

Process to prevent surface degradation

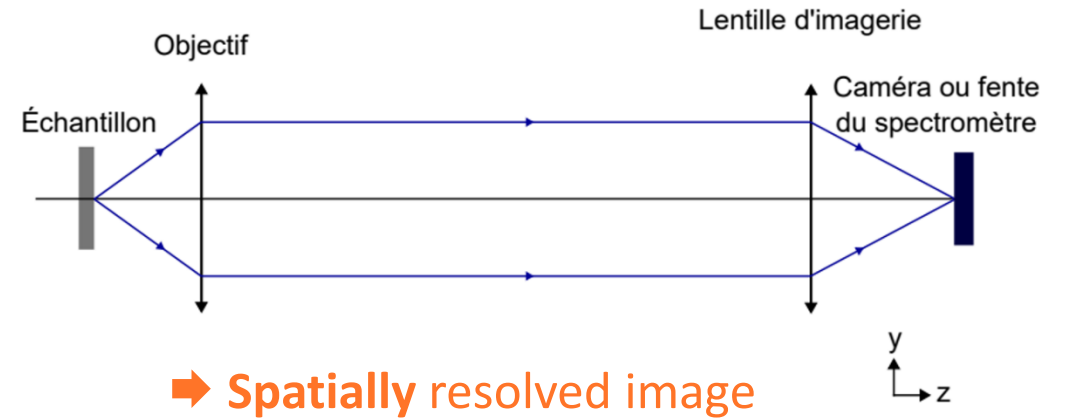


C. Symonds et al., *Appl. Phys. Lett.* 122, 261105 (2023)

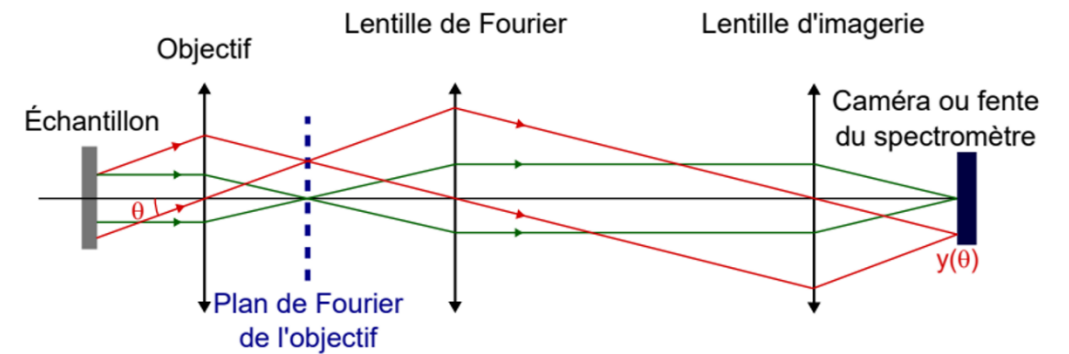
Manips



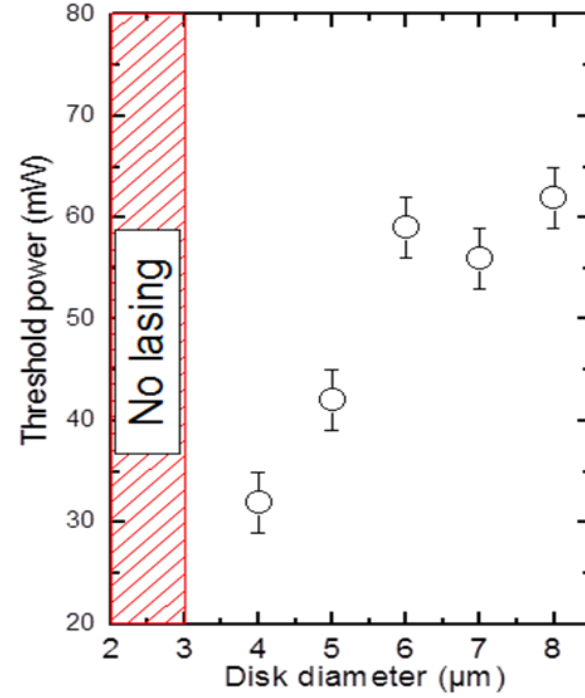
Imagerie directe



Imagerie du plan de Fourier



➔ **Spectrally and angularly resolved image** -> dispersion relation



➔ Threshold decreases with disk diameter