Raman Confocal Microscopy
with the Highest Spatial Resolution

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High spatial resolution chemical imaging / analysis is a target for many researchers in nanotechnology and biology.

Confocal microscope equipped with spectrograph is a good choice for non-destructive chemical analysis with Raman spectroscopy.
Layout of the Raman instrument – Confotec NR500 (SOL instruments)

Raman confocal microscope "Confotec NR500" (SOL instruments Ltd.) was developed as a highest spatial resolution device

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Ultra-low frequency Raman measurements of CdI2 (Cadmium Iodide) using a Confotec NR500 system
A pinhole blocks the scattered light which is coming from the out-of-focus points.

Confocal apertures define the volume from which signal is collected.

Confocal Micro-Raman:
- Use of pinhole aperture to decrease off-focal rays
- Much smaller background
- 3D information
- Slightly higher lateral resolution

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Comparison of Lateral Resolution Properties

| λ = 488nm | NA = 0.95 |

Lateral resolution is 1.39 times better

Intensity Distributions in the focal point

Airy disc radial intensity distribution

Axial intensity distribution
Lateral (XY) spatial resolution

\( \lambda = 488 \text{ nm}, \ NA = 0.95 \)

- Rayleigh criterion (313 nm)
  \[ R_{\text{Lateral}} = \frac{0.61 \lambda}{NA} \]

- Sparrow criterion (241 nm)
  \[ R_{\text{Lateral}} = \frac{0.47 \lambda}{NA} \]

- Abbe criterion (257 nm)
  \[ R_{\text{Lateral}} = \frac{0.50 \lambda}{NA} \]

- Unresolved
The line spread function (LSF) is the derivative of the edge response. The width of the LSF is usually expressed as the Full-Width-at-Half-Maximum (FWHM). The width of the edge response is usually quoted by the 10% to 90% distance.

Experimental estimation of spatial resolution

Lateral resolution estimation (XY resolution):

Axial resolution estimation (Z resolution): Defocus Response
Si edge response function

Position along X-axis scanning, nm
Point Spread Function: Experimental measurement

UV laser reflection, NA=0.95

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Lateral spatial resolution

![Graph showing the relationship between XY resolution and Wavelength for different NA values.](image-url)
3D Raman imaging capability

Intensity distribution (Si peak)  Si peak position

Scan area: 50 x 50 x 7 um
Spatial resolution enhancement techniques in microscopy

Several approaches and methods for further spatial resolution improvement below the diffraction limit:

**Nanojet** (Near-field Raman imaging using an optically trapped dielectric microsphere)

**Special illumination / detection** (structured laser beam illumination)

**Tip Enhanced Raman scattering**

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New technique: Photonic nanojet enhancement

- Spatial Resolution can be achieved below the diffraction limit
- Raman signal may be enhanced by small particle
Photonic nanojet: Finite-difference time-domain (FTDT) simulation

Photonics nanojets produced by polystyrene microspheres (n1=1.59, n2=1, λ=400nm):

Microsphere super-resolution focusing (nanojet) key properties

1. The transverse beam diameter of the nanojet can reach $\lambda/2n$, where $\lambda$ is light wavelength and $n$ is the refractive index of particle. In case of a polystyrene particle with $n=1.6$, the resolution limit is about 0.313$\lambda$.

2. Nanojet can appear for a certain range of the diameter of the dielectric microsphere from $2\lambda$ to more than $40\lambda$.

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Nanojets can enhance the backscattering of visible light by several orders of magnitude.

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Near-field Raman Imaging with Confotec Using Optically Trapped Dielectric Microsphere

The spot size of the beam (the full width at half maximum) was calculated to be 78 nm.

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Near-field Raman Imaging with Confotec Using Optically Trapped Dielectric Microsphere
Illumination/Detection channel Tuning for Spatial Resolution Improvement

Optical system response function (PSF)

The lateral resolution with ring-shaped light illumination is 1.18 times better than with circular illumination.
Lateral resolution (XY) is 1.17 times better.
Axial resolution (Z) is 1.15 times better.
Structured light Illumination
TERS (Near-field imaging) system
(a) TERS (nano-Raman) map of individual single-walled nanotube bundle. Lateral resolution is <50 nm.

(b) Raman spectra from the bundle with (red) and without (black) enhancing TERS probe. (c) TERS enhancement factor vs. Tip-sample distance for vertically oscillating AFM cantilever and horizontally oscillating Au wire. S. Kharinstev, G.G. Hoffmann, P.S.Dorozhkin, G.de With and J.Loos
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Thank you very much for your attention!

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