MŰEGYETEM 1782

Nanoplasmonic Laser Fusion Target Fabrication - Considerations and Preliminary Results (NAPLIFE Project)

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11.09.2020.

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ELEKTRONIKAI TECHNOLÓGIA TANSZÉK

BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
DEPARTMENT OF ELECTRONICS TECHNOLOGY

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Speaker Introduction

- Attila Bonyár is an associate professor at the Department of Electronics Technology at Budapest University of Technology and Economics.
- He has two M.Sc. degrees in electrical engineering and biomedical engineering and a Ph.D in electrical engineering.
- His research activities are focused on the development of optical, affinity type biosensors, utilizing low-dimensional nanomaterials, plasmonics and nanometrology (AFM).
- Chair of the IEEE Hu&Ro EPS&NTC joint chapter.
- IEEE NTC (Nanotechnology Council) AdCom member, Nanopackaging TC member.
- IEEE NTC Region 8 Chapters Coordinator

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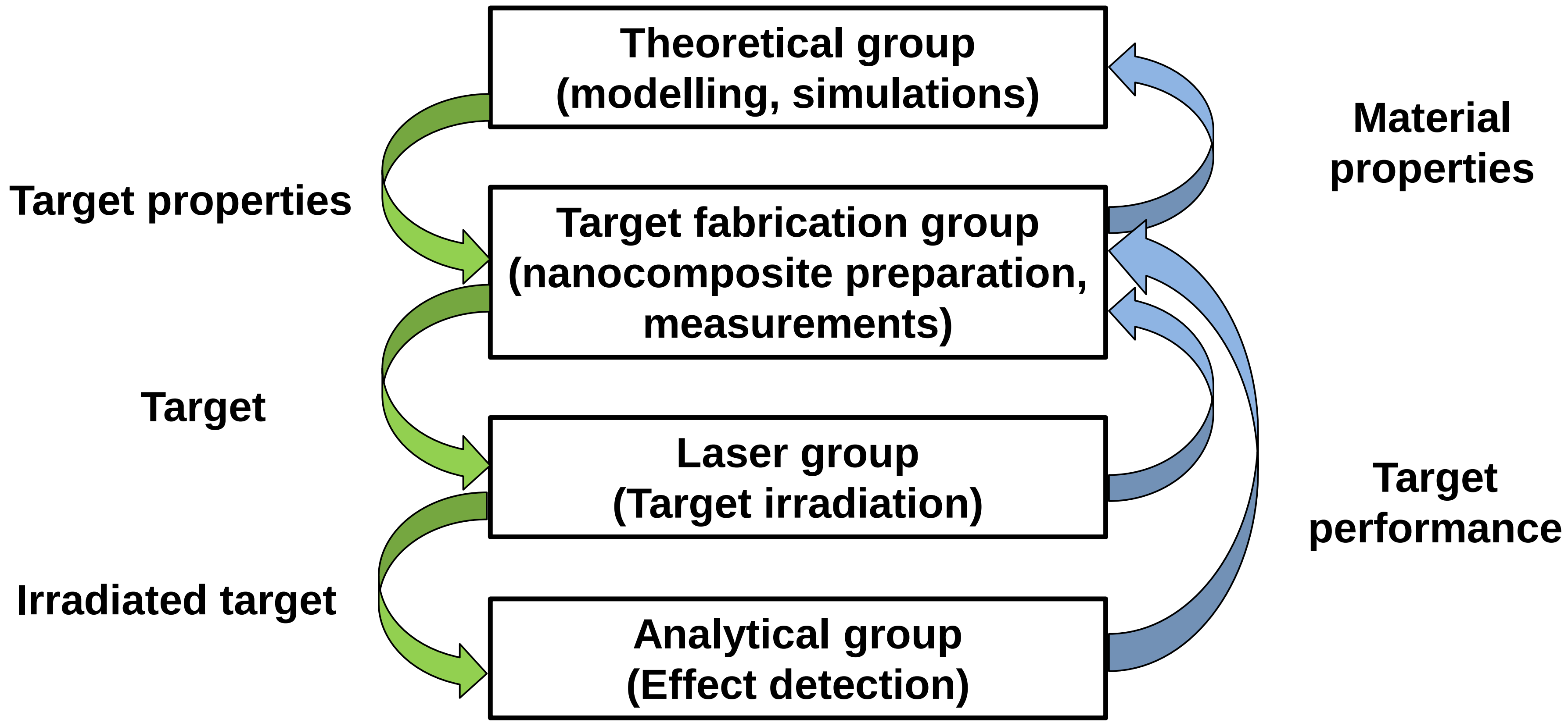
Agenda

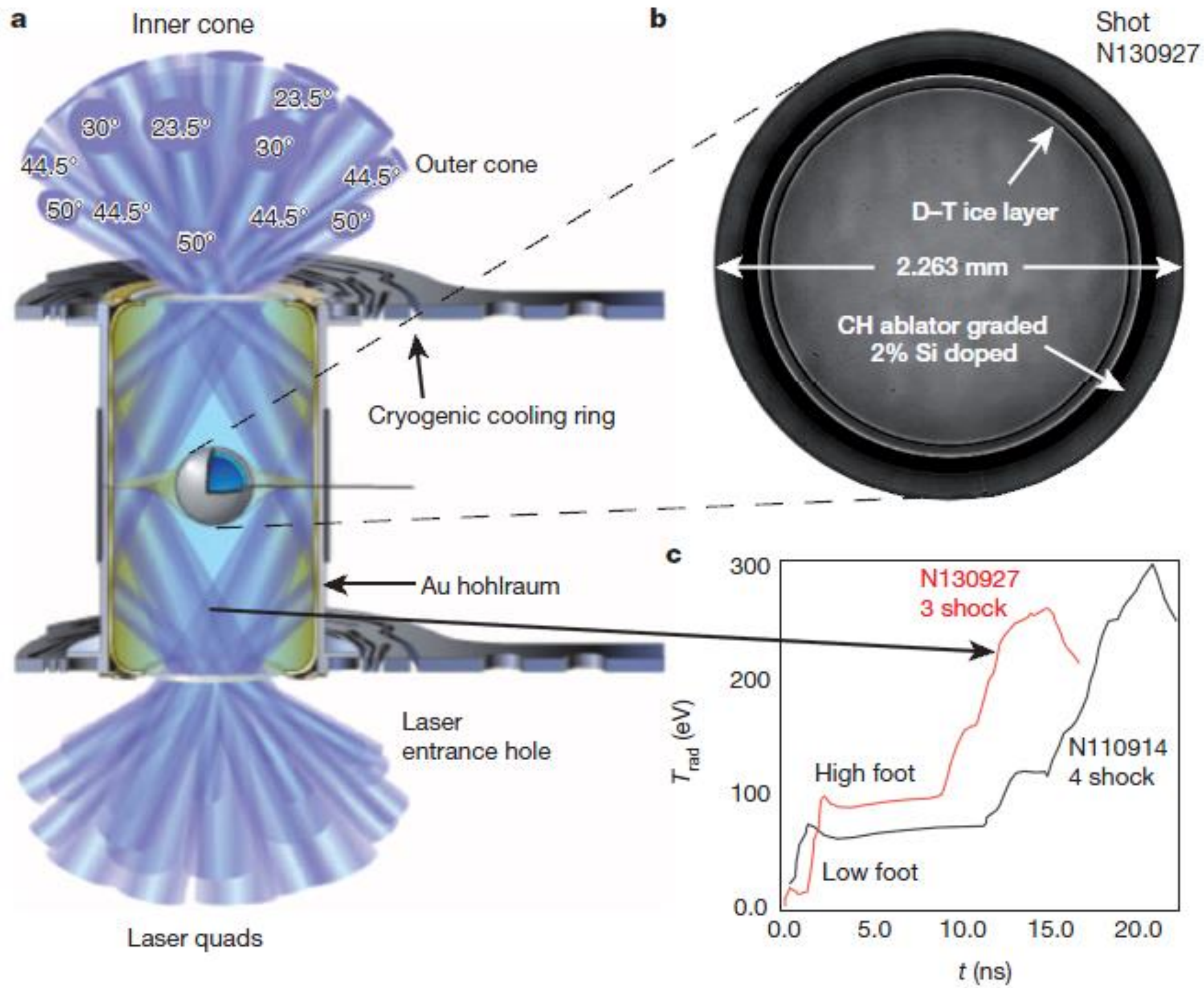
1. NAPLIFE Introduction
2. Laser fusion target considerations
3. Nanocomposite preparation
4. Fabrication methods
5. Refractive index measurements – Ellipsometry
6. Refractive index measurements – LSPR sensor
7. Absorbance measurements
8. Laser irradiation experiments
9. Raman-spectroscopy on irradiated targets

1. NAPLIFE Introduction

Nano-Plasmonic Laser Inertial Fusion Experiment Collaboration



2. Target fabrication considerations



…for validation.

Time profile of the laser beam:

Initial pre-compression of ~ 10 ns,

→ Stable compression

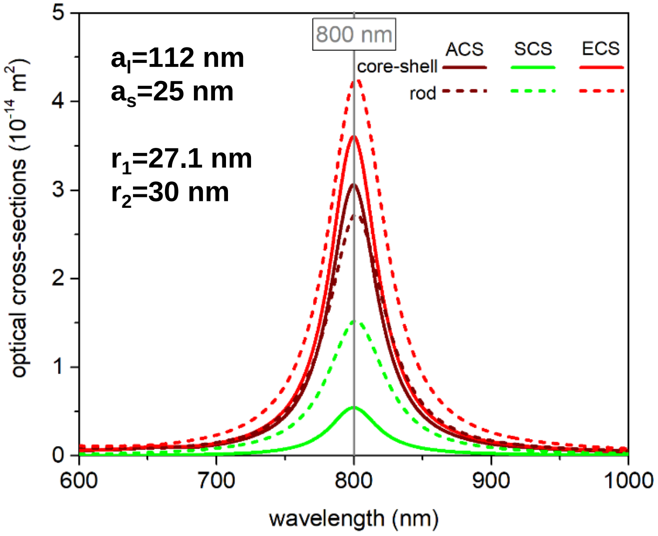
→ Then final "shocks" of ~ 15 ns to ignite

[O.A. Hurricane et al., Nature, 506, 343 (2014), doi:10.1038/nature13008]

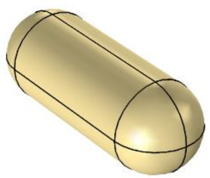
2. Target fabrication considerations

Our general idea is to increase the absorptivity of the target by using different types of nanomaterials, such as core-shell structures and nano rods. Calculations via solving the Maxwell equations, and evaluating the Ohmic heating were performed.

individual cross-sections

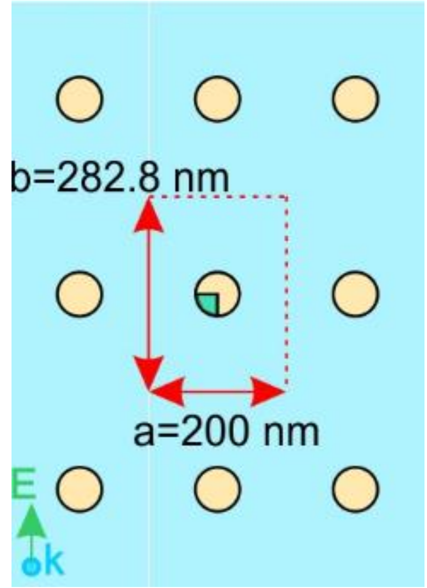


nanorod

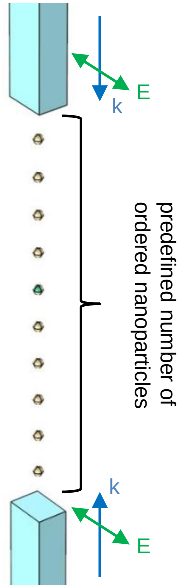


core-shell

ordered



one- / two-sided irradiation



1 ps laser pulse length, λ = 800 nm. One-sided & two-sided irradiation tested, 85-100 % absorption in the DT target length h. Nano-antenna shapes, layer configurations, layer distribution varied & analyzed.

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[M. Csete, et al., University of Szeged, HU]

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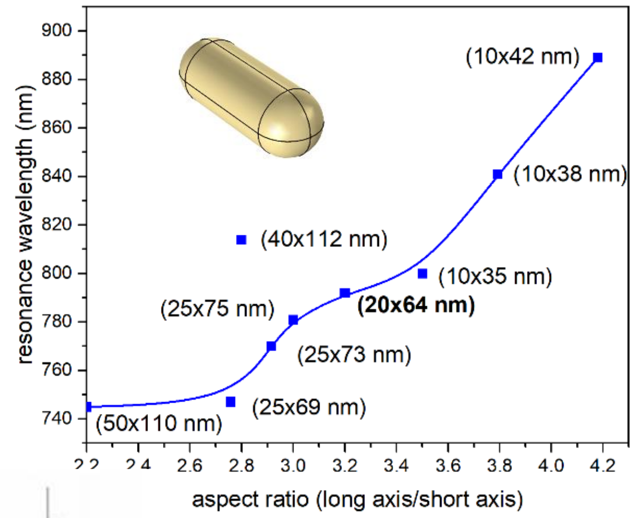
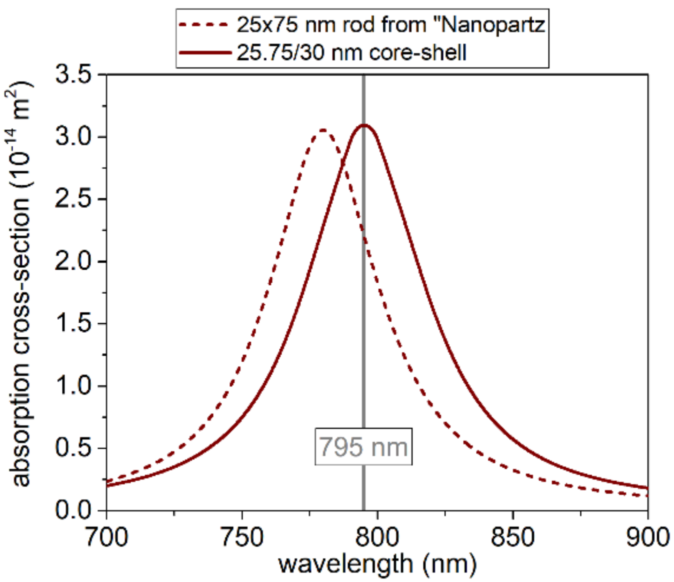
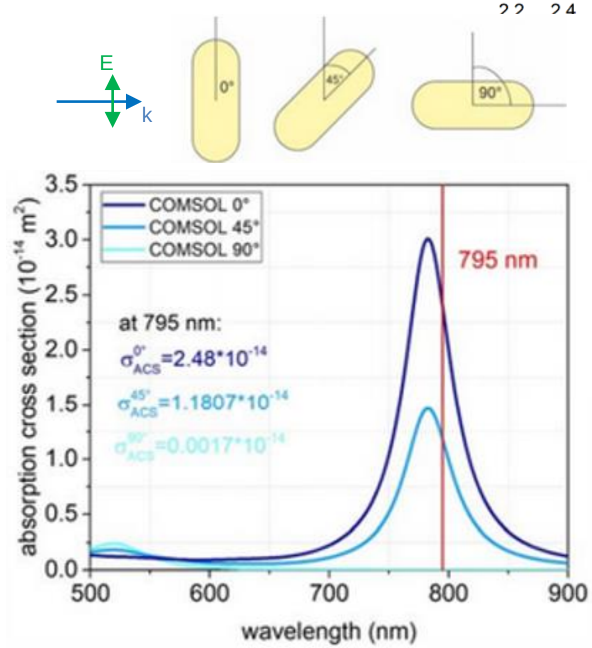
2. Target fabrication considerations

Simulations were performed to

- **optimize the particle geometry considering the RI of the target.**
- **investigate the effect of random orientation and distribution.**
- **maximize the absorption (and heating) along the target.**







$\sigma^{0°}{}_{ACS}/\sigma^{0°}{}_{GCS} = 14.245$

$\sigma^{45°}{}_{ACS}/\sigma^{45°}{}_{GCS} = 9.9052$

$\sigma^{90°}{}_{ACS}/\sigma^{90°}{}_{GCS} = 0.0346$

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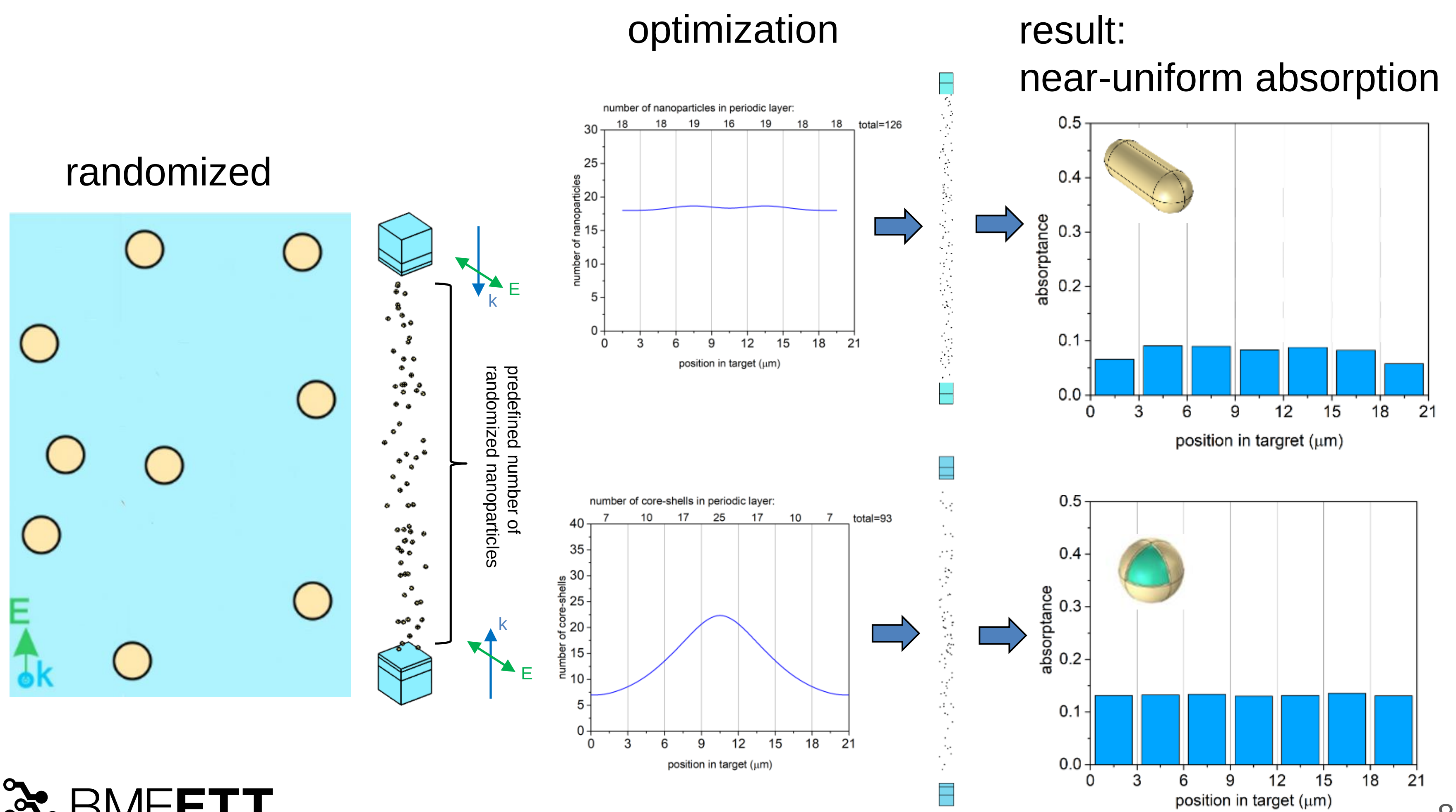
2. Target fabrication considerations

Steady-state simulations -> random nanoresonator distributions
-> uniform heating throughout UDMA target



[M. Csete, et al., University of Szeged, HU]

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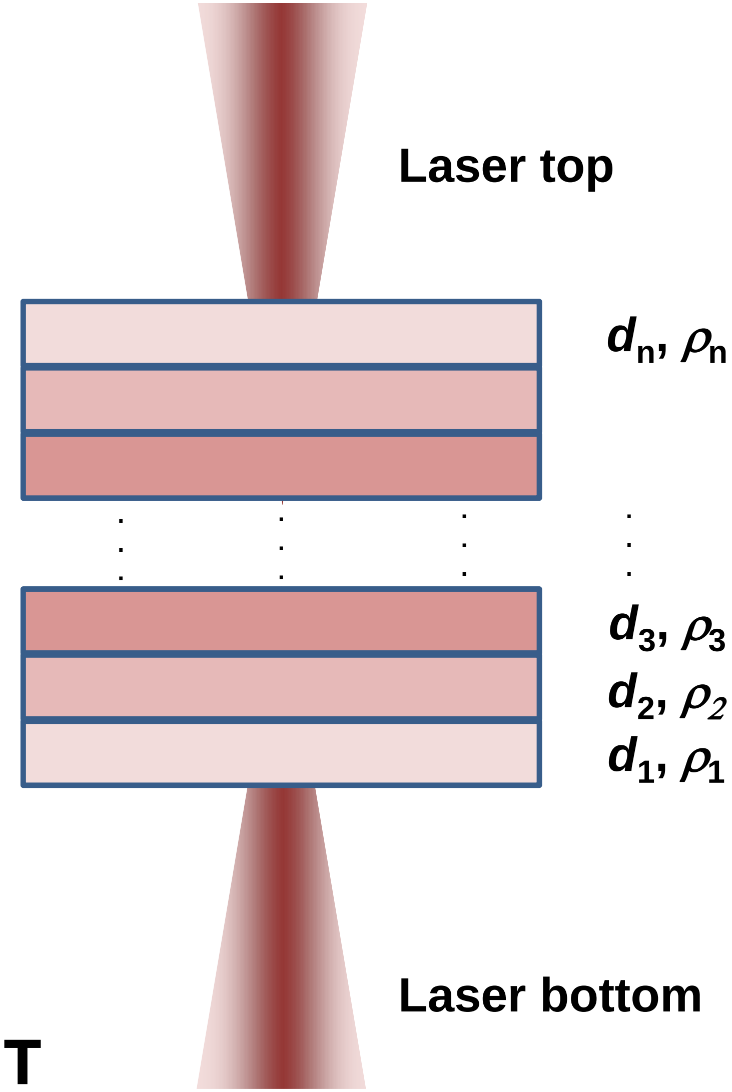
2. Target fabrication considerations

Concept of our target for nanoplasmonic laser fusion



Target parameters (from simulations):

Number of layers n=10

$d_1=d_2=\ldots=d_n$= 2 µm

D = sum(d) = 20 µm

ρ_n: different concentration of nanoparticles in one layer.

3. Nanocomposite preparation

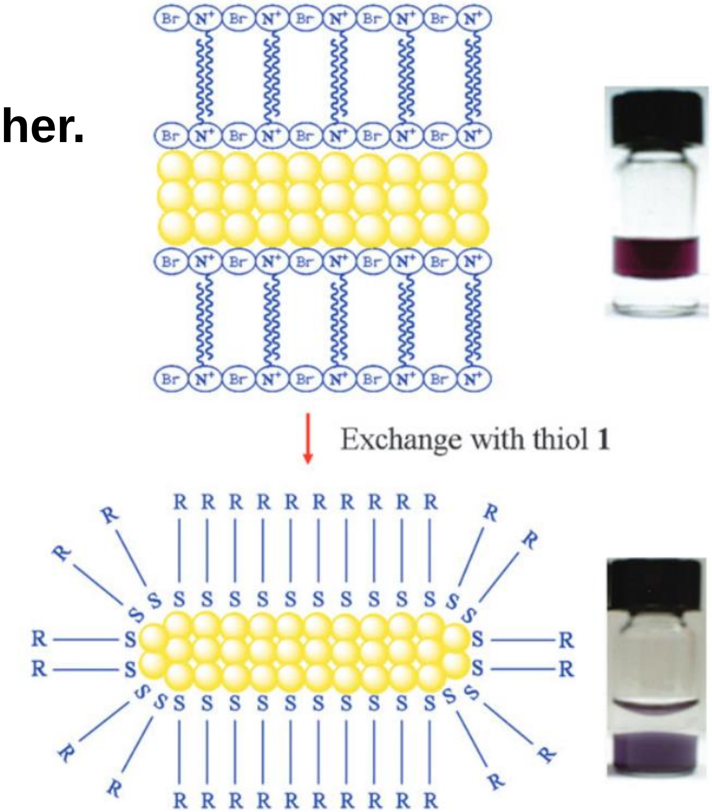
The fusion target will be a **nanocomposite**, where the **nanoparticles are doped into the bulk of a polymer**. The type of the polymer and the polymerization itself needs to be selected according to our **requirements:**

- **Uniform particle distribution,**
- **Avoid particle aggregation,**
- **Long-time particle stability,**
- **Possibility to build layers on each other.**

- **Polymerization type:**
  - Solution polymerization,
  - Bulk polymerization,
  - Photopolymerization.

- Particle **capping** should be controlled.
  - Hydrophilic (synthesis),
  - Hydrophobic (for doping).

- **Nanoparticle phase transfer**



[El Khoury, 2009, 10.1039/b901826c]

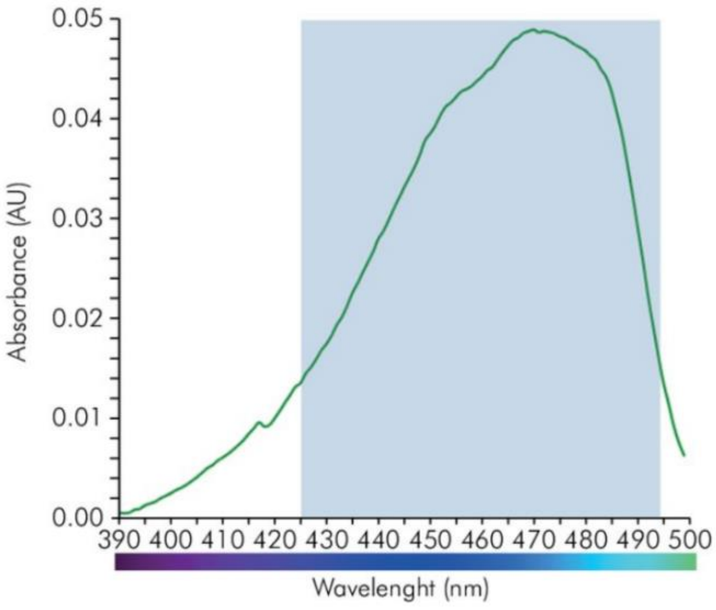
3. Nanocomposite preparation

The selected polymerization method is **photopolymerization**:

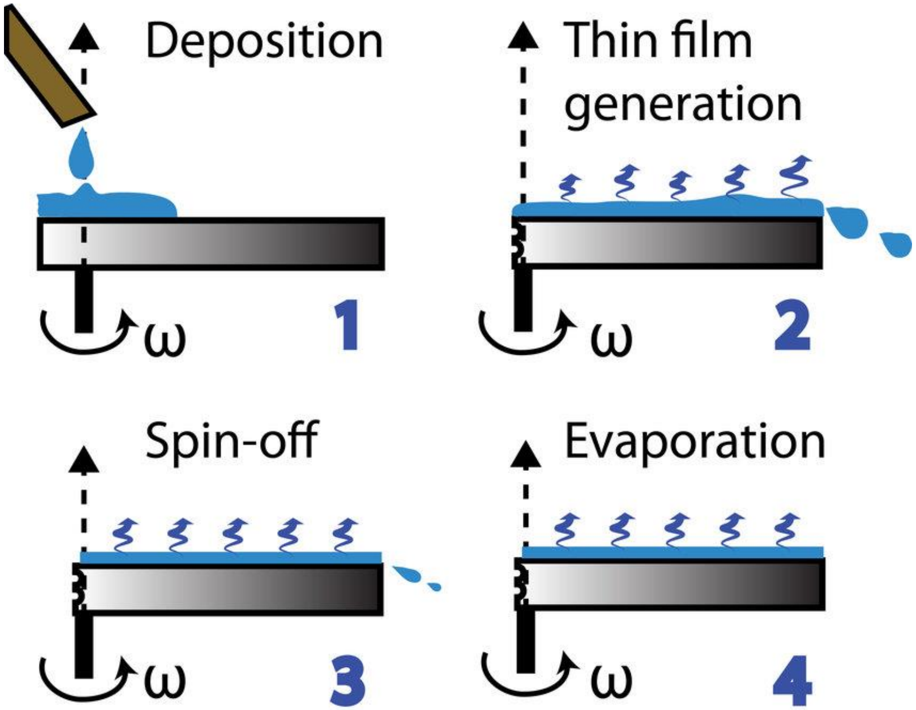
- Works with thin layers (see microtechnology resists e.g. SU-8).
- Fast polymerization (a couple of minutes).
- Polymerized layers are stable in organic solvents.
- Layers can be built on each other.

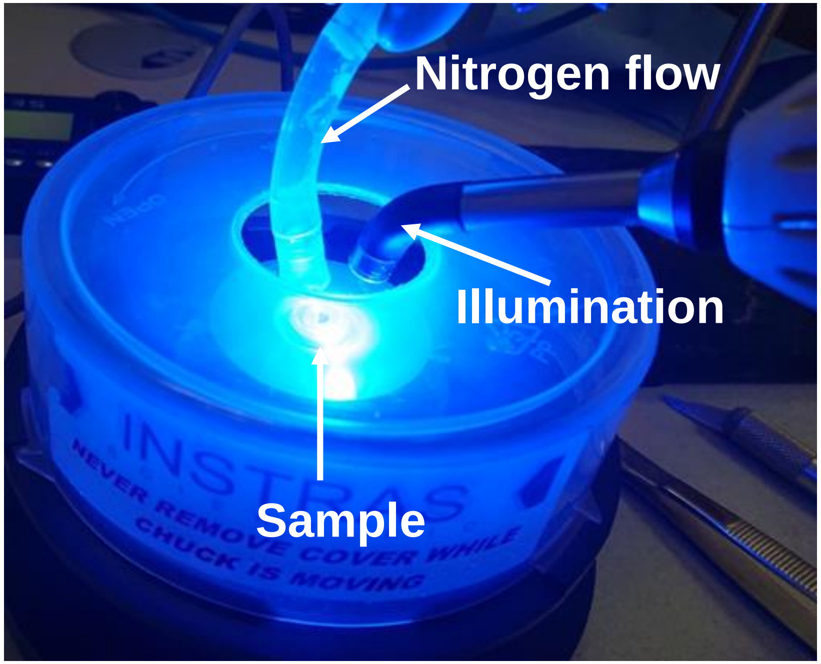
The selected polymer is **UDMA** (urethane dimethacrylate) with **TEGDMA** (Triethylene Glycol Dimethacrylate) dilution monomer, **CQ** (Camphorquinone) photoinitiator and **EDAB** (ethyl 4-dimethylaminobenzoate) co-initiator, which is a well-known mixture in dentistry.

Emission spectrum and equipment used for the photopolymerization



4. Fabrication methods – Spin Coating





[Rodrigo Perez Gartia: 10.13140/RG.2.2.31031.78247]

Challenges:

- **The viscosity needs to be controlled.**
- **There is non-polymerized film on top of the polymerized layer.**
- **Surface roughness is not ideal.**

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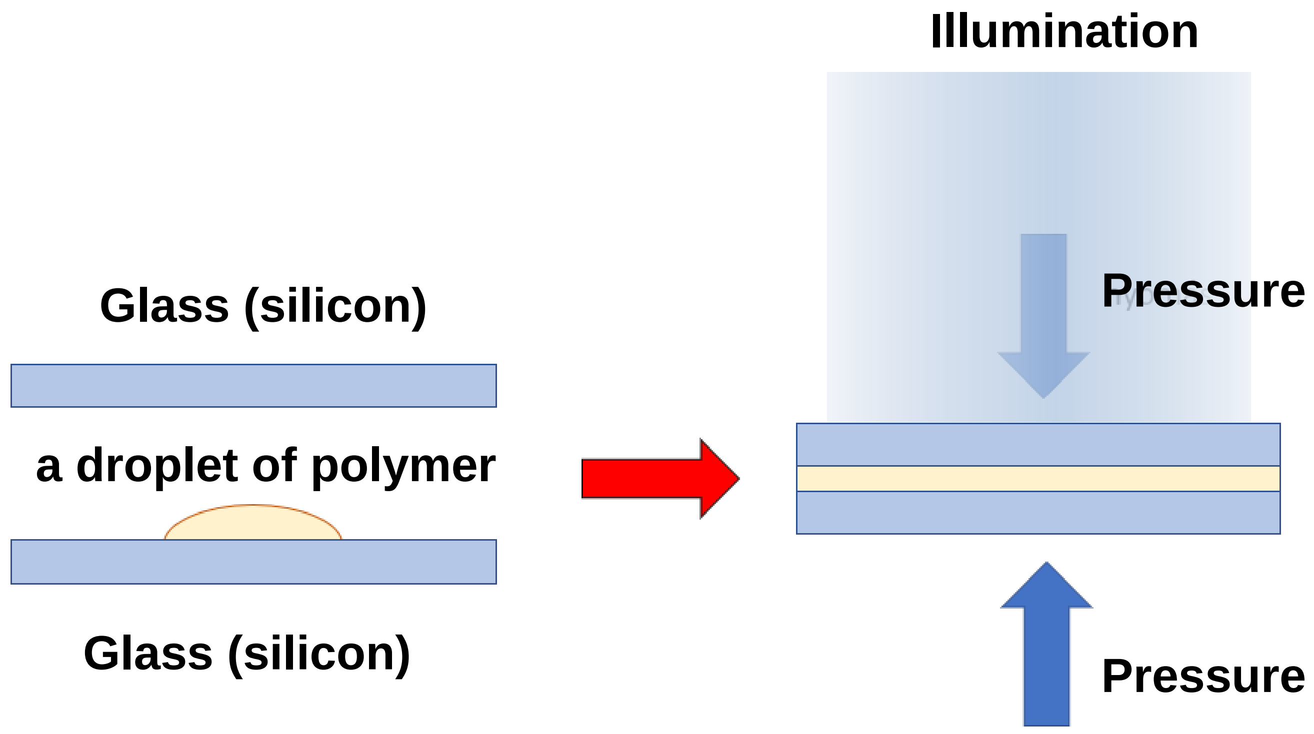
4. Fabrication methods – Sandwich Pressing



Challenges:

- **the viscosity needs to be controlled,**
- **layer uniformity needs to be controlled (pressing).**

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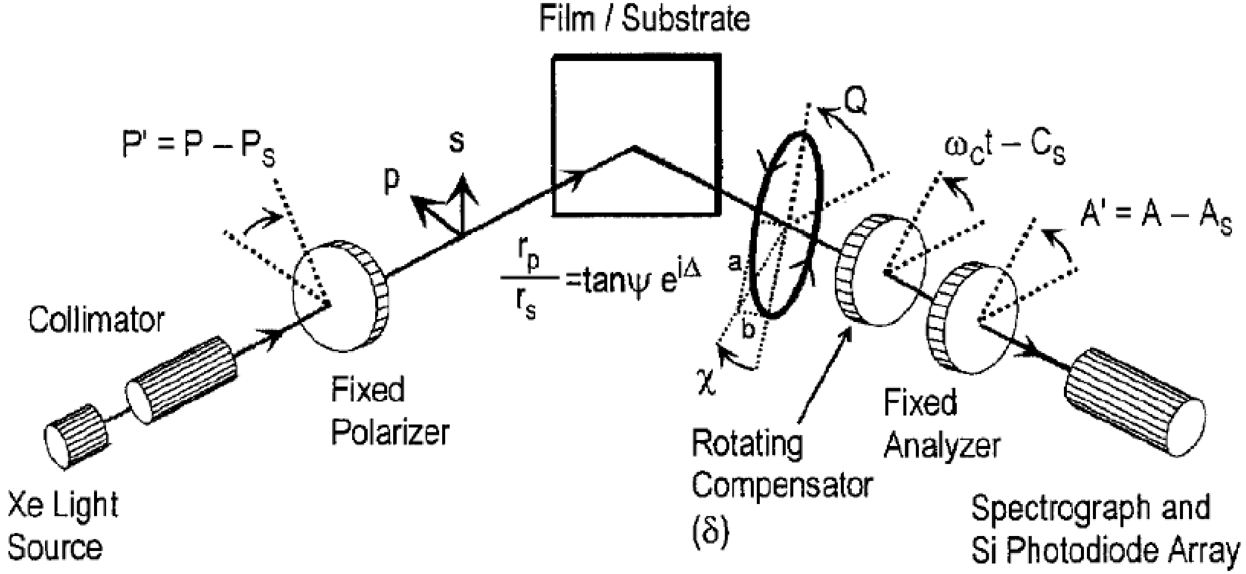
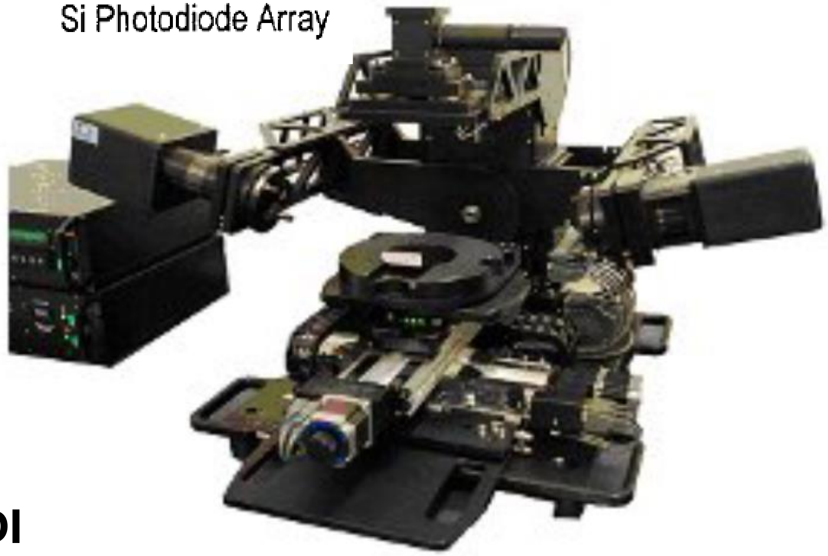
5. Refractive index measurements - Ellipsometry



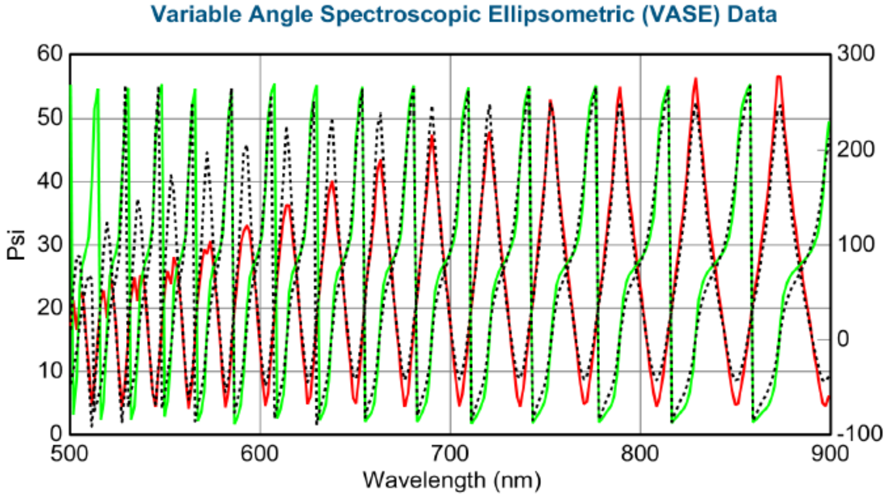
For the simulations the complex refractive index sensitivity is needed!

ELKH, Centre for Energy Research, Institute for Technical Physics and Materials Science



Woollam M-2000DI

5. Refractive index measurements - Ellipsometry



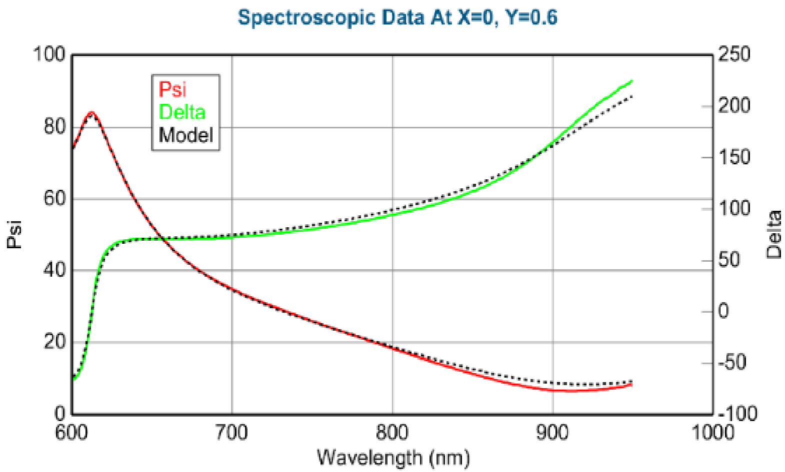
OPTICAL MODEL

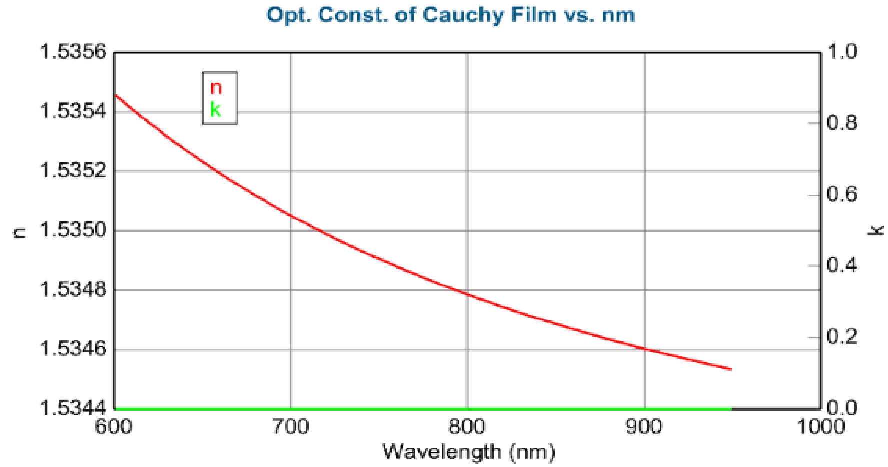
- Layer # 1 = Cauchy_layer Thickness # 1 = **5279.49 nm** (fit)
  A = **1.785** (fit) B = **0.00747** (fit) C = **-5.8015E-05** (fit)
  - **Urbach Absorption Parameters**
    k Amplitude = **0.06464** (fit) Exponent = **3.688** (fit)
    Band Edge = 400.0 nm

Substrate = Si_JAW

Top: Results obtained on a spin coated thick (~5um) sample

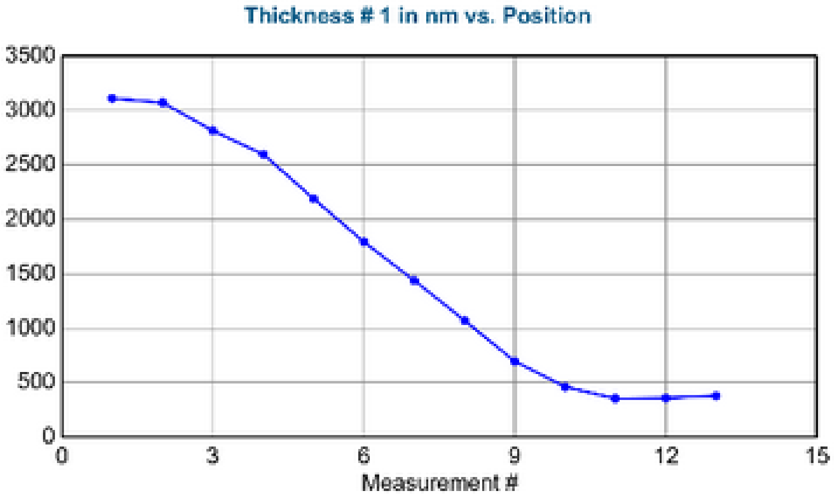
Bottom: Sample made with sandwich pressing, thickness below 1 um

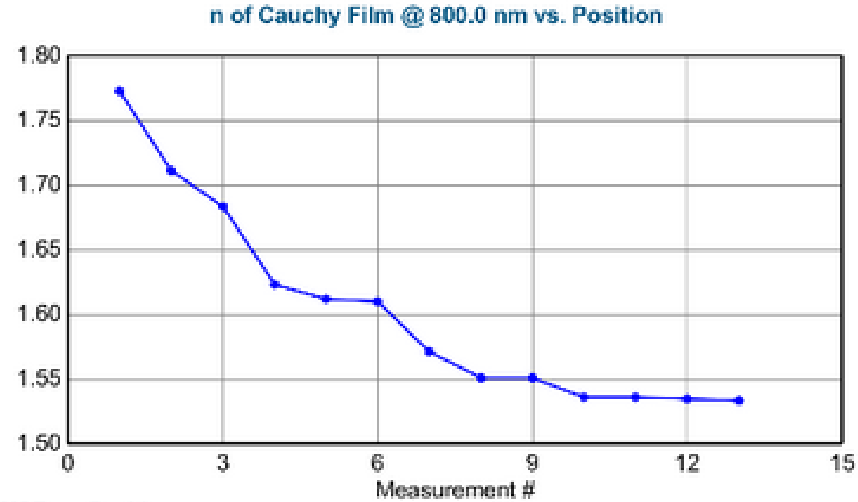




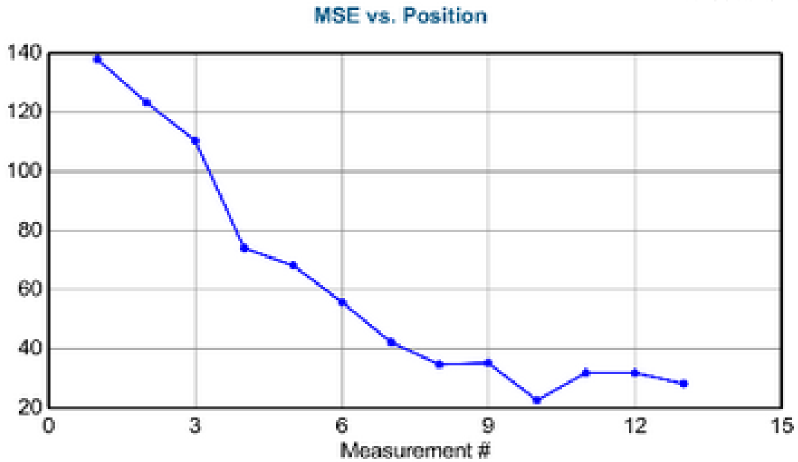
5. Refractive index measurements - Ellipsometry

Correlation between the sample thickness, the obtained refractive index, and the MSE of model fitting





Obtained along a line with decreasing sample thickness



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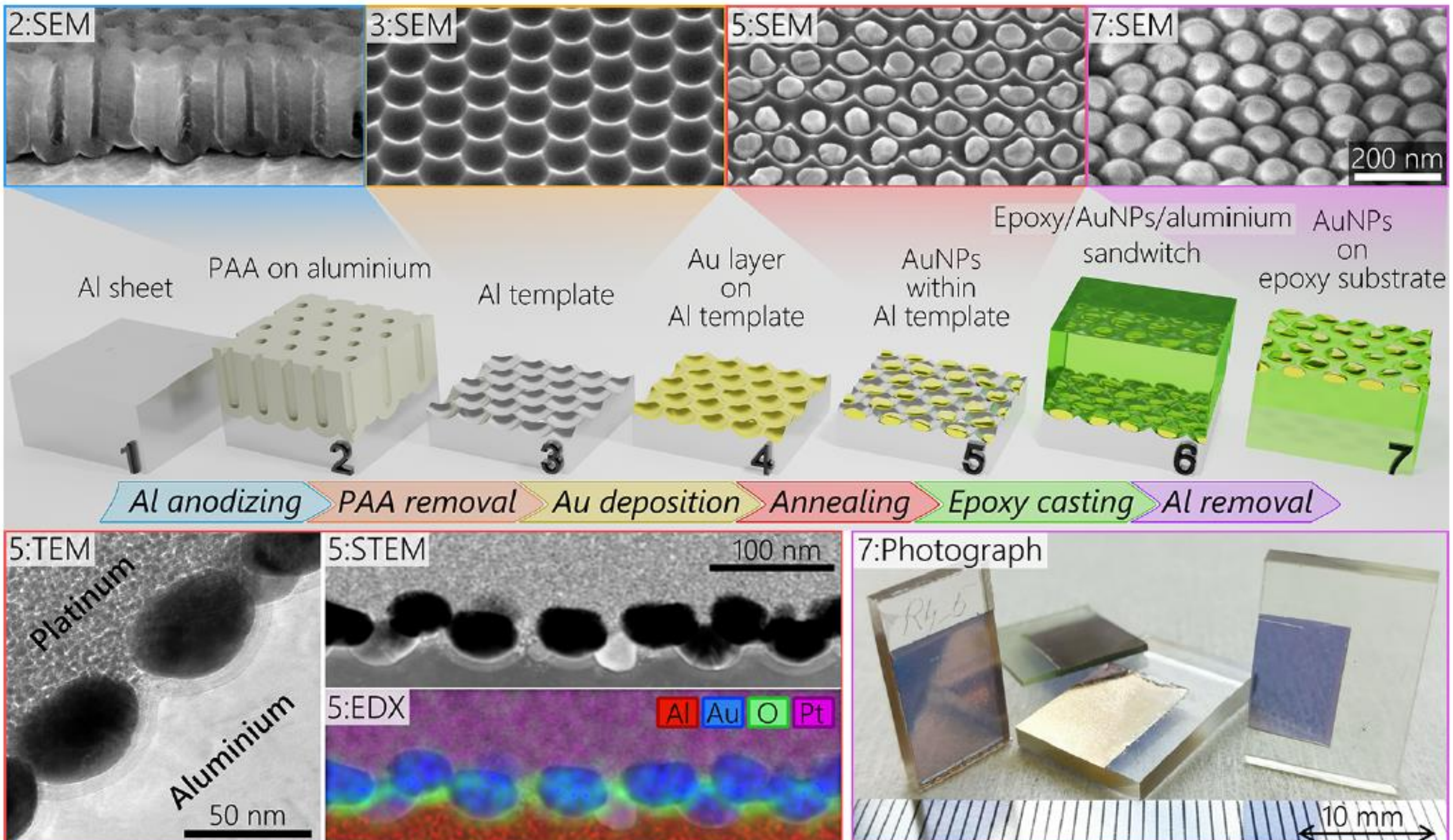
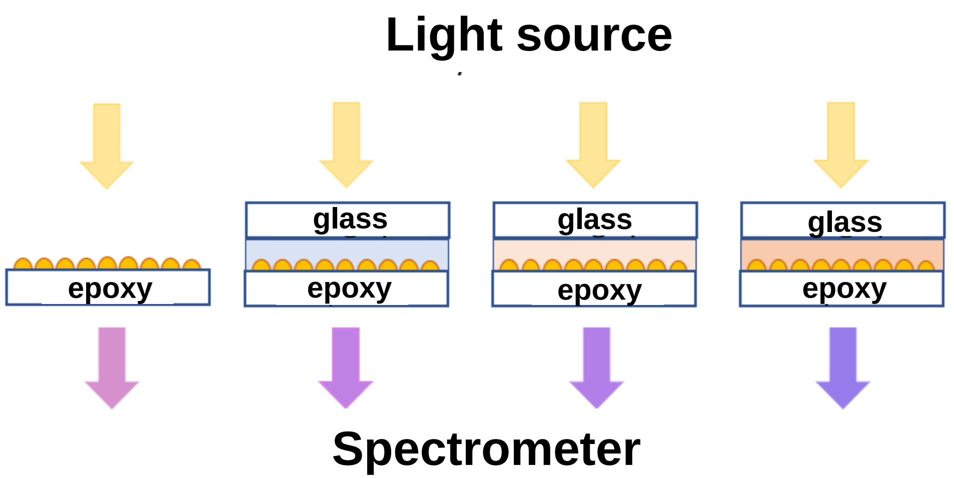
6. Refractive index measurements – LSPRi sensor

[Lednický, 2020ACS APPLIED MATERIALS & INTERFACES 12 : 4 pp. 4804-4814. , 11 p. (2020)]

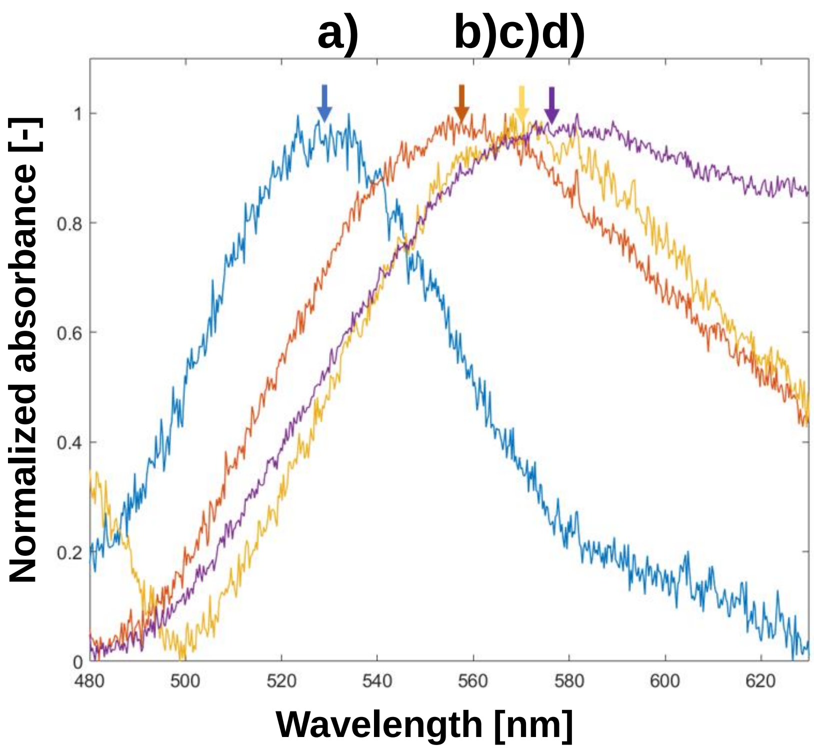
Interesting method: LSPRi nanocomposite to measure the RI of the polymer



6. Refractive index measurements – LSPRi sensor



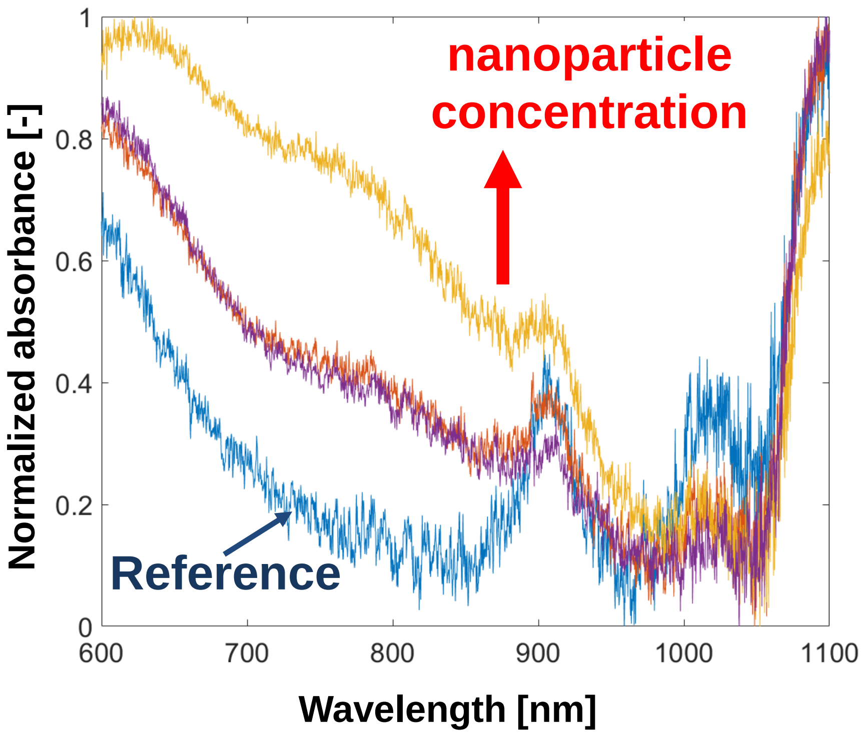
a) air; b) water; c) prepolymer mixture; d) polymer



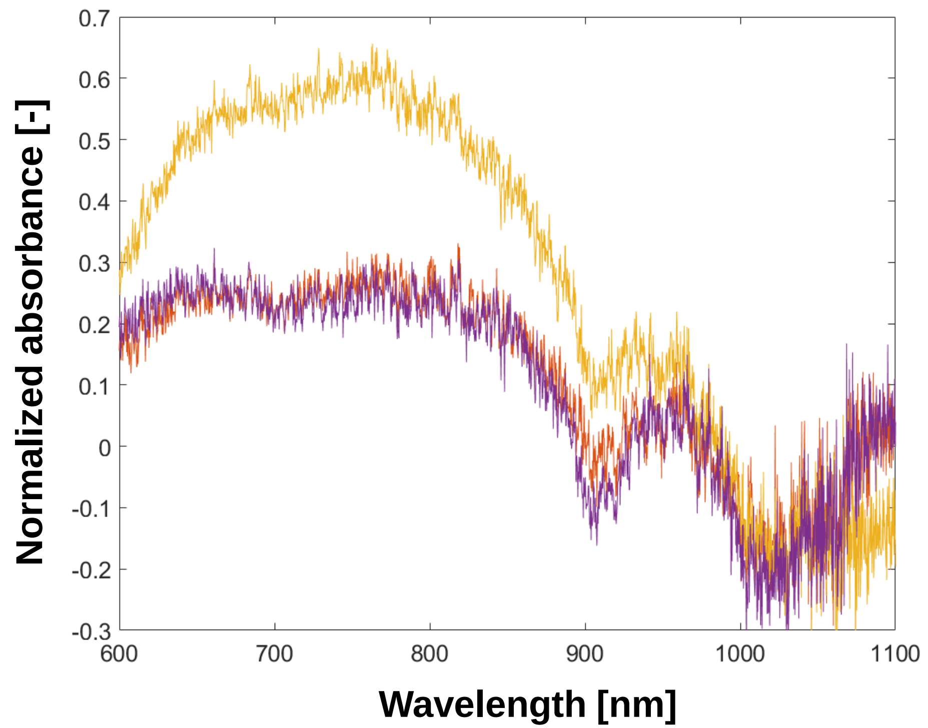
Peak positions: air 528 nm, water: 558 nm, prepolymer mixture: 570 nm, polymer: 577 nm.
From this the refractive index sensitivity of the sensor is: 90 nm/RIU.
The refractive index of the prepolymer is 1.466; the polymer: 1.544.

7. Absorbance measurements

Measured in transmittance mode with a VIS-NIR spectrometer



After subtracting the reference



Further optimization is needed!

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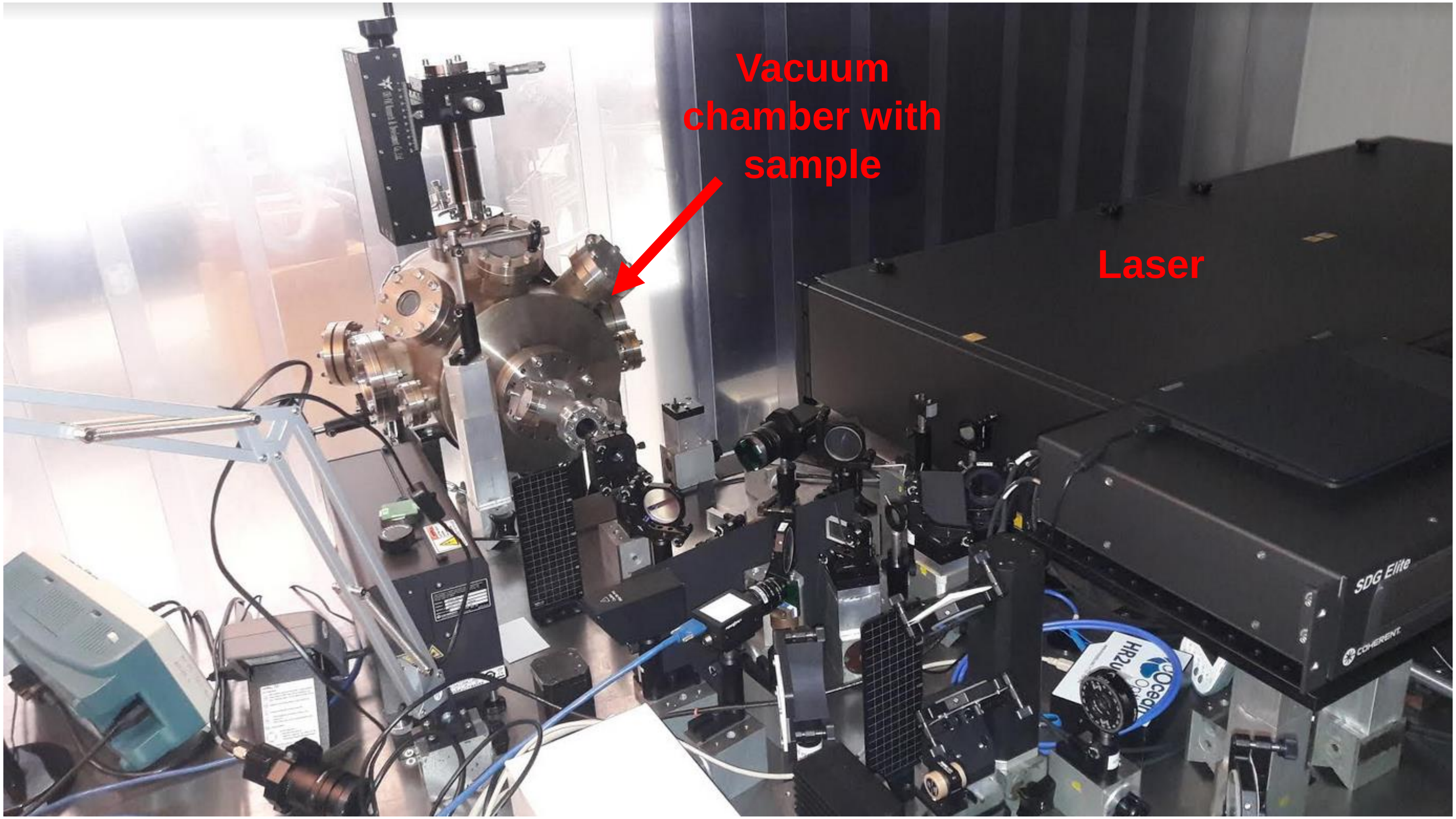
8. Laser irradiation experiments

The setup at Wigner Research Centre for Physics



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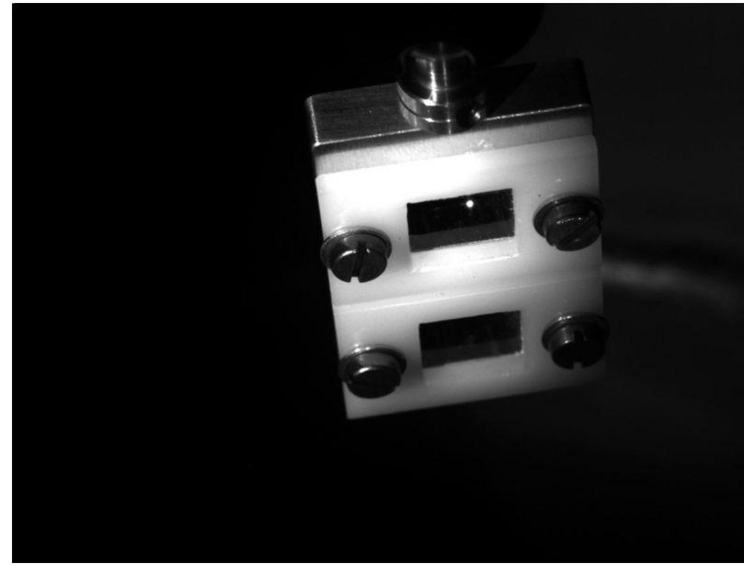
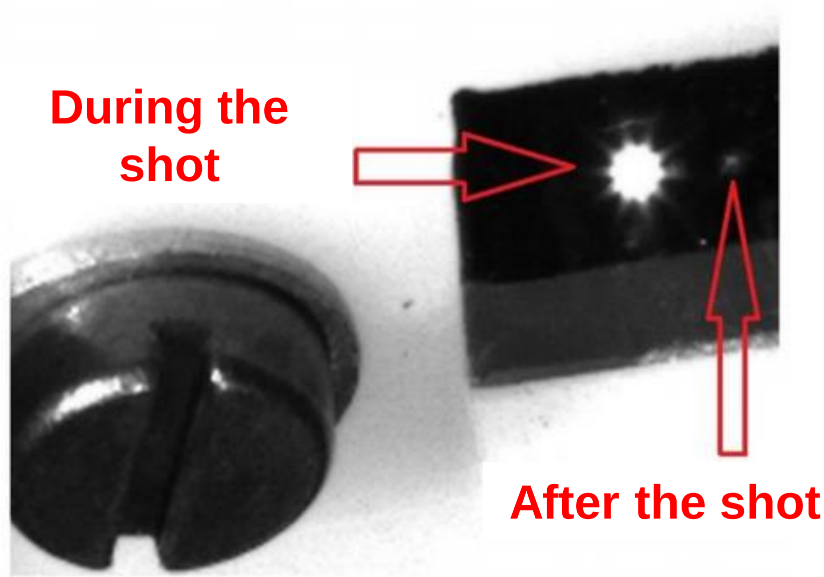
8. Laser irradiation experiments

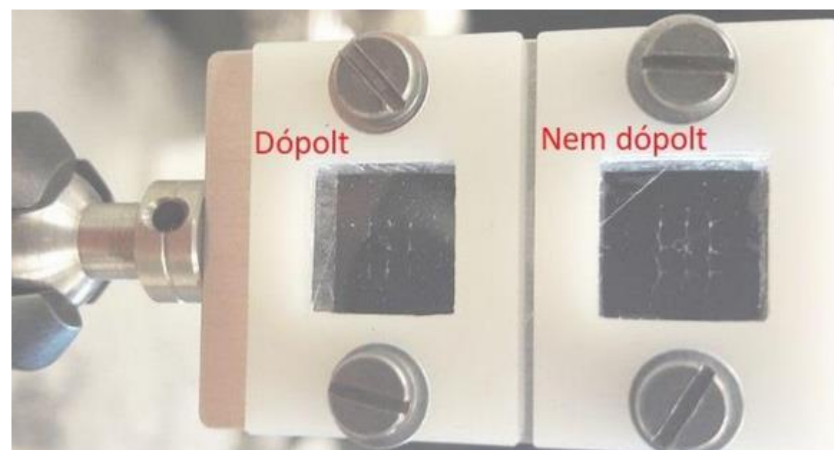
Main laser parameters

Impulse energy ~ 32 mJ
Impulse length ~ 45 fs
Focusing lens: f = 50 cm
Beam diameter without focusing ~ 12 mm
Beam diameter in the focus ~ 100 μm
Calculated intensity in the focus ~ 8×10^{16} W/cm^2





After irradiation (one side only!)



9. Raman spectroscopy on irradiated targets

Renishaw inVia mikro-Raman spectrometer and a LeicaDM2700 optical microscope

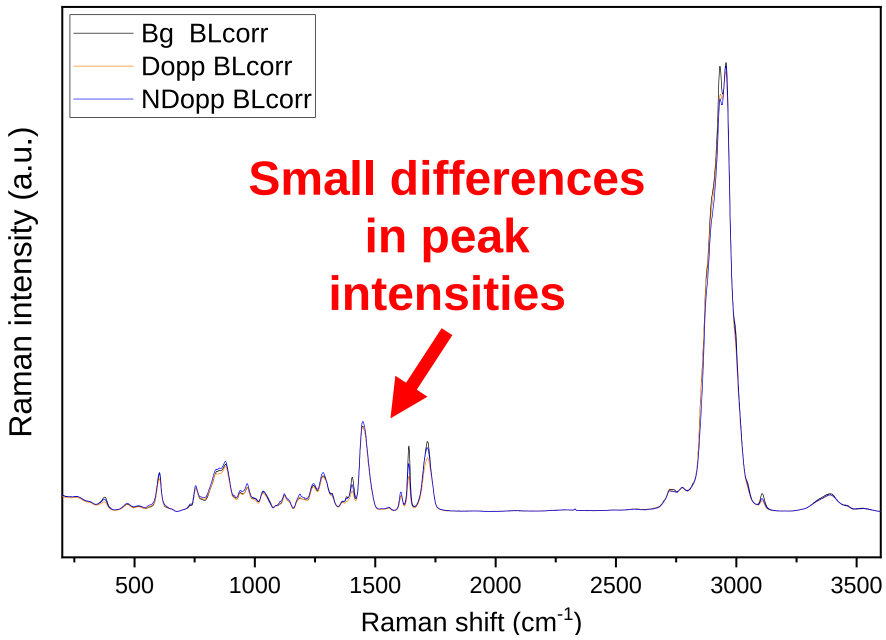
Experimental conditions

Excitation wavelength: 532 nm
Focus diameter: 1.3 μm
Laser intensity in focus: 6 mW
Exposition time: 10 s
Accumulation number: 20

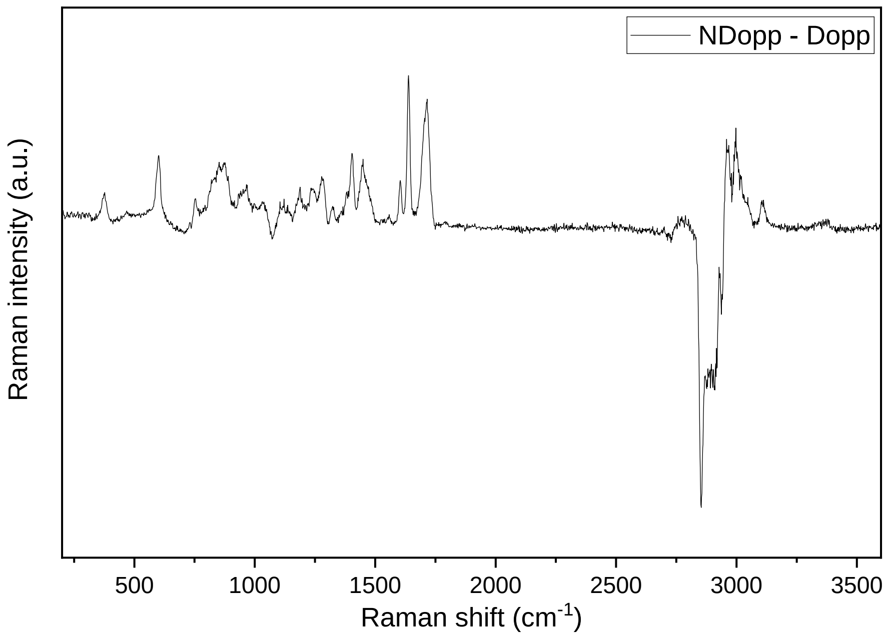
5 points were averaged for each sample

9. Raman spectroscopy on irradiated targets

Normalized and background corrected Raman intensities



Doped - reference sample (differential Raman intensities)



Differences in the intensities of carbon-related peaks can be observed for the doped samples

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Conclusions

- **A concept for nanoplasmonic laser fusion with two-sided laser illumination was presented.**
- **Preliminary experiments are being performed on nanocomposites: polymers doped with nanoparticles.**
- **The effect of the nanoparticles' properties on the absorption of the target was discussed.**
- **Target fabrication technologies were introduced.**
- **Preliminary characterization results obtained on the first batch of nanocomposites were presented, including ellipsometry, optical spectroscopy and Raman spectroscopy.**

Acknowledgements

The presenter would like to thank all the partners for their contribution to the talk.

The NAPLIFE Collaboration would like to thank for the financial support of the Eötvös Loránd Research Network and the Wigner Research Centre for Physics.

ELKH Eötvös Loránd Kutatási Hálózat

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