MŰEGYETEM 1782

NAPLIFE Collaboration

Nanoparticle doping of fusion targets

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BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
DEPARTMENT OF ELECTRONICS TECHNOLOGY

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 Ph.D + habilitation 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 Hungary&Romania EPS&NTC (Electronics Packaging Society and Nanotechnology Council) joint chapter since 2019.
- IEEE EPS/NTC Nanotechnology/Nanopackaging Technical Committee chair since 2022, co-chair since 2019.
- IEEE NTC Region 8 Chapters Coordinator.

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Agenda

1. Introduction of the NAPLIFE Collaboration and our work group

2. Considerations for target fabrication

3. Nanocomposite target preparation – results

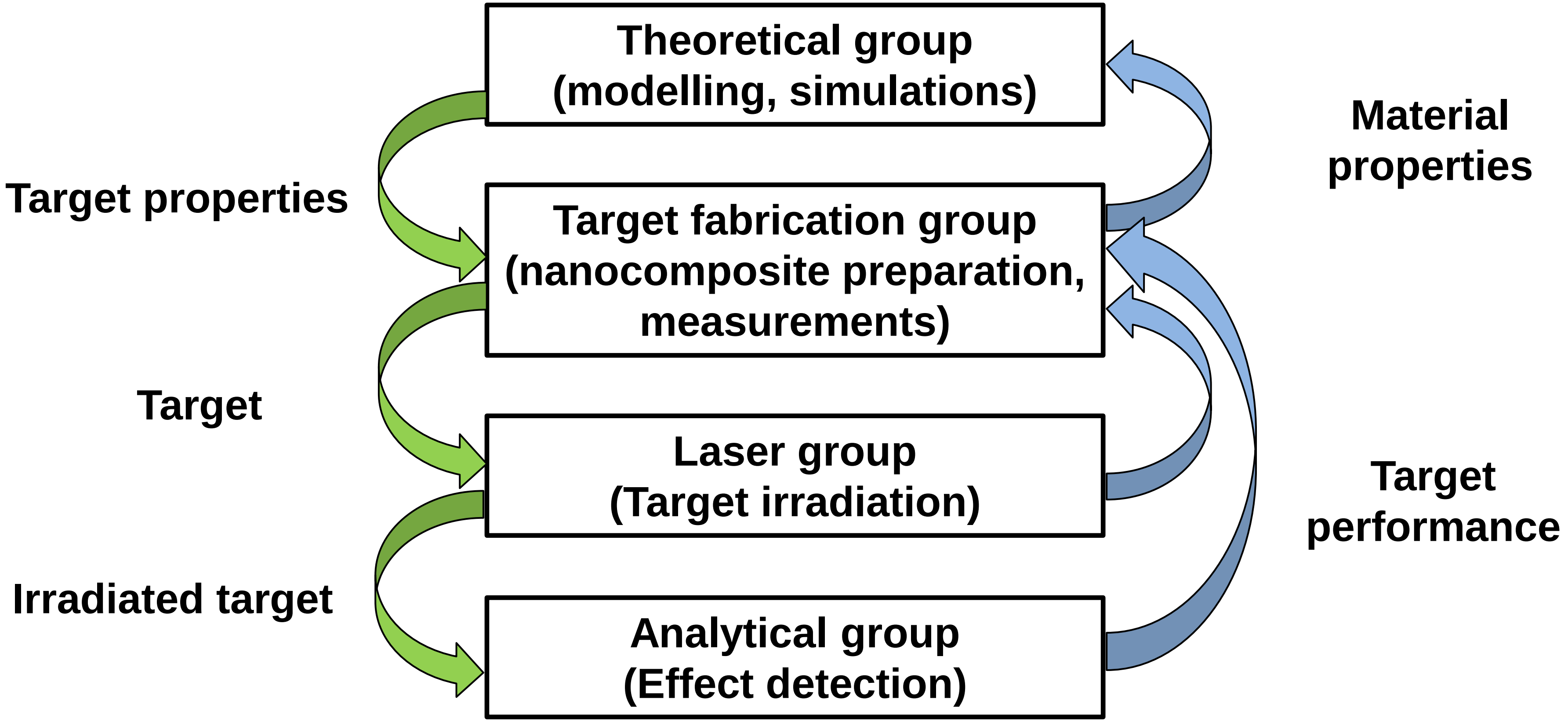
   - Tuning of plasmonic properties

   - Controlling the layer thickness

4. Conclusions

1. Introduction of the NAPLIFE project

Nano-Plasmonic Laser Inertial Fusion Experiment Collaboration



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1. Introduction of the Target Fabrication Group

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Dr. Bonyár Attila
Associate Professor

Alexandra Borók, Shereen Zangana, Rebeka Kovács
PhD Students

Coordination, target fabrication from nanocomposite, optical measurements, etc.

Dr. Szalóki Melinda
Assistant Professor

Debreceni Egyetem
Fogorvostudományi Kar

Polymer chemistry, doping of nanomaterials, nanocomposite preparation

Dr. Petrik Péter
Senior Research Fellow,
Head of Laboratory

MFA
Energiatudományi Kutatóközpont

Optical measurements (ellipsometry), transmission electron microscopy (Dr. **Zsolt Fogarassy**)

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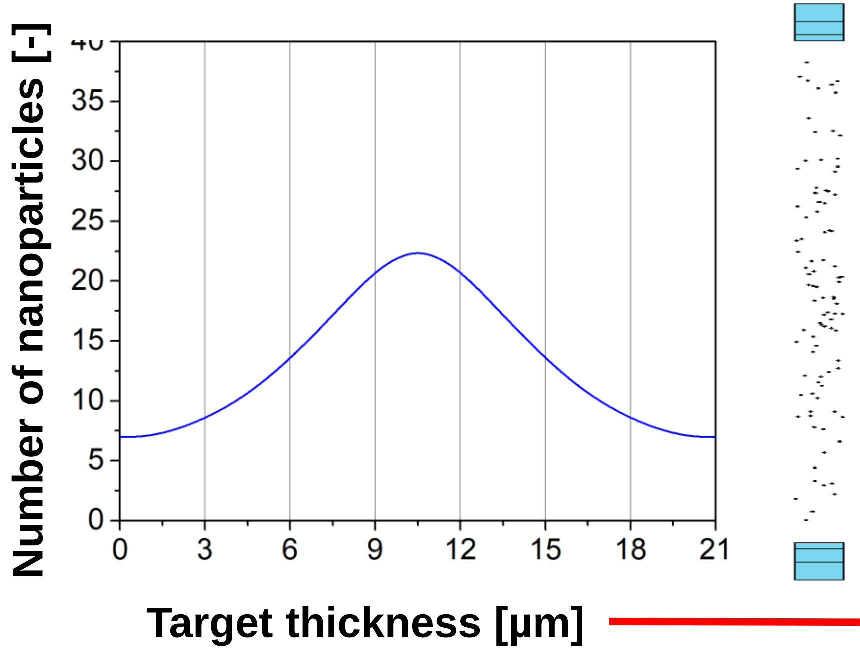
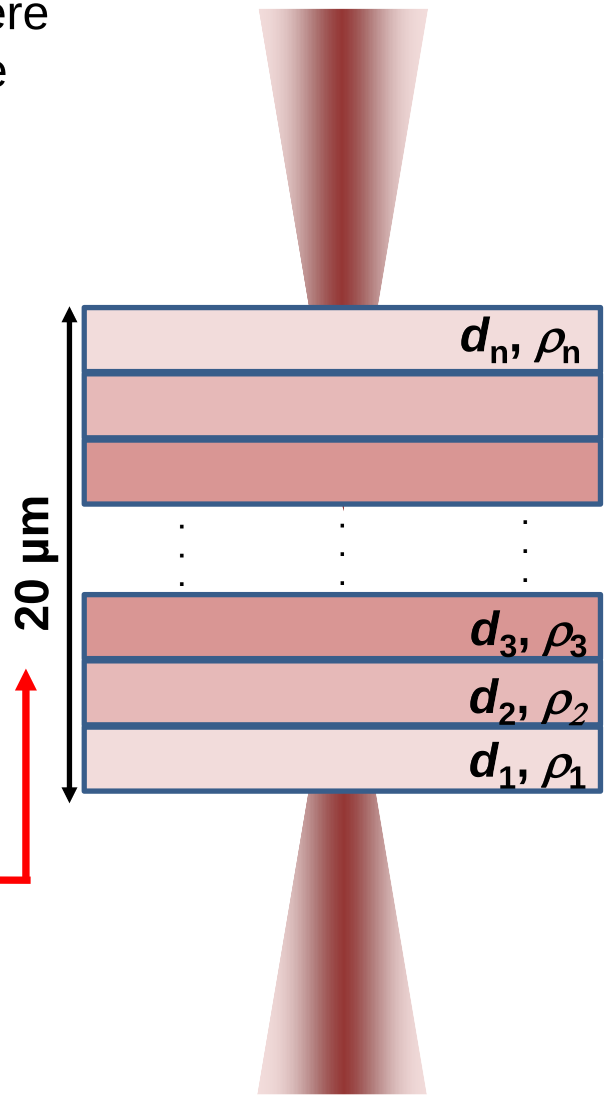
2. Considerations for the target

The planned target is a **model material**, where the density of the nanoparticles (and thus the absorption) in controlled in layers.

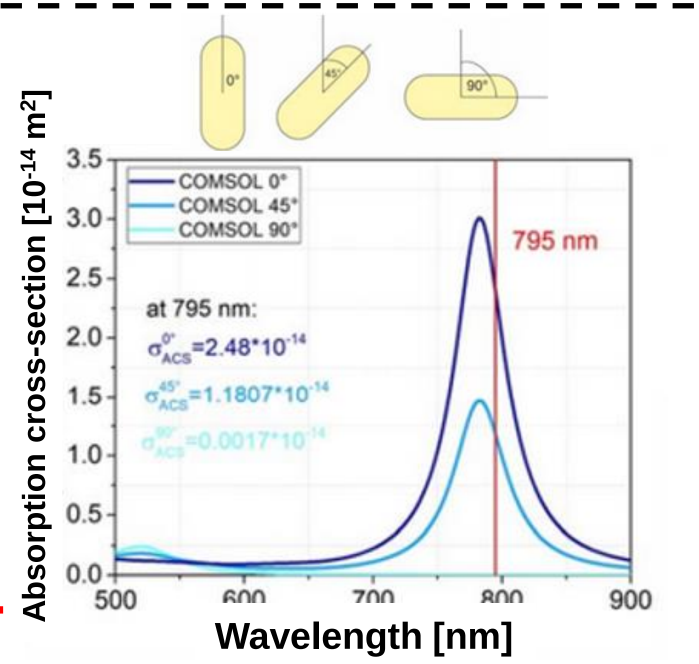


Calculations from the Theory Group

Laser beam



Laser beam



Calculations from the Theory Group

Target schematics considering two-sided irradiation

Number of layers: n=10

$d_1 = d_2 = \ldots = d_n = 2\ \mu m$

D = sum(d) = 20 µm

ρ_n: concentration of the nanoparticles in the layers.

2. Considerations for the target

Boundary conditions (requirements):

- The continuous nanoparticle distribution will be approximated with layers of constant nanoparticle densities.
- The layer thickness needs to be controlled (approx. 2 µm).
- The absorption peak should be at 795 nm.
- The nanoparticle density should be controlled, aggregation should be avoided.
- Multiple particle types should be tested (e.g. nanorods, nanoprisms, core-shells…)

Questions to be answered:

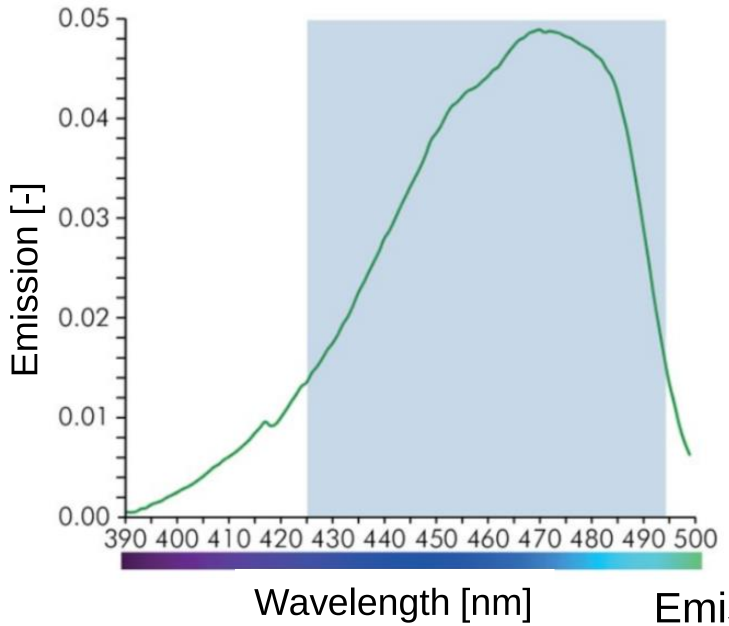
- What matrix material should we use?
- How to control the layer thickness and build layers on top of each other?
- How to synthetize nanoparticles with various shape and size?
- How can we control the plasmon absorption peak of the final target material?

2. Considerations for the target

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.

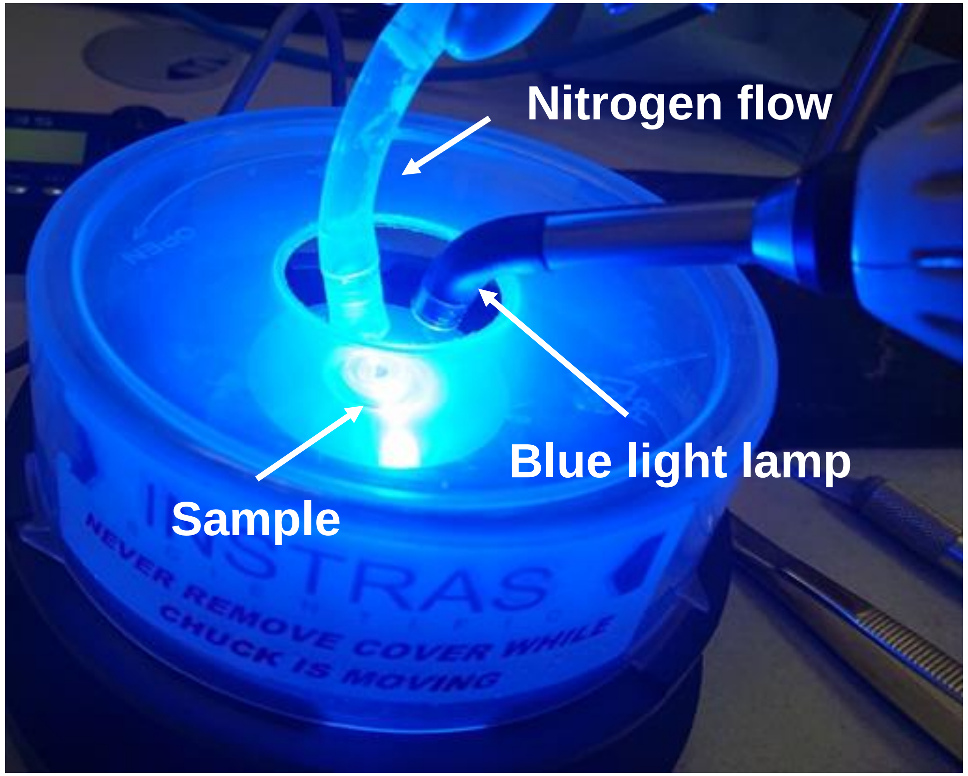
The selected polymer is **UDMA** (urethane dimethacrylate) with **TEGDMA** (Triethylene Glycol Dimethacrylate) dilution monomer, **CQ** (Camphorquinone) photoinitiator and **EDAB** (ethyl 4-dimethylaminobenzoate) co-initiator, which is a well-known mixture in dentistry.

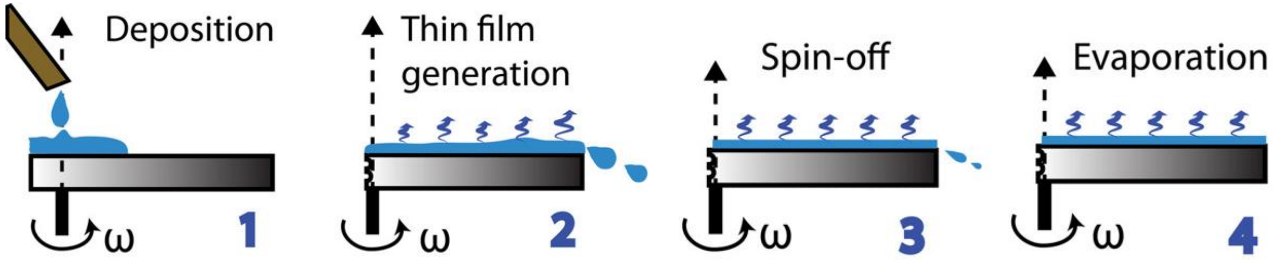


Emission spectrum of a standard blue-light lamp

Acrylate resin in cavity

3. Target preparation – layering technologies





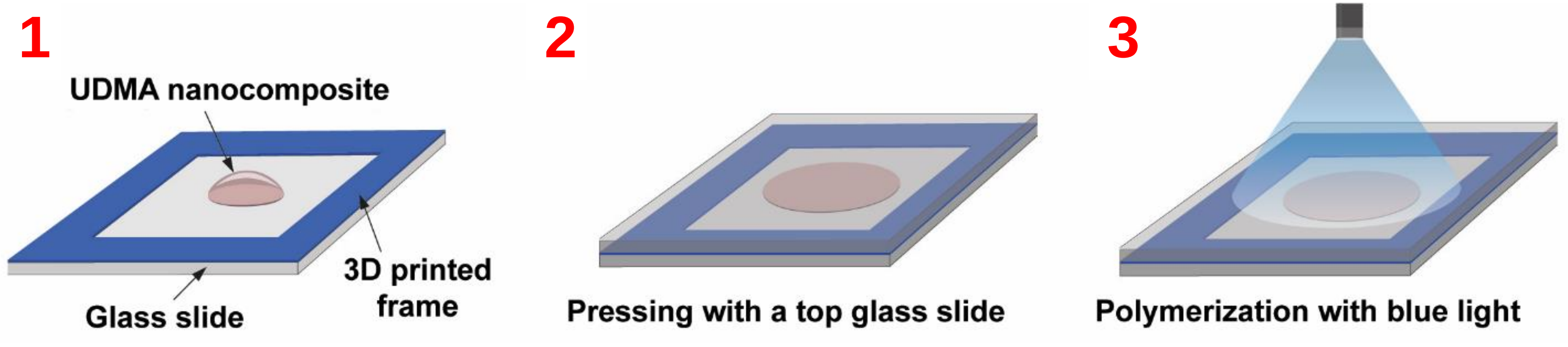
(Source: Rodrigo Perez Gartia)

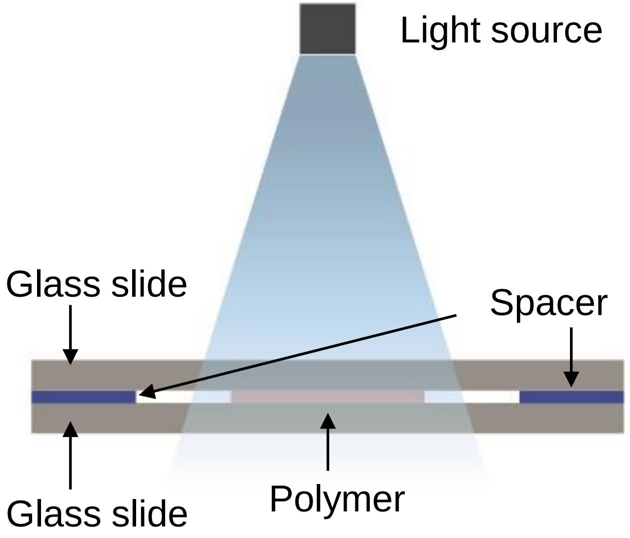
<u>Advantages / Disadvantages:</u>

+ Precise control over layer thickness.
- Viscosity has to be controlled.
- The polymerisation is sensitive to oxygen.

3. Target preparation – layering technologies

Polymerization during mechanical shaping between glass slides



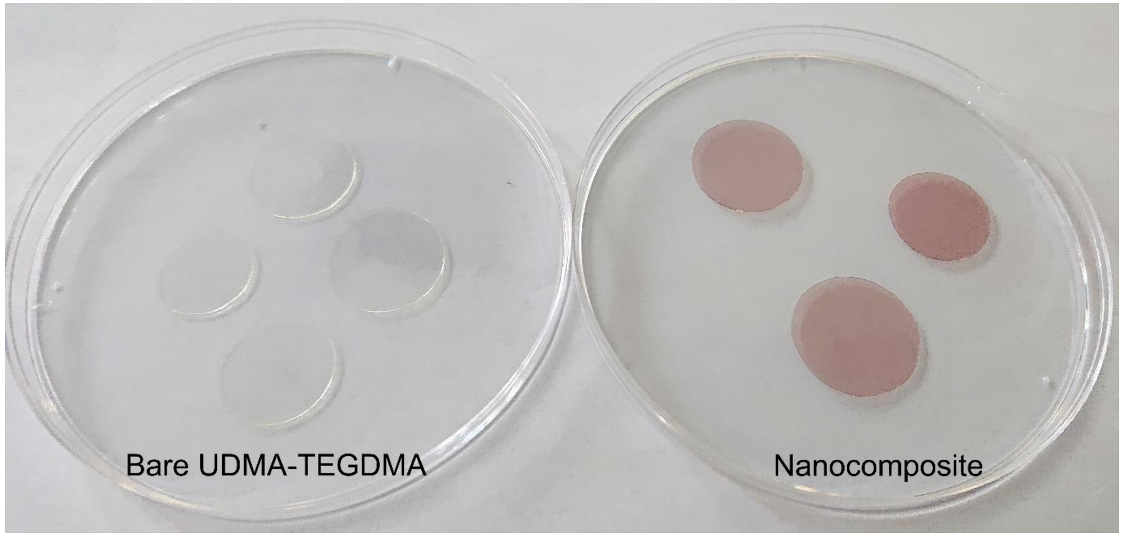


Advantages / Disadvantages:

+ Oxygen is not an issue.
+ Optically perfect, smooth layer.
- Viscosity has to be controlled.
- The thickness is hard to be controlled in the µm range.

Future improvement:

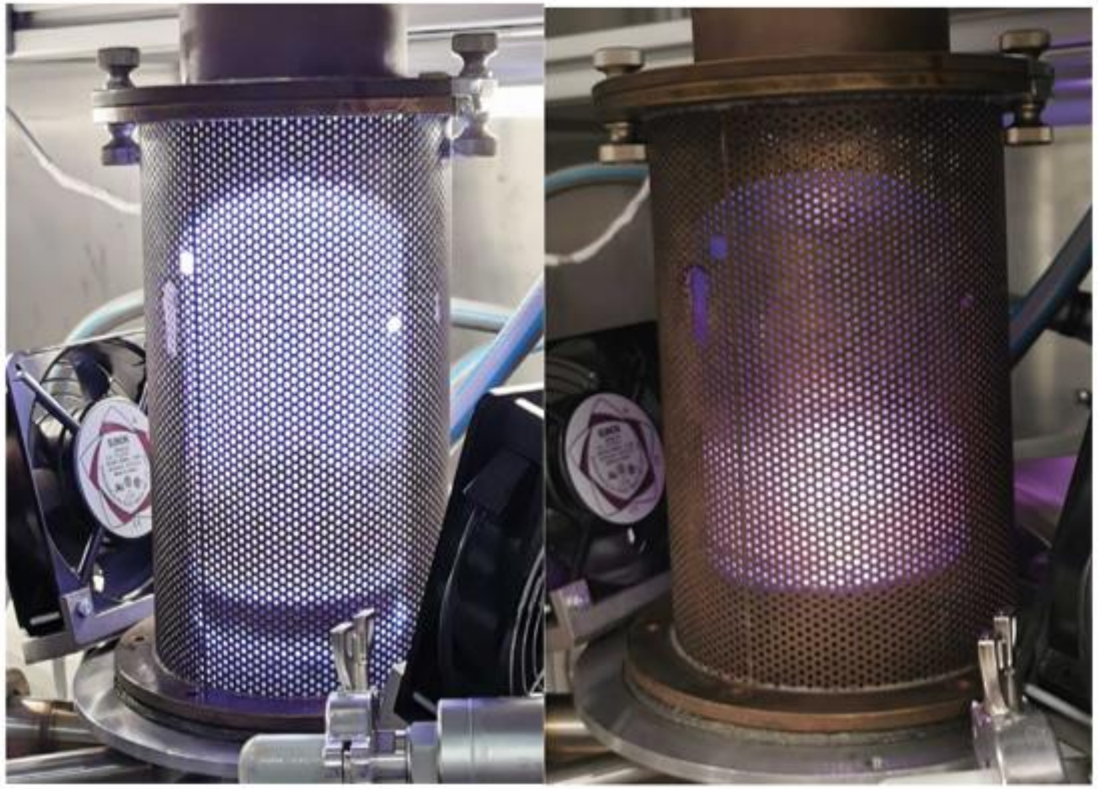
Multi-levelled frame created with thin film technology.



3. Target preparation – controlling the layer thickness

Plasma etching of the UDMA-TEGDMA material

High-power plasma reactor using focused H plasma (left) and defocused Ar plasma (right).



A reproducible etching rate of **80 nm/min** was found in O_2 plasma at 300 W power, 0.3 mbar pressure.

Low-pressure plasma chamber using O_2 (left) and Ar+Hr (right) as process gases for plasma generation.

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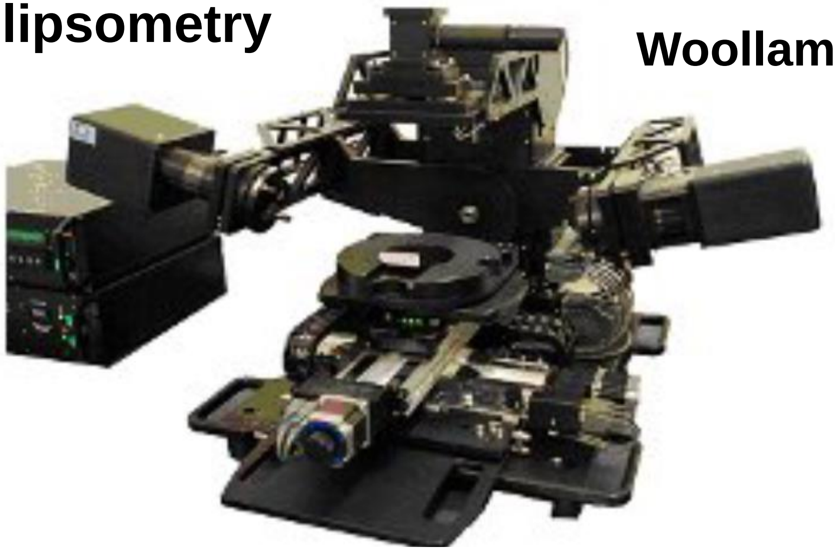
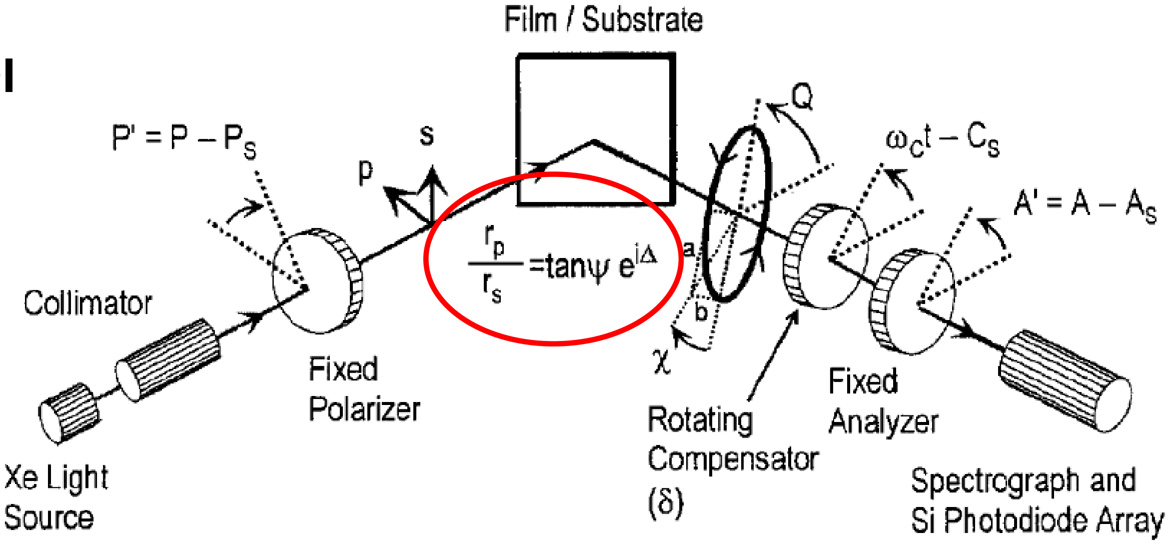
3. Target preparation – layering technologies

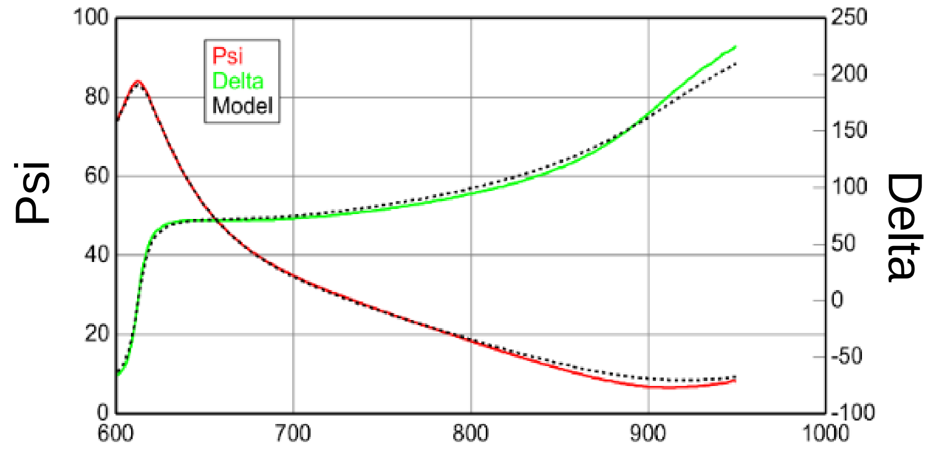
Ellipsometry

Woollam M-2000DI

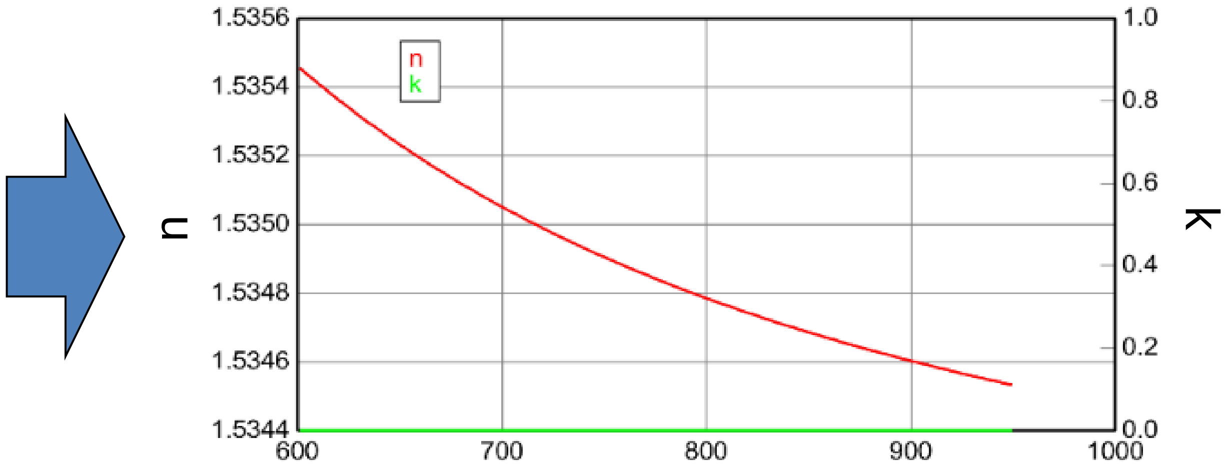




The measured Psi-Delta and the fitted model



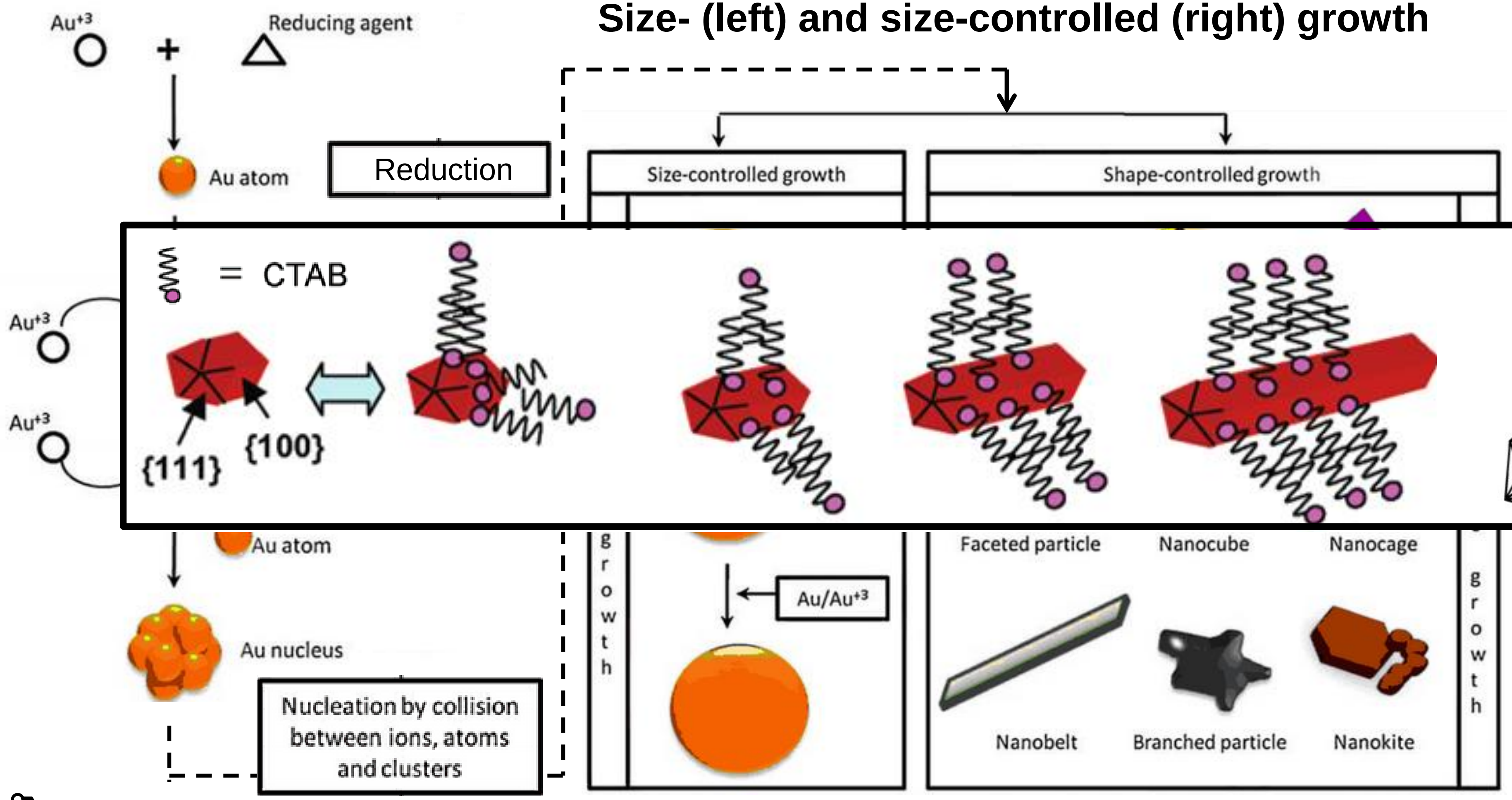
The complex refractive index (1 µm layer)



3. Target preparation – nanoparticle synthesis

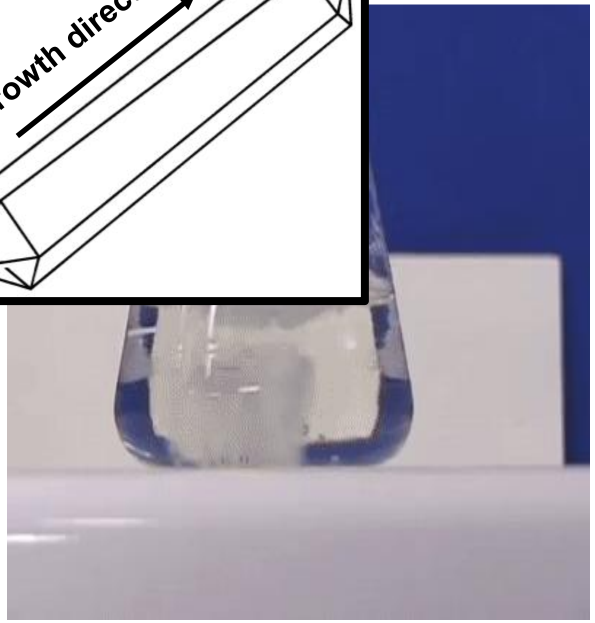
Gold nanoparticles from $HAuCl_4$ solutions

Size- (left) and size-controlled (right) growth



$HAuCl_4$ salt crystals

nthesis



(Source: Nguen et al, 2011)

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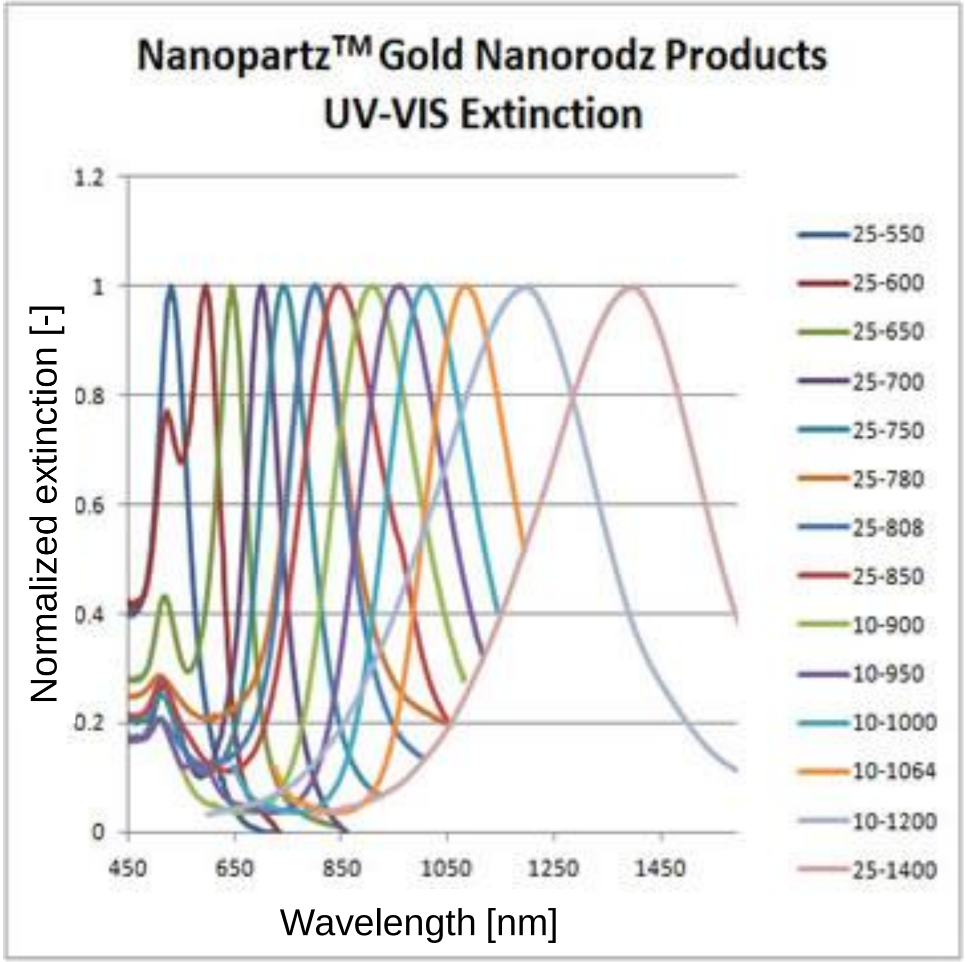
3. Target preparation

Absorbance measurements with optical spectroscopy



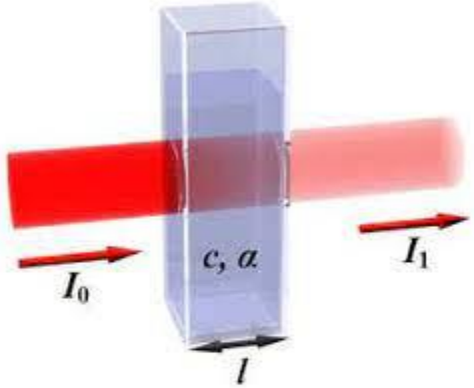
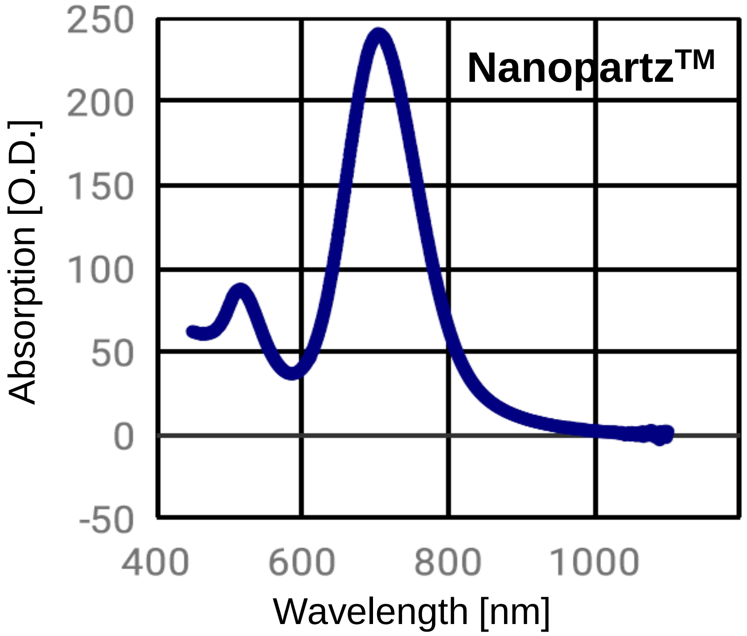
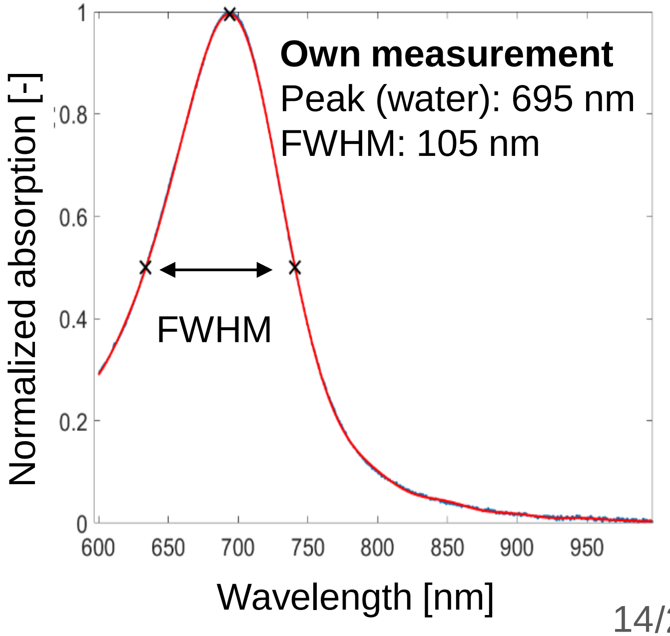


Illustration of the optical (dip) probe measurement setup (right)

Absorption spectra of 25 × 75 nm gold nanorods. Left: manufacturer. Right: own measurement





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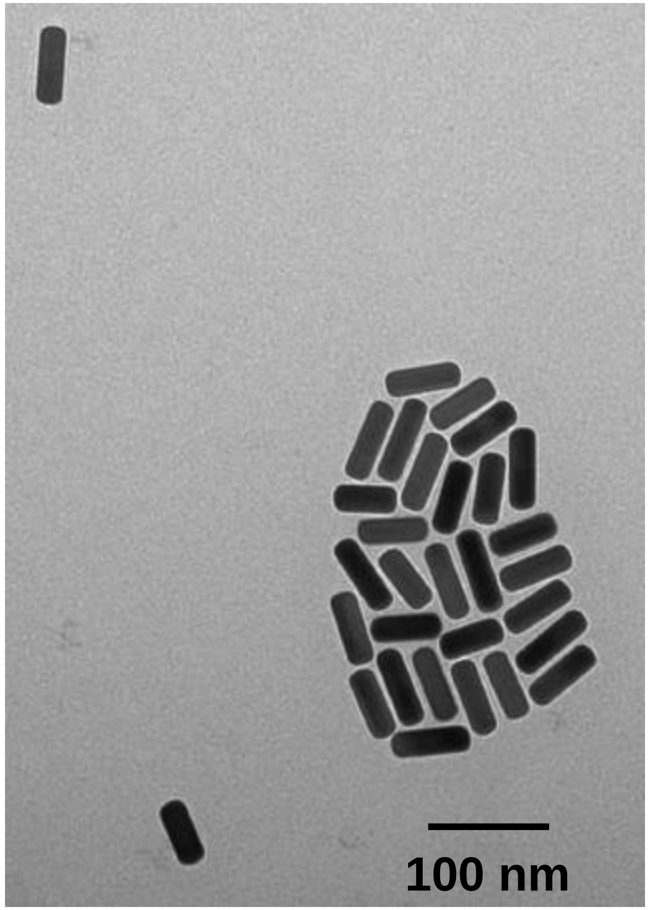
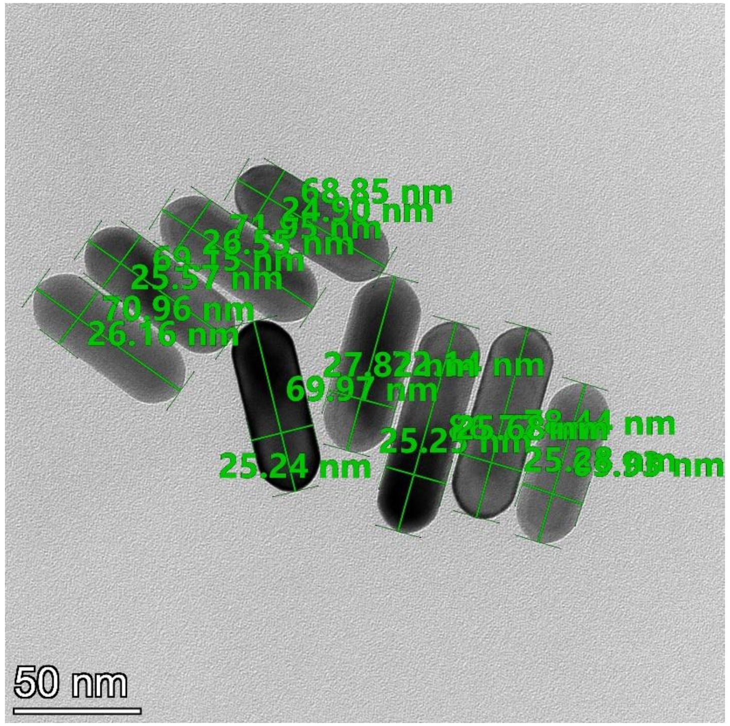
3. Target preparation – nanoparticle size control

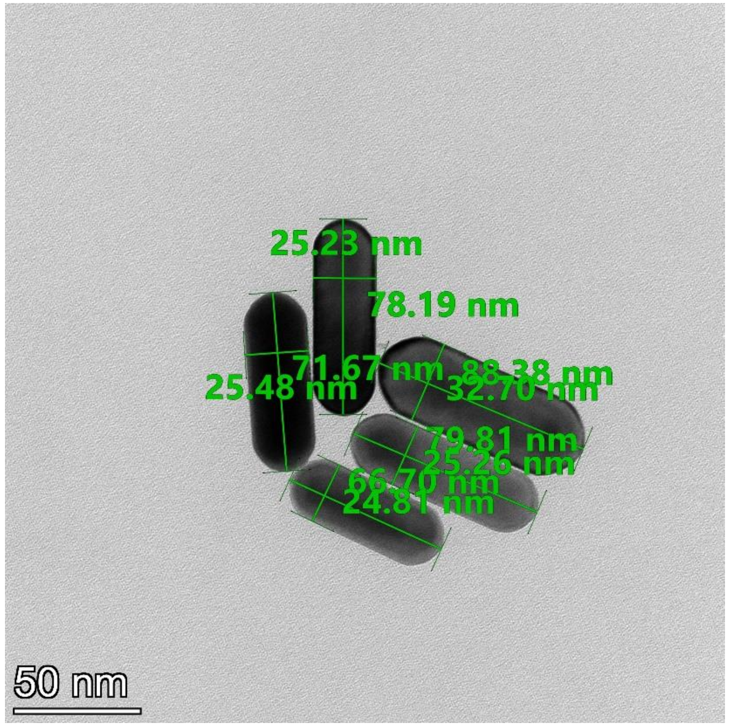
Transmission electron microscopy (TEM)

Nanopartz™ datasheet



Own measurements (Fogarassy Zsolt, ELKH-EK-MFA)





Nominal values from the manufacturer: **25 × 75 nm (±10 %)**

Own measurements:
Average (deviation) for 28 nanoparticles: **26** (1.65) **× 76** (7.97) **nm**

3. Target preparation – nanoparticle size control

Transmission electron microscopy (TEM)

A new direction: gold and silver nanoprisms, synthetized in Jena (Germany).

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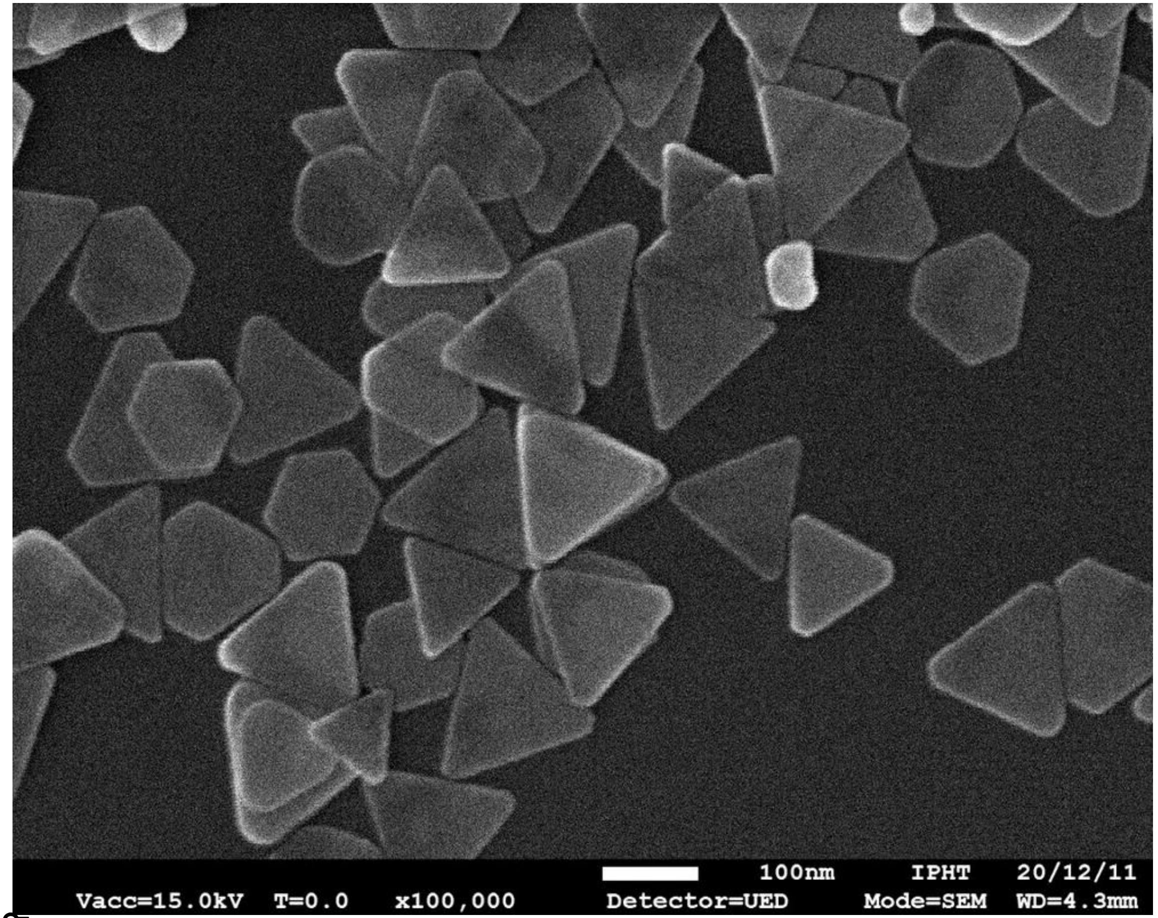

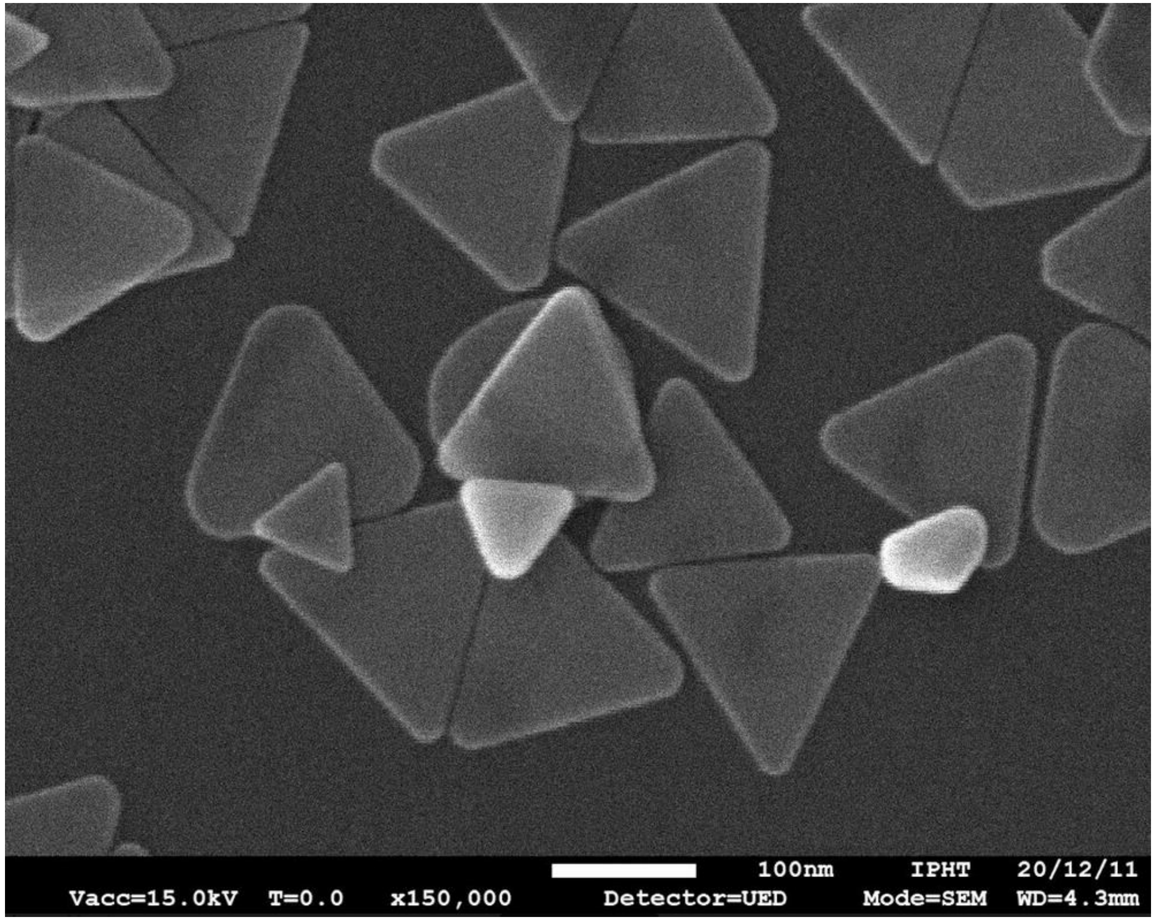

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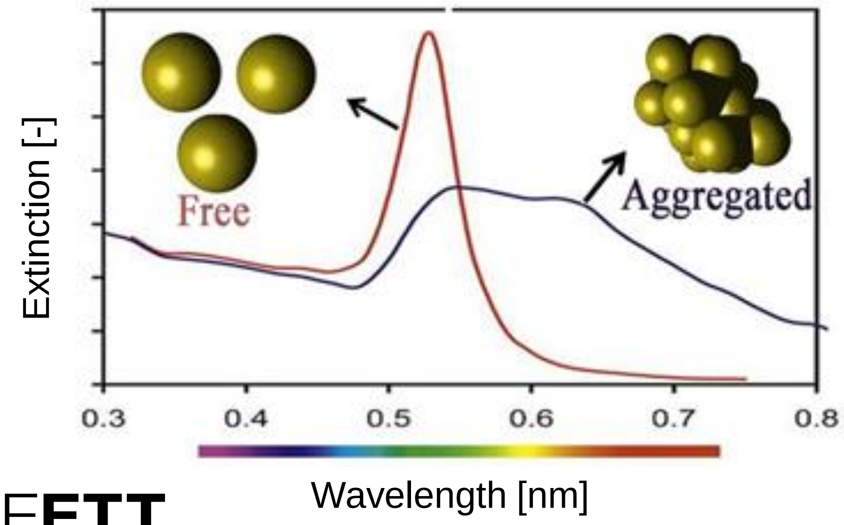
3. Target preparation – nanoparticle phase transfer

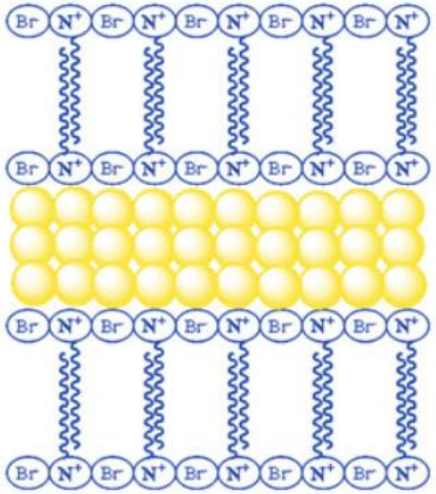
Importance of the molecular layer covering the nanoparticles (capping)

It is important to make the nanoparticles soluble in the polymer matrix, to avoid aggregation and to ensure uniform distribution.

Solubility is defined by the <u>molecular capping</u>.

Illustration of particle aggregation

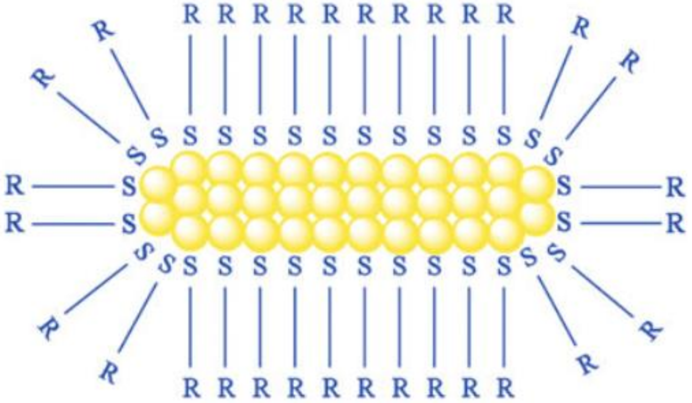




Water + nanoparticles (top)

Organic solvent (bottom)

Phase transfer: changing CTAB to alkanethiol



Water (top)

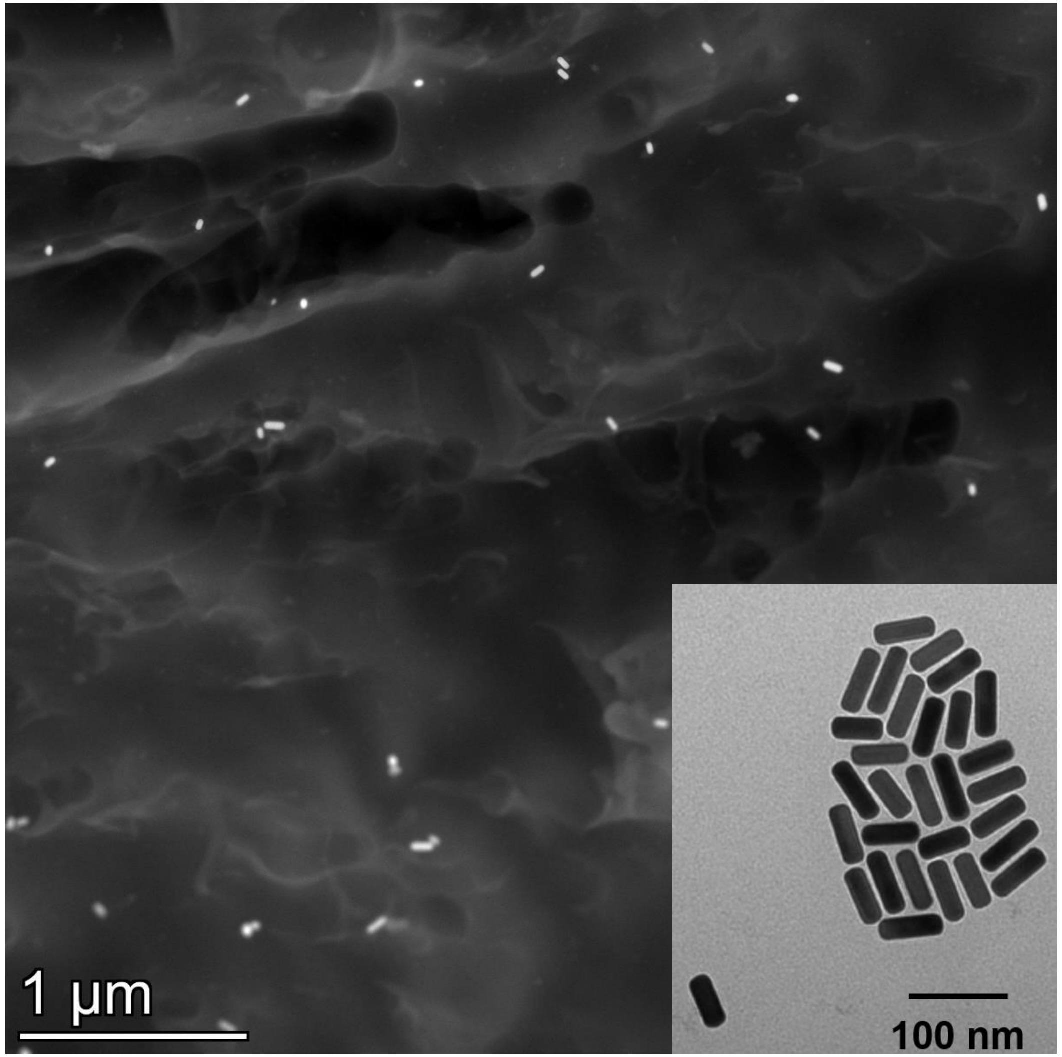
Organic solvent + nanoparticles (bottom)

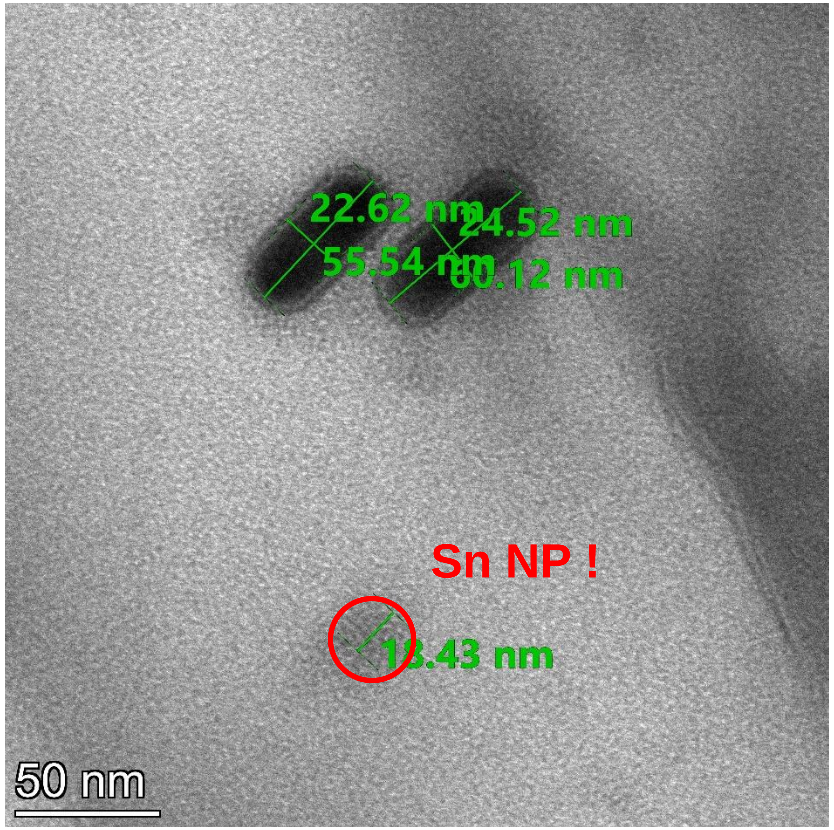
3. Target preparation – particle distribution control

Investigation of the embedded particles with TEM

Density of nanorods: 9-20 db μm^{-3}

Calculated from stock solution: 2 db μm^{-3}

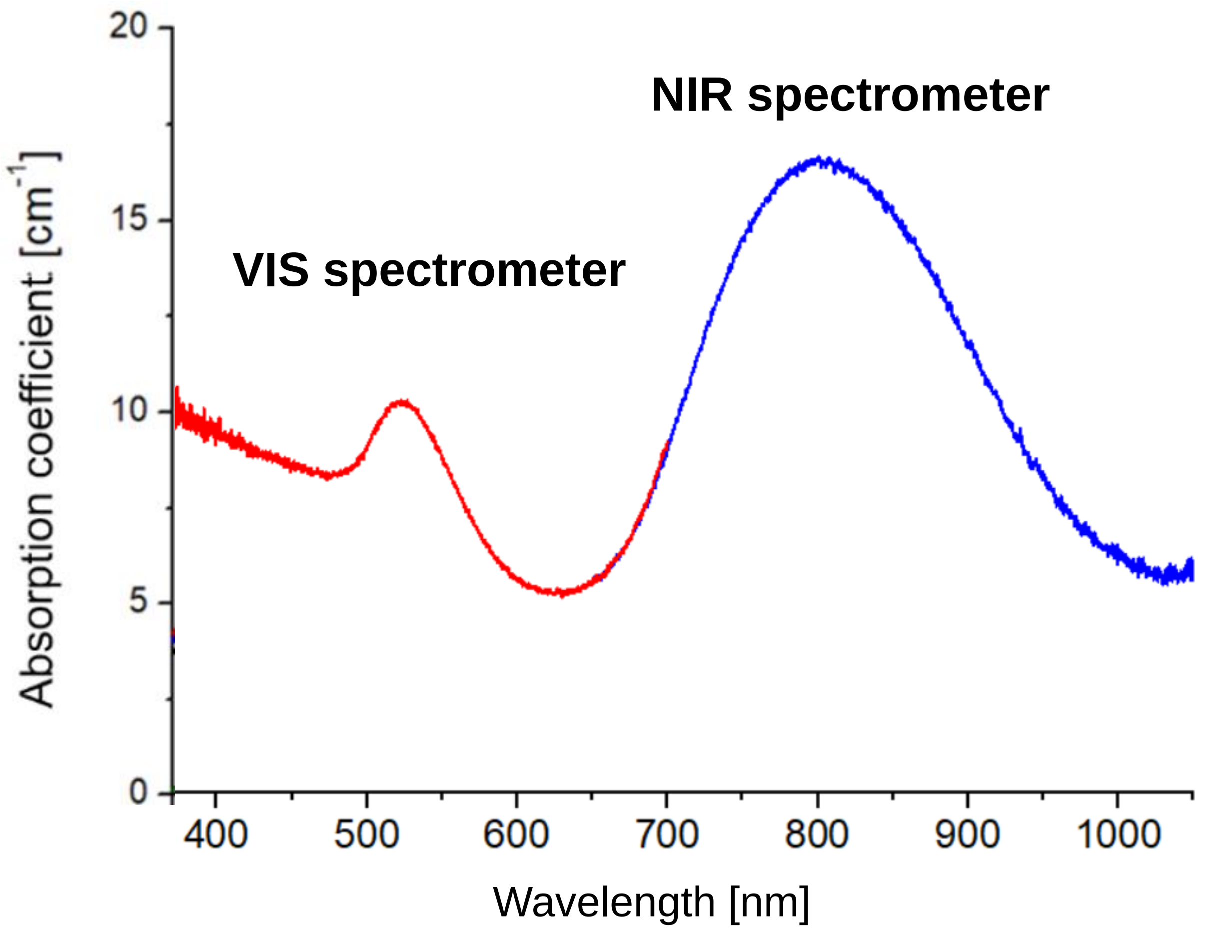




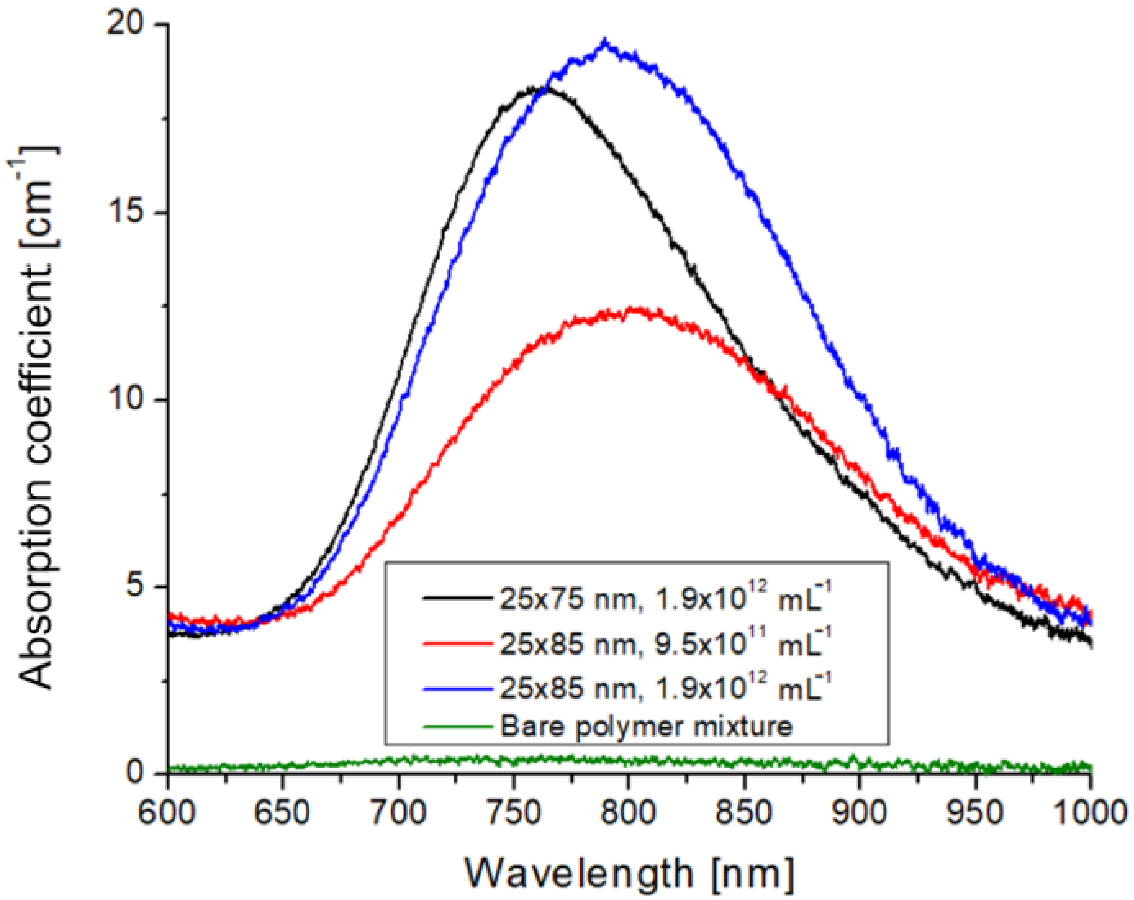
3. Target preparation – particle distribution control

Investigation of the absorbance with optical spectroscopy

Full spectrum of the nanocomposite (25x85 nm rods)

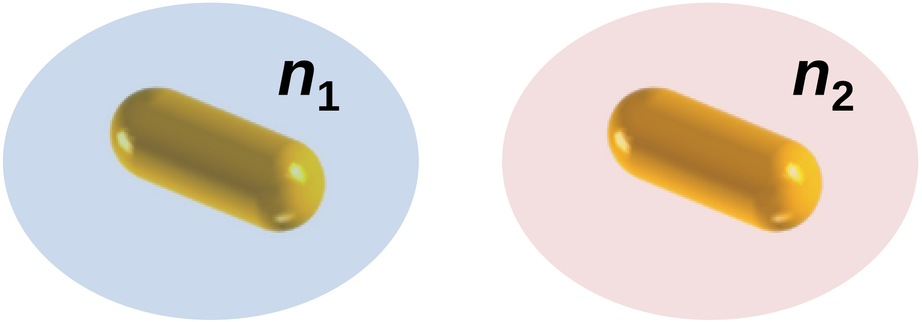


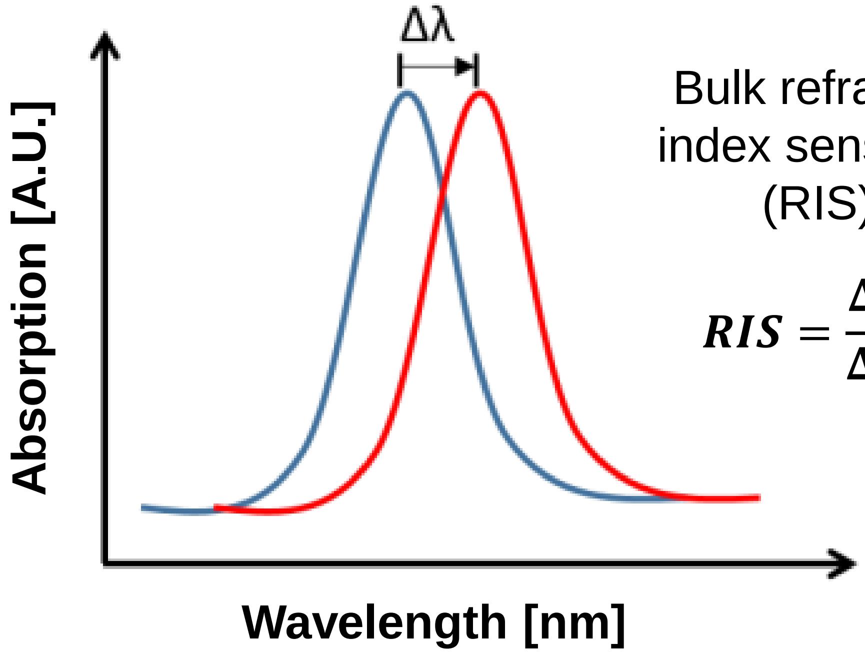
Nanoparticle aggregation starts at 3.8×10^{12} mL^{-1}



3. Target preparation – fine tuning the absorption band

Refractive index sensing with nanoparticles

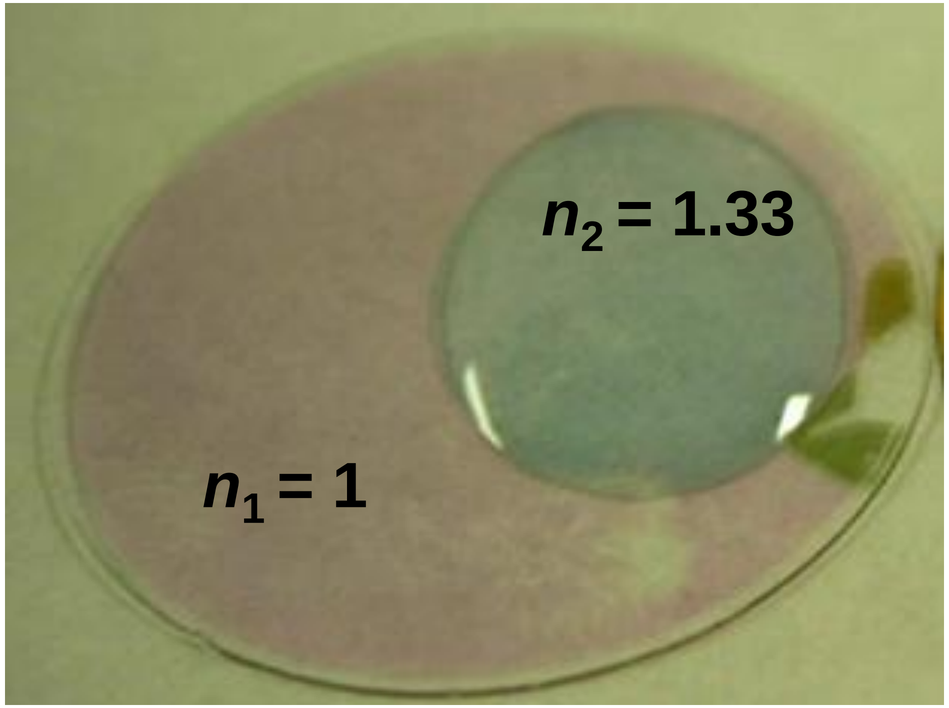




Bulk refractive index sensitivity (RIS):

$$RIS = \frac{\Delta\lambda}{\Delta n}$$

Illustration: gold nanodiscs on glass in water and in air



Source: Springer, Nanoplasmonic Sensors (2012)

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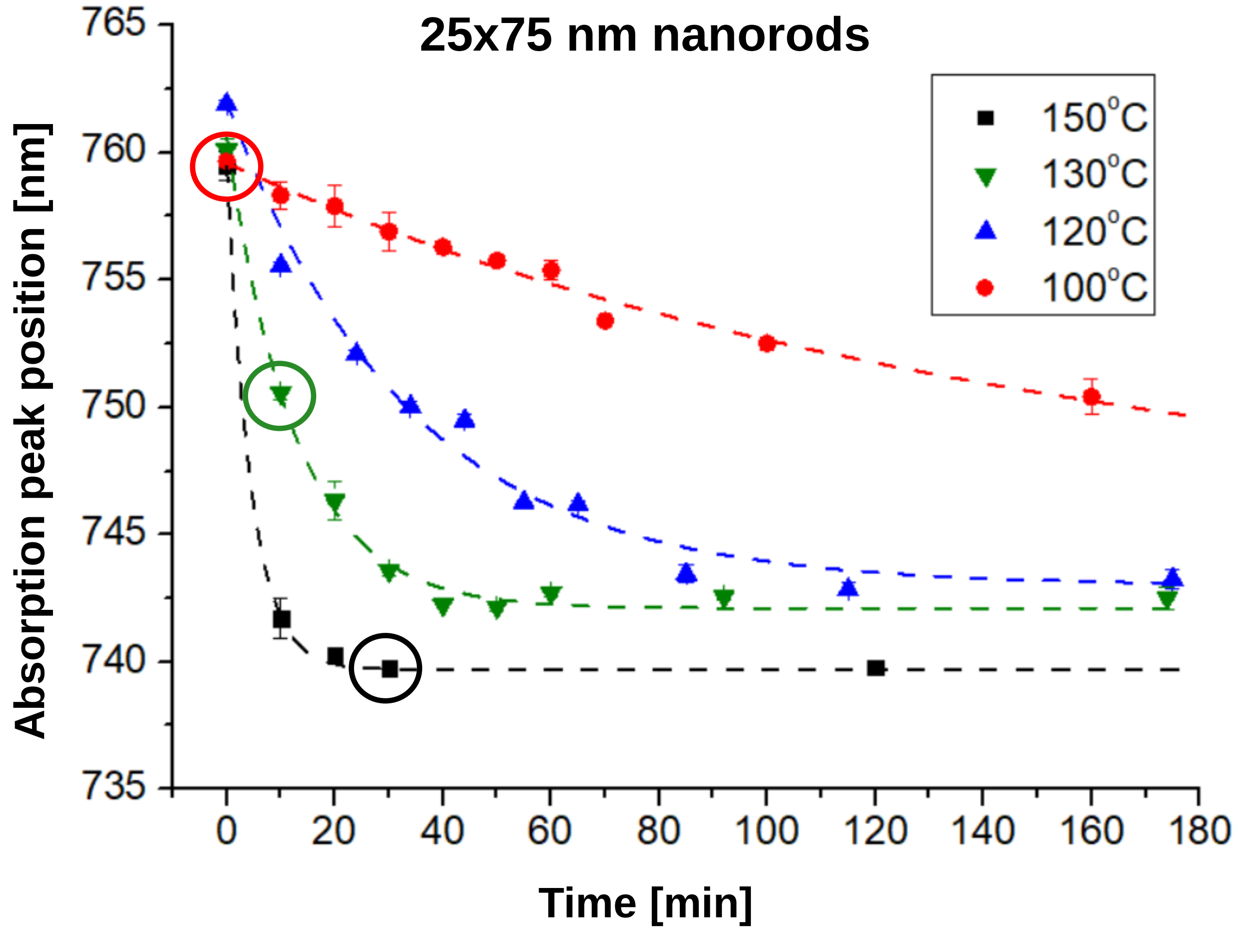
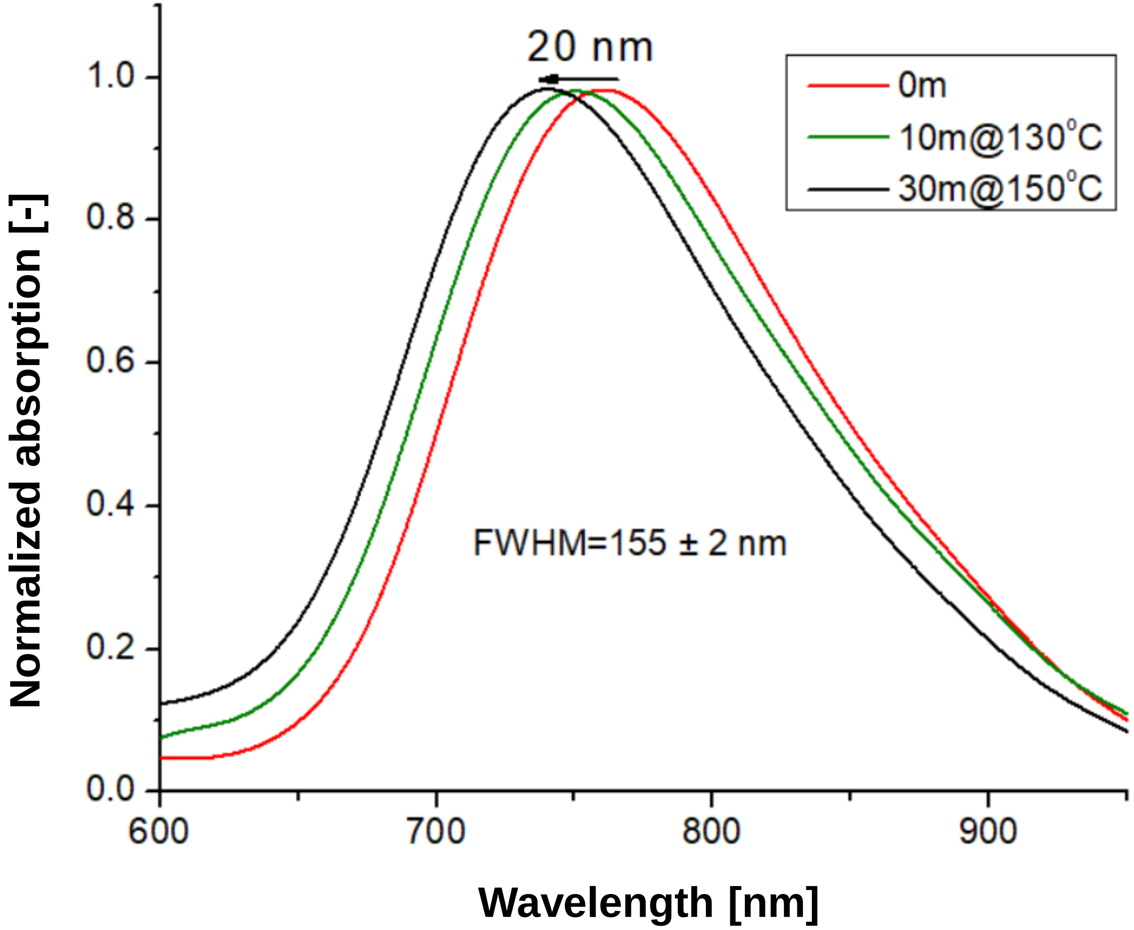
3. Target preparation – fine tuning the absorption band

Heat treatment was used to shift the absorption band – control with time and temperature





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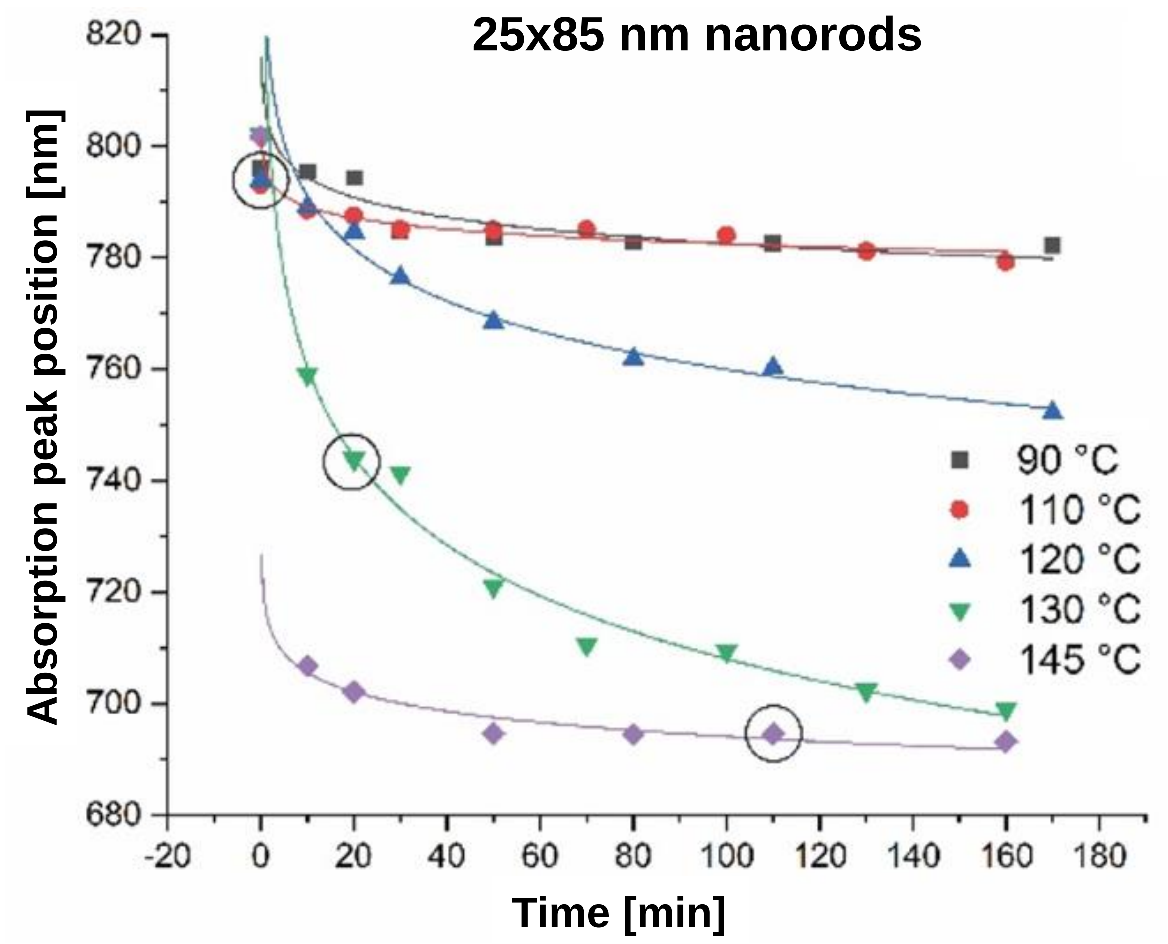
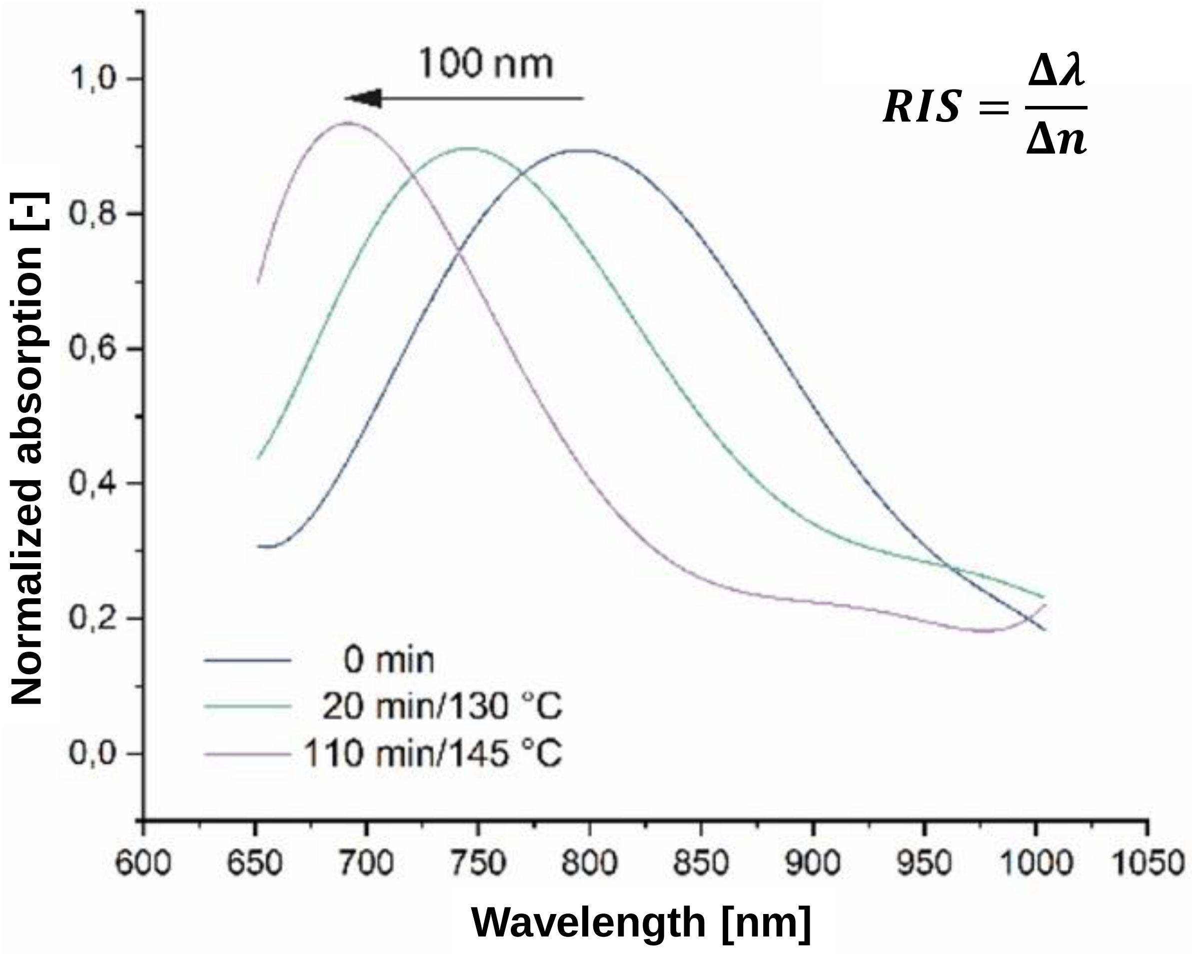
3. Target preparation – fine tuning the absorption band

The charts can be used to control the absorption in a wide range





$$RIS = \frac{\Delta\lambda}{\Delta n}$$

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Conclusions

“Take-home messages”

- Our current target is a model material made of a nanocomposite (doped polymer).
- Layering technologies are used to realize pre-defined nanoparticle distributions along the target’s thickness.
- Nanoparticle synthesis and doping are controlled with optical spectroscopy and TEM.
- A method based on thermal treatment was developed to fine tune the plasmon absorption band of the nanocomposite.

Acknowledgements

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Wigner

MFA

Energiatudományi
Kutatóközpont

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