Turbidity Spectrometry for Nanoparticles Size Measurement

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Outline

1. The problem of NPs size measurement
2. NPs size measurement by Turbidity Spectrometry (TUS)
3. TUS approaches
4. TUS potential and limitations
5. TUS in Nanopat project: the challenge of inline monitoring

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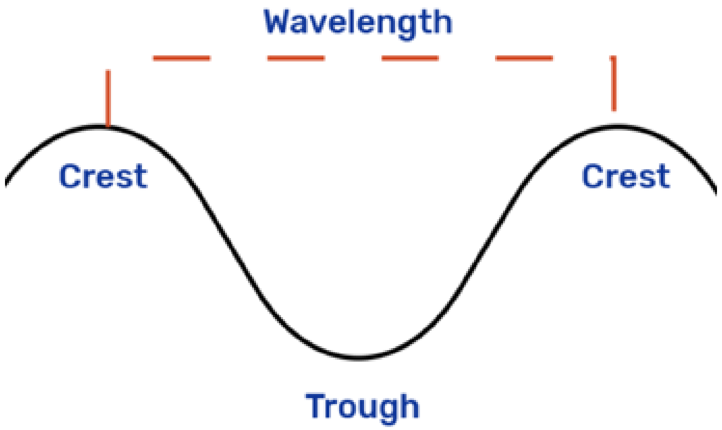
The problem of NPs size measurement

NPs use in commercial products

NPs are smaller than light diffraction limit!

wavelength (400-750 nm)



50 nm NP

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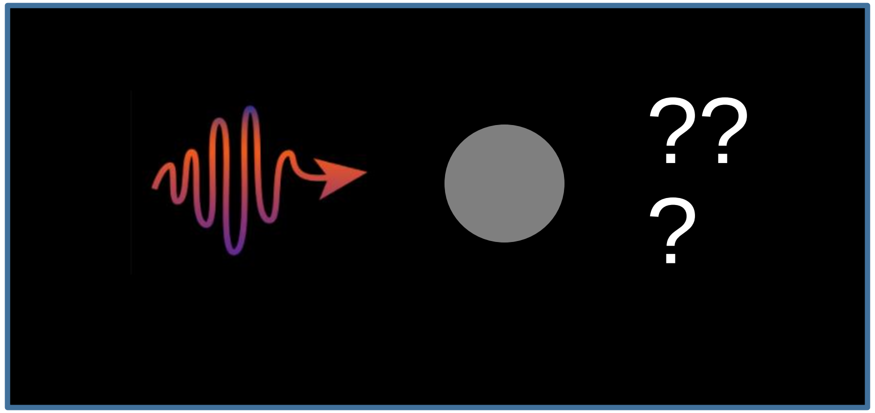
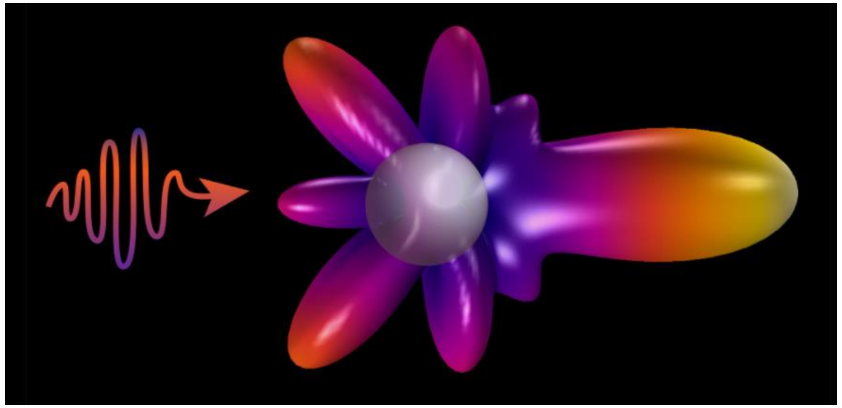
NPs size measurement by Turbidity Spectrometry (TUS)

Does light interact with NPs?



Mie Theory calculations:



Forward scattering depends on:

- wavelength of light
- NPs refractive index
- NPs size

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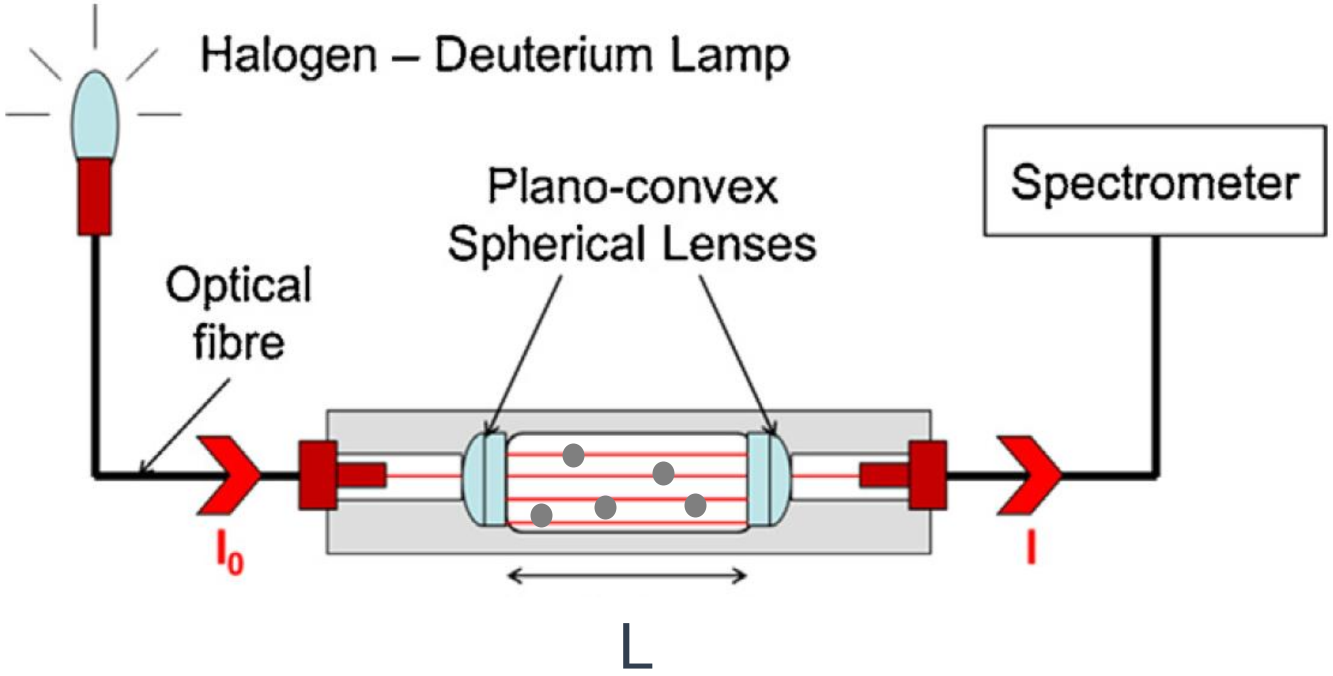
NPs size measurement by Turbidity Spectrometry (TUS)

Turbidity spectrometry (TUS) for NPs size measurement



- White illumination (λ_1, λ_2...)
- NPs in a solvent
- Spectral measurements

Surfaces A: Physicochem. Eng. Aspects 468 (2015)

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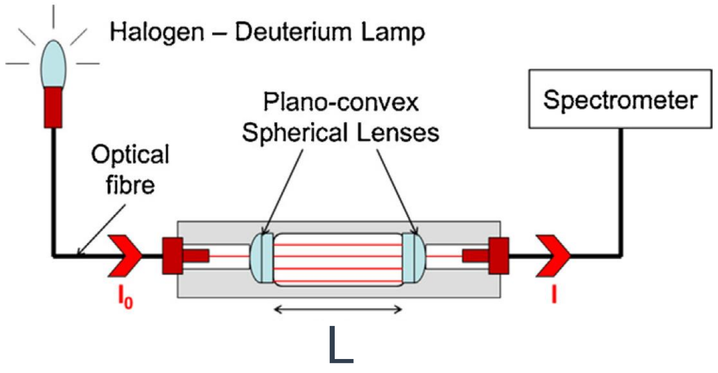
NPs size measurement by Turbidity Spectrometry (TUS)

TUS theory and different approaches

Measured turbidity:



$$\tau_{\lambda_0} = \frac{1}{l} \ln\left(\frac{I_0}{I}\right)$$

Calculated turbidity:

Hypothesis:

1. spherical shape
2. non-absorbing NPs
3. single-scattering

$$\tau_{\lambda_0} = N \frac{\pi D^2}{4} K_{\text{scat}}$$

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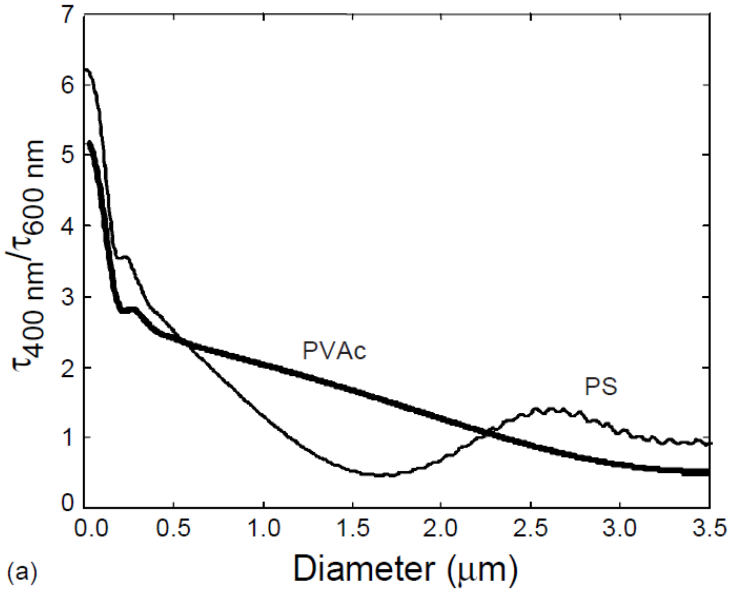
What can TUS provide

Turbidity ratio:

$$\frac{\tau_{\lambda 01}}{\tau_{\lambda 02}} = \frac{K\left(\frac{D}{\lambda_\mathrm{m}}, \frac{n_\mathrm{p}}{n_\mathrm{m}}\right)_{\lambda 01}}{K\left(\frac{D}{\lambda_\mathrm{m}}, \frac{n_\mathrm{p}}{n_\mathrm{m}}\right)_{\lambda 02}}$$



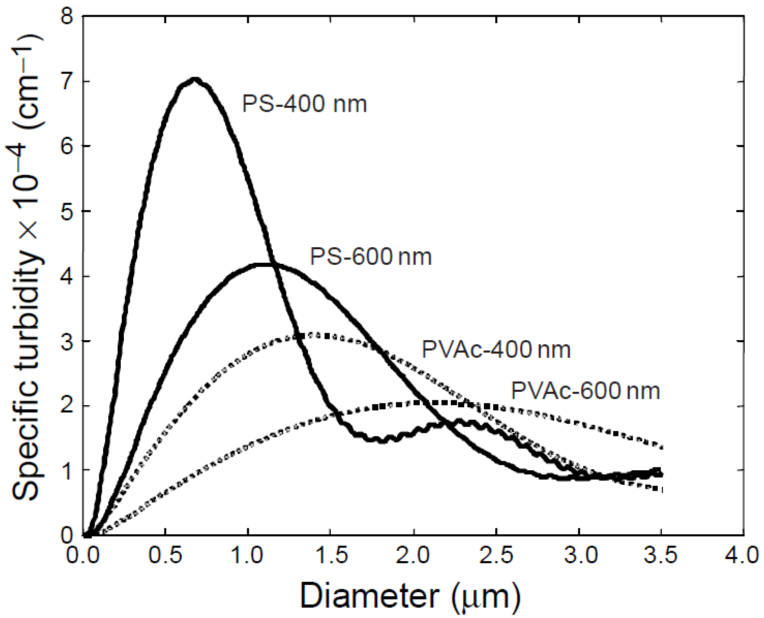
NPs minimum size ~ 100 nm

Specific turbidity:

$$\frac{\tau_{\lambda 0}}{\phi} = \frac{3}{2}\frac{K\left(\frac{D}{\lambda_\mathrm{m}}, \frac{n_\mathrm{p}}{n_\mathrm{m}}\right)}{D}$$

NPs volume fraction

$$\phi = N\frac{\pi D^3}{6}$$



NPs minimum size ~ 40 nm

Kurti, DOI: 10.1002/9780470027318.a1517

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TUS potential and limitations

Advantages:

- NPs size measurement down to 40 - 100 nm
- NPs size distributions down to few hundreds nanometers
- Simple and cheap system
- Measurements as fast as ~ 1-2 seconds

Limitations:

- Concentrated NPs solutions require dilution
- NPs size range depends on their refractive index

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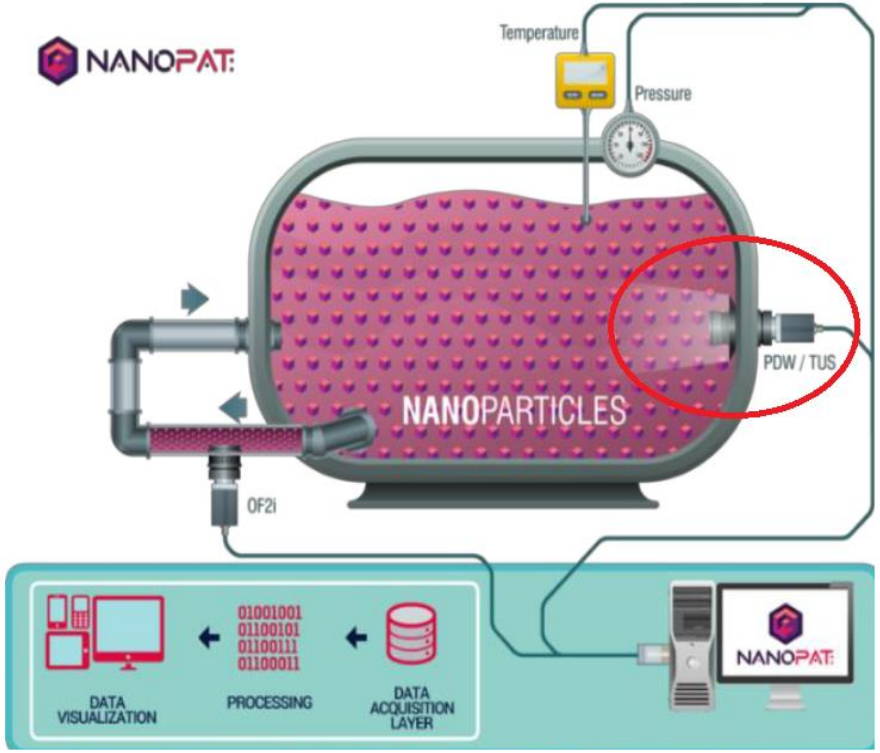
TUS applications in Nanopat project

Is it possible to use TUS for real-time and inline NPs size monitoring?

- Laboratory level:

- Intermediate level

- Industrial level:



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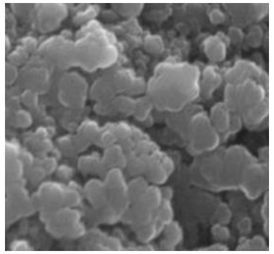
TUS applications in Nanopat project

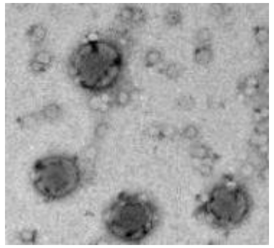
The Nanopat project and the challenges of industrial environment, TUS part:

Silica NPs synthesis



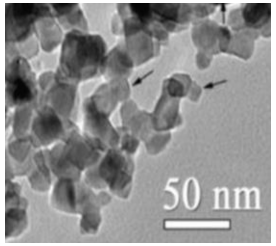
innoFSPEC
Innovative faseroptische Spektroskopie und Sensorik

Polymeric NPs synthesis (PMMA composites)



POLYMAT

Ceramic NPs in electroplating processes (TiO_2, SiC)



Med Uni Graz

- NPs are strongly aggregated, shapes not necessarily spherical
- Optical density at end of synthesis is high, no single scattering hypothesis
- At end of synthesis NPs size can be broadly distributed
- Solution refractive index can change during the process

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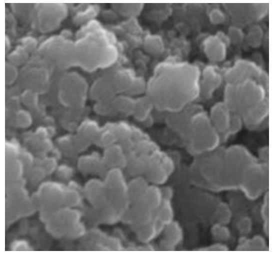

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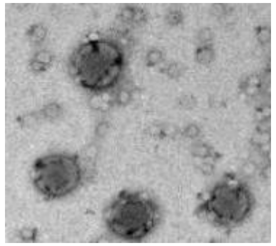

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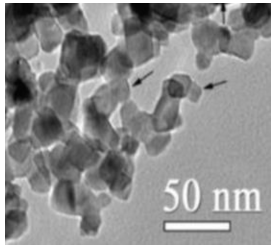

Approaches:

- NPs solution dilution, when required
- Machine learning for NPs size monitoring
- Focusing on specific reaction stages

Initial results:

- Polymeric NPs measurements down to 40 nm at RTO
- Silica NPs measured down to 50 nm in the lab

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Thank you!

NANOPAT:

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