AFM-Raman, SNOM and TERS: Recent Advances and Applications

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Product Line

AFM

SOLVER NANO

- Compact desktop AFM/STM for both education and science
- Full set of AFM/STM modes
- High AFM/STM performance
- Closed-loop Scanner

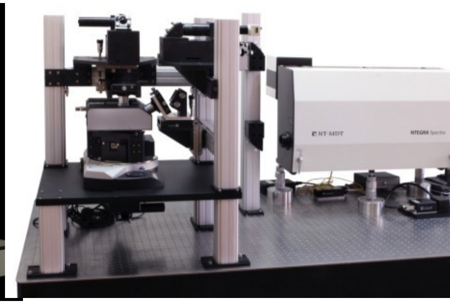
NEXT / TITANIUM

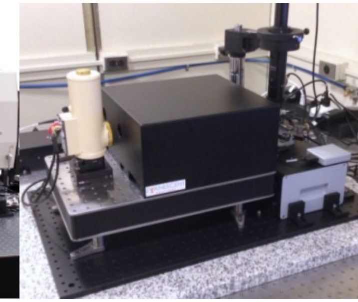
- AFM/STM with exceptional level of automation
- Fast, precise and low-noise closed-loop scanner
- High resolution imaging due to extremely low noise and high stability
- Full set of standard and advanced AFM/STM modes
- HybriD Mode™

NTEGRA

- Modular high performance AFM/STM for wide range of applications
- Low noise and high resolution
- Full set of standard and advanced AFM/STM modes
- HybriD Mode™

AFM-Raman / IR / TERS





NTEGRA SPECTRA II

- SPM
- Automated AFM laser, probe and photodiode
- Confocal Raman / Fluorescence / Rayleigh Microscopy
- Tip Enhanced Raman Scattering (TERS)
- TERS optimized system for all possible excitation/detection geometries
- HybriD Mode™

NTEGRA IR

- IR sSNOM system
- High resolution AFM
- Stabilized CO_2 laser
- HybriD Mode™

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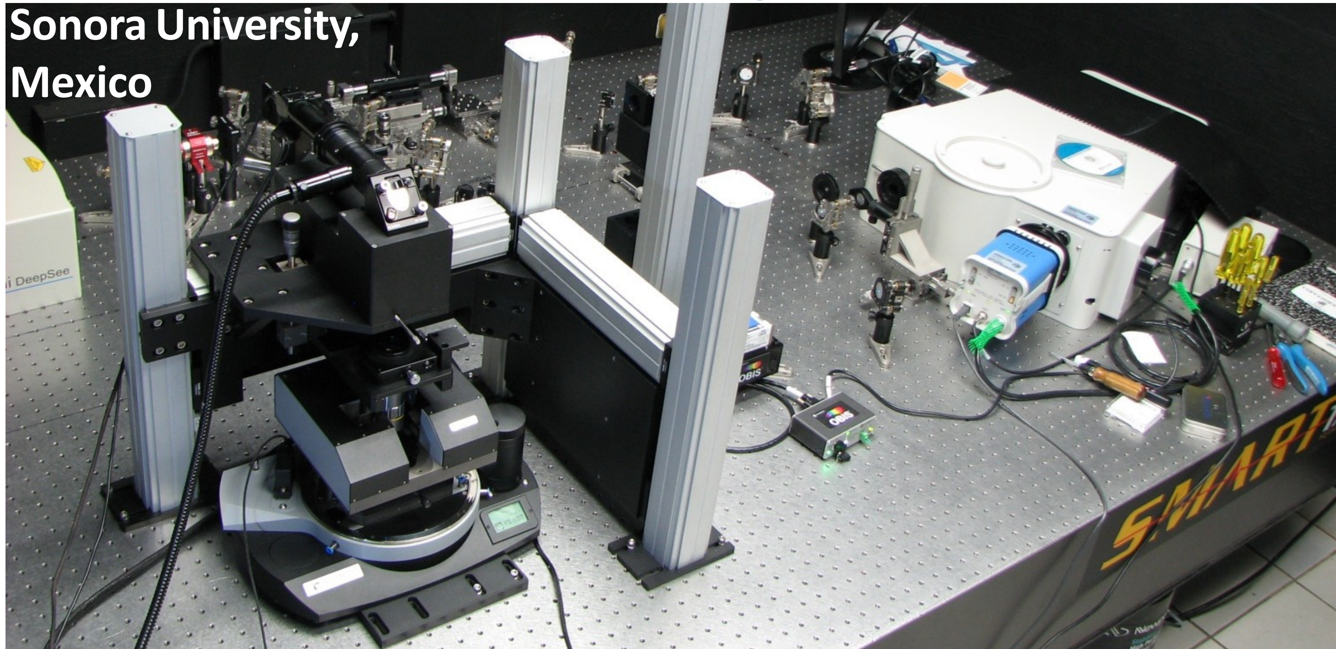
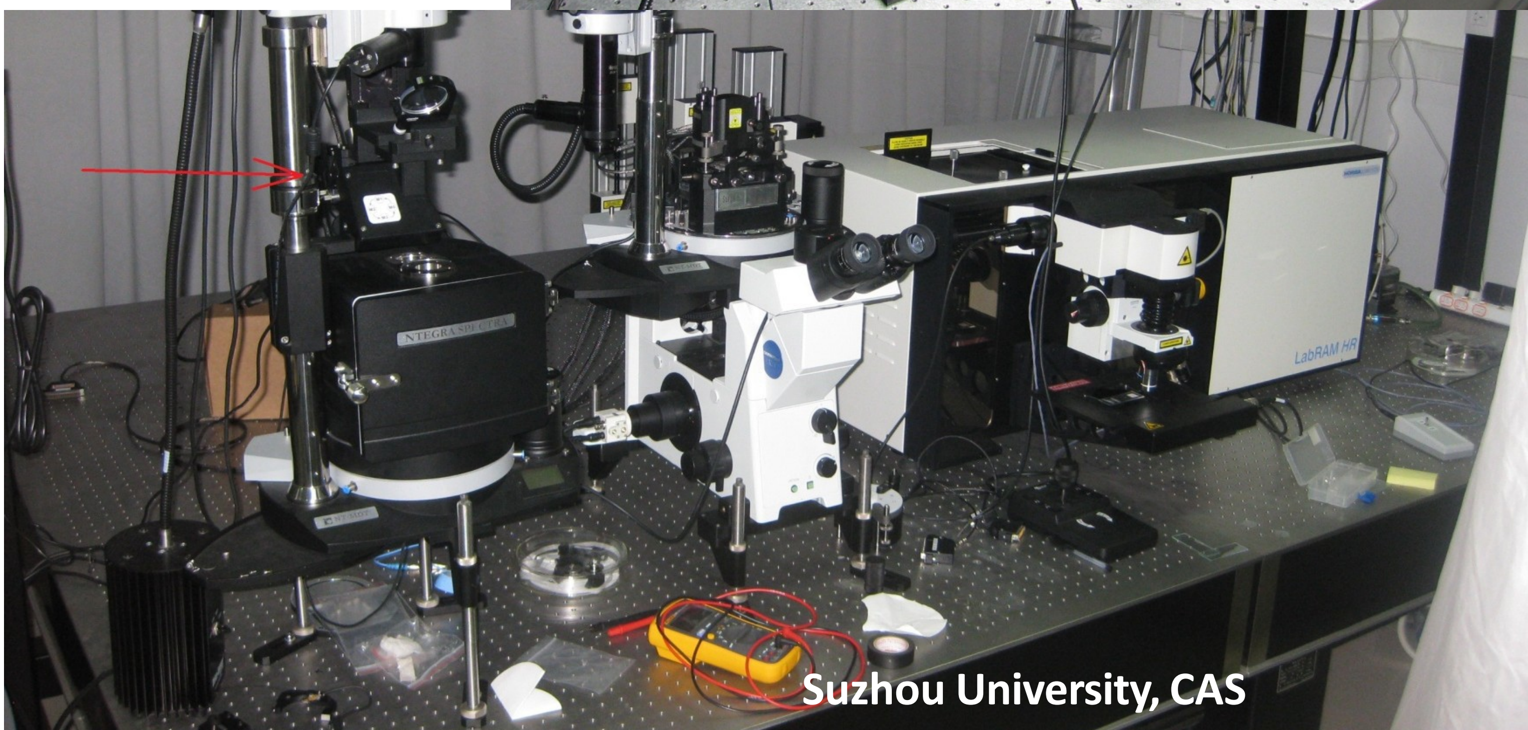
Spectrum Instruments

Integration with Horiba Scientific spectrometers





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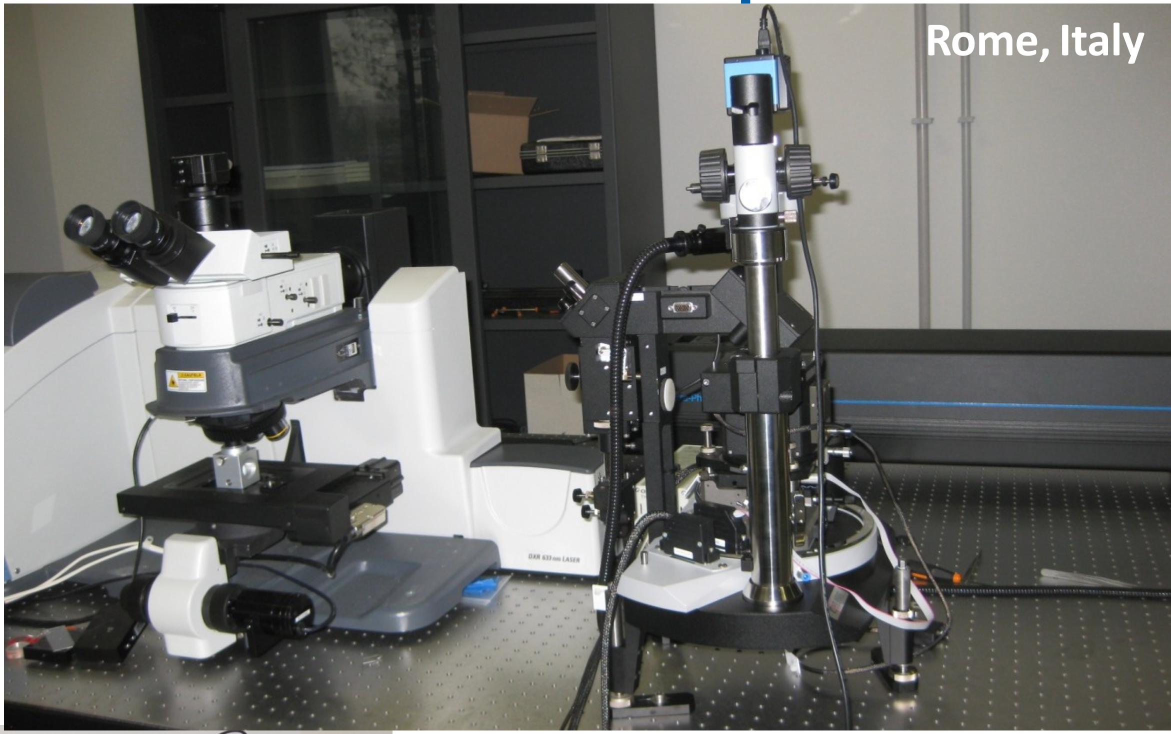
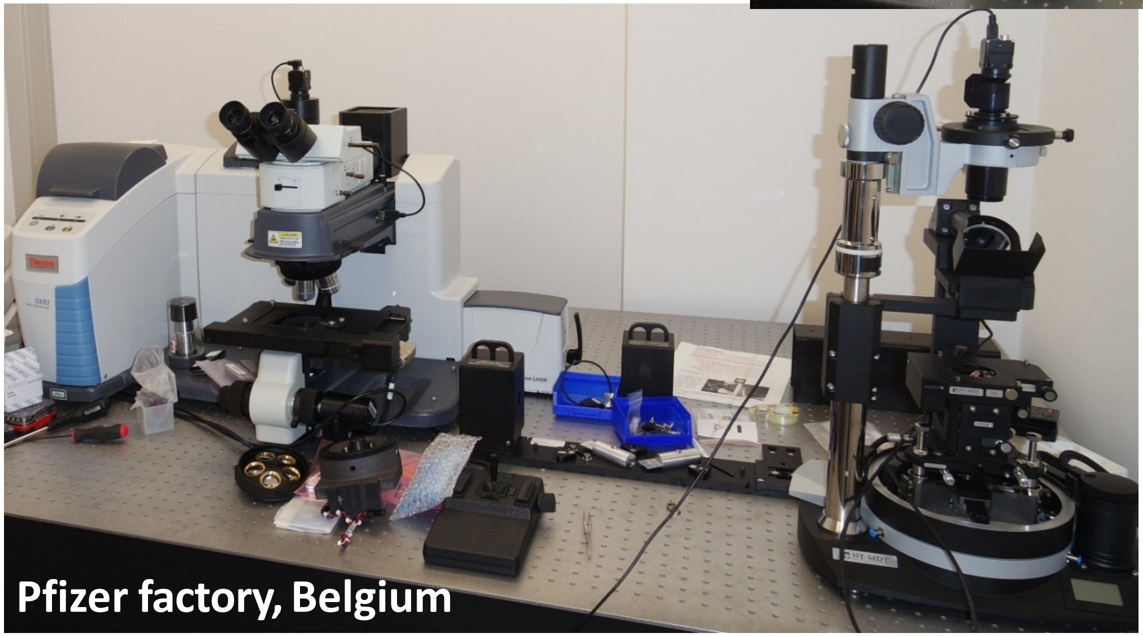
Integration with Thermo Fisher Scientific DXR spectrometer





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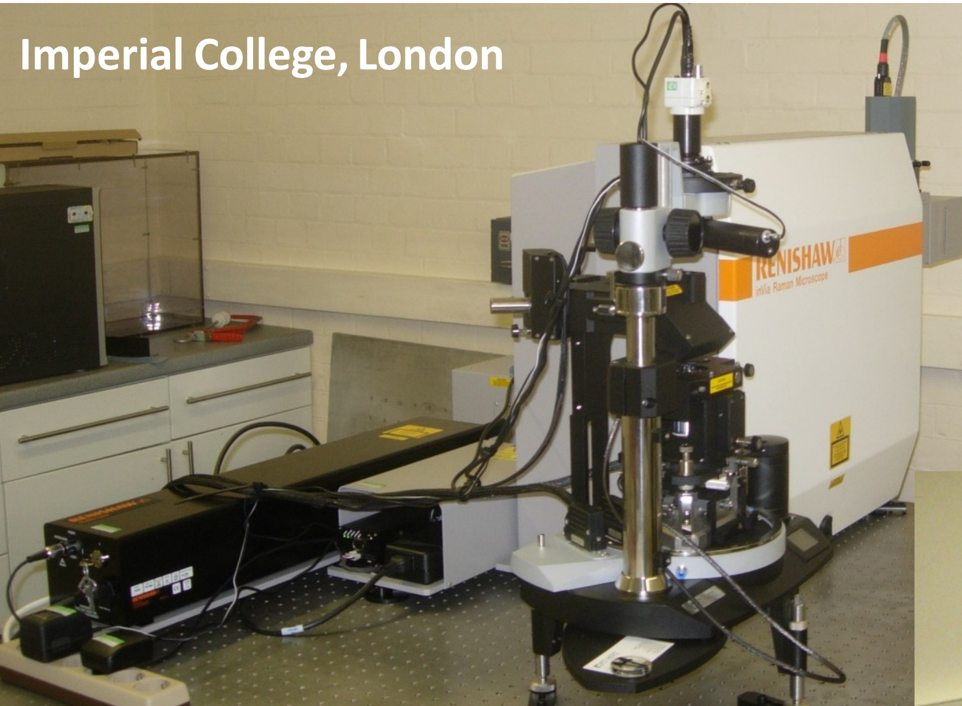
Integration with Renishaw inVia spectrometer



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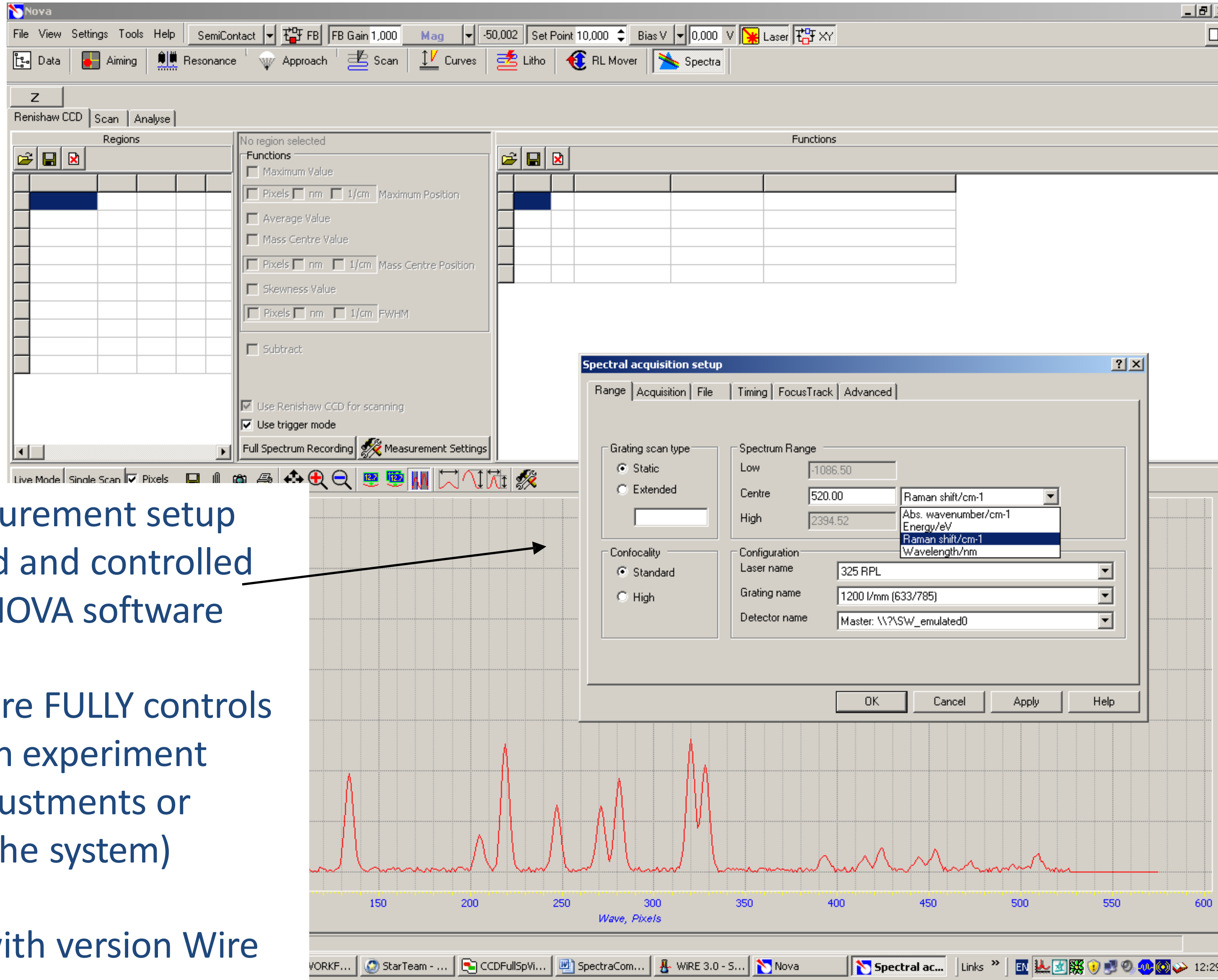
NT-MDT + Renishaw integrated software



1. Renishaw measurement setup menu is opened and controlled from NT-MDT NOVA software

2. NT-MDT software FULLY controls the AFM-Raman experiment (except rare adjustments or calibrations of the system)

3. Compatibility with version Wire 3.x, 4.x, 5.0

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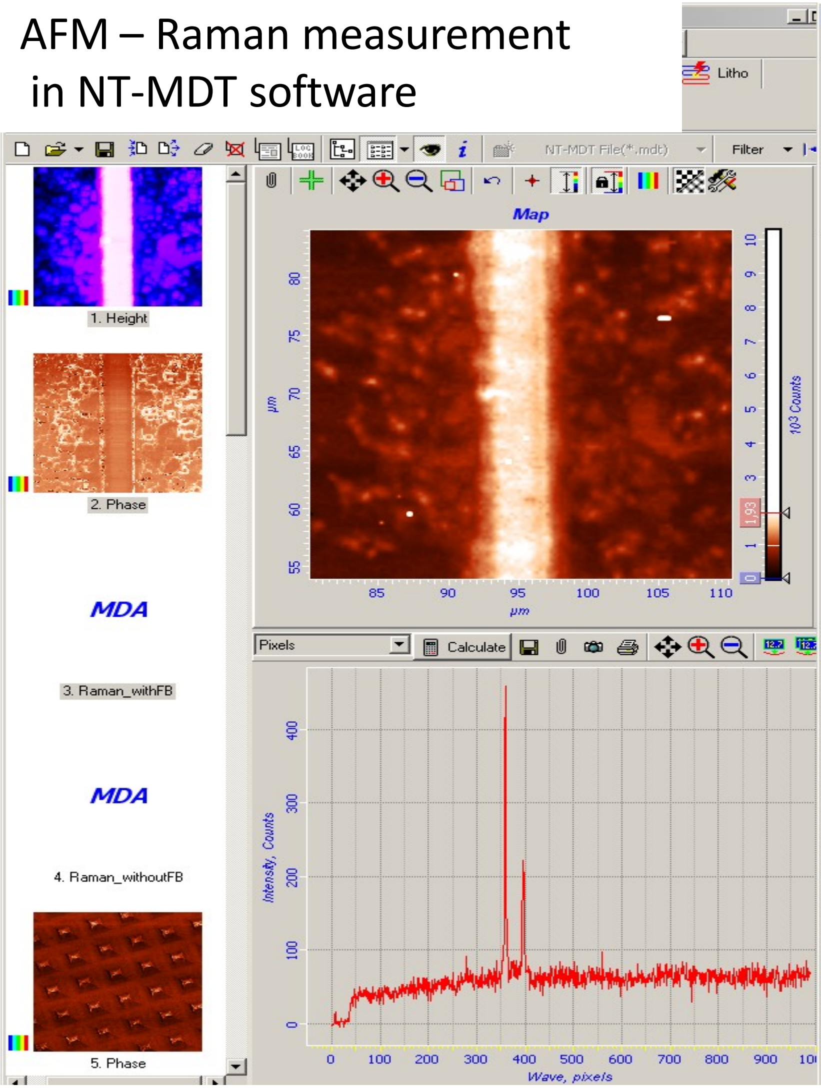
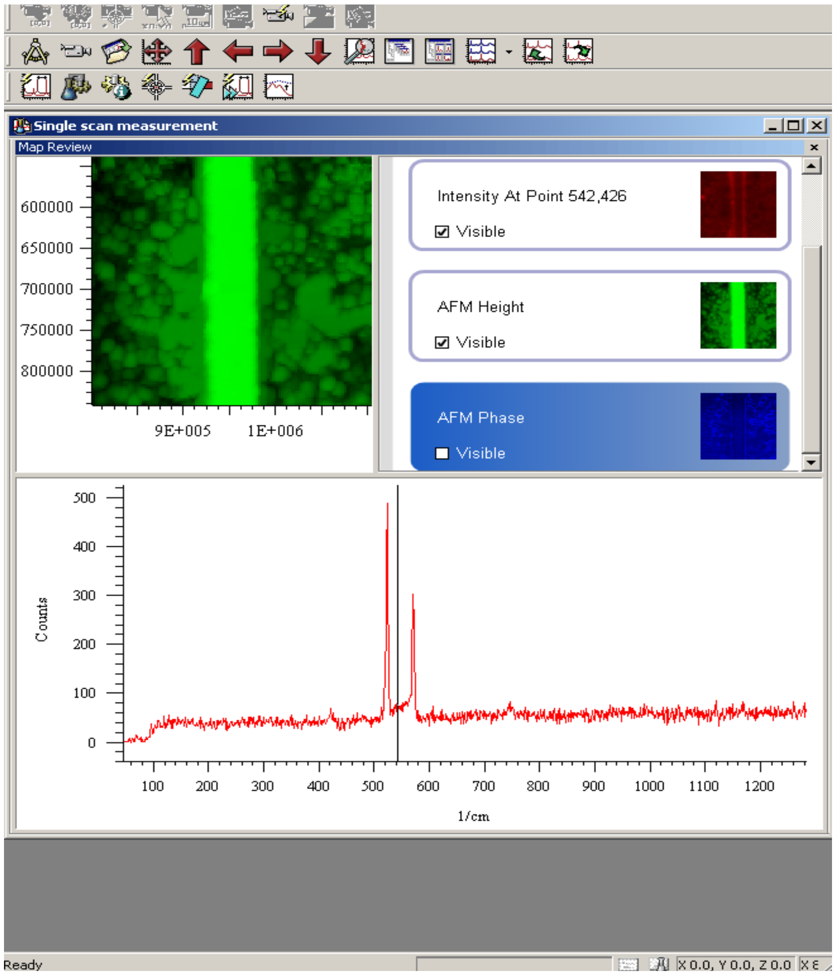
NT-MDT + Renishaw data analysis software

AFM – Raman measurement
in NT-MDT software



Data is exported
to Renishaw Wire 3.x

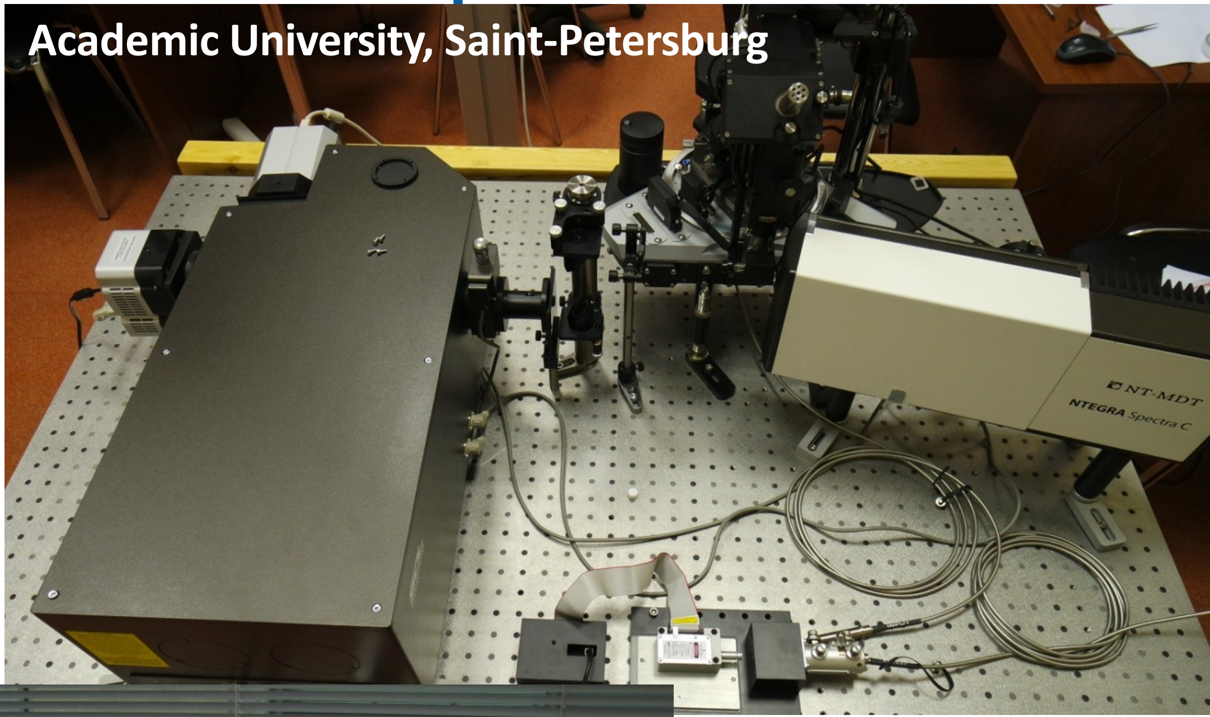


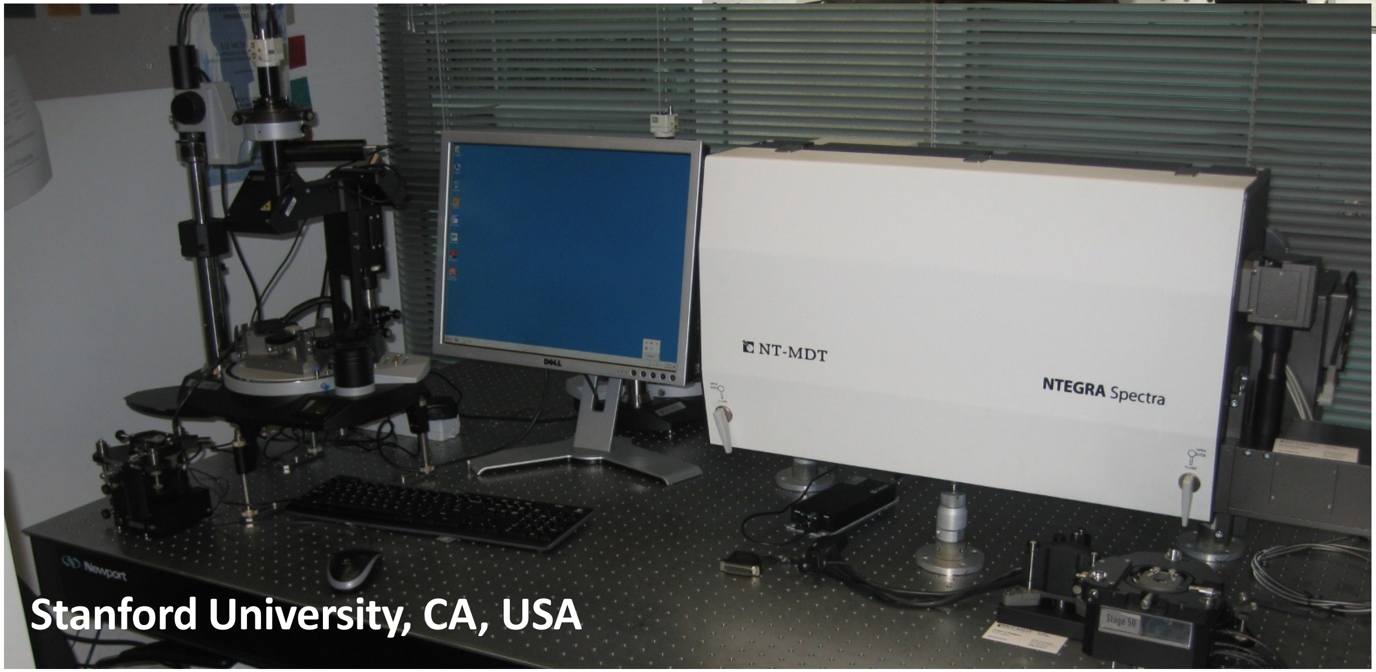
EXACTLY THE SAME DATA in two programs: NT-MDT & Wire-3

All scans can be seen and analyzed in any software: AFM (height, phase etc) & Raman maps.

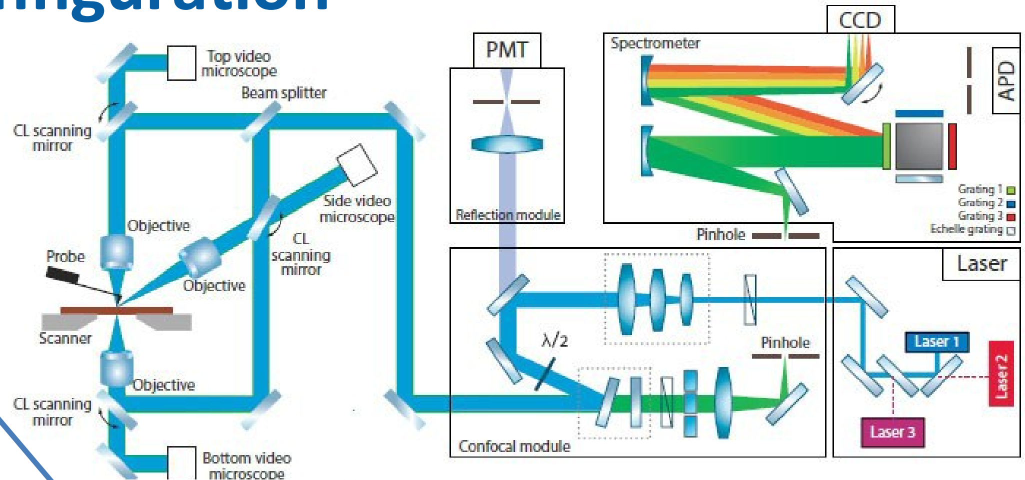
Data from NT-MDT Nova was exported into WIRE-3

Integration with NT-MDT spectrometers





NTEGRA Spectra II in Upright, Inverted and Side illumination configuration



Light input from side (with scanning mirror)

Top optics (LED illuminator & camera)

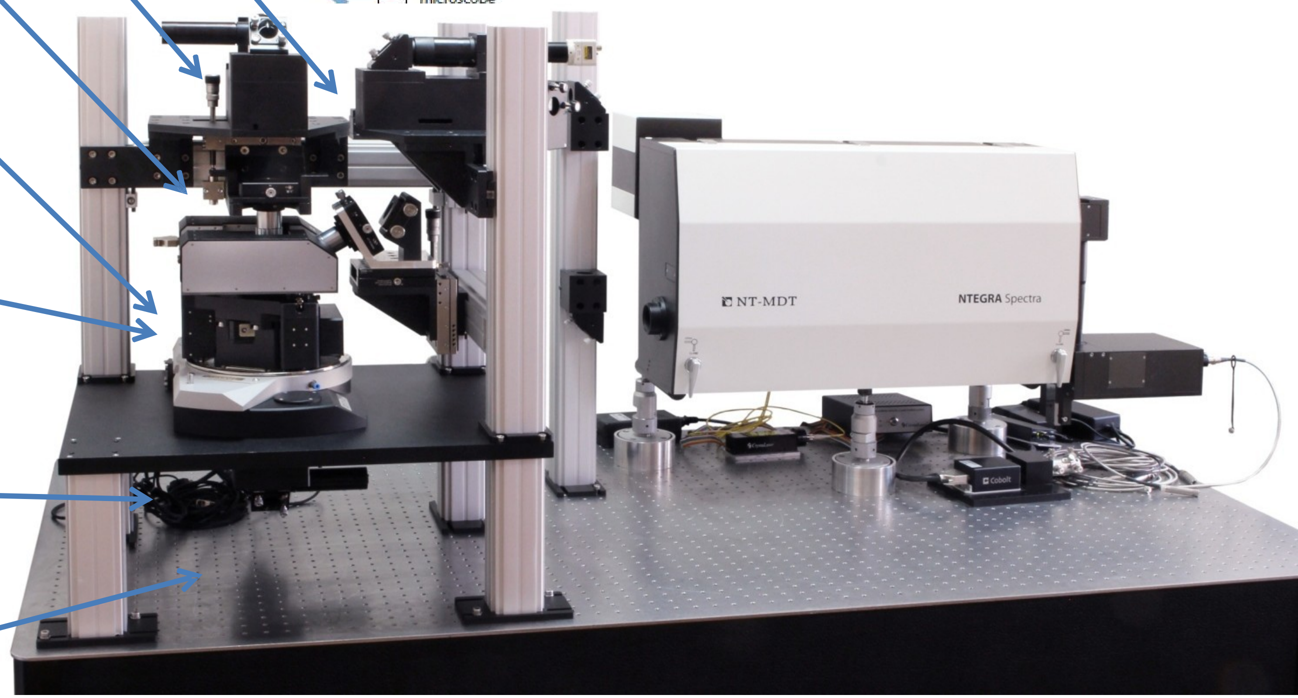
Light input from top (with scanning mirror)

Optical AFM (AFM probe + 100x objective on the top)

XYZ sample stage (bottom illumination objective inside)

Light input from bottom (with scanning mirror)

Bottom optics (LED illuminator & camera)



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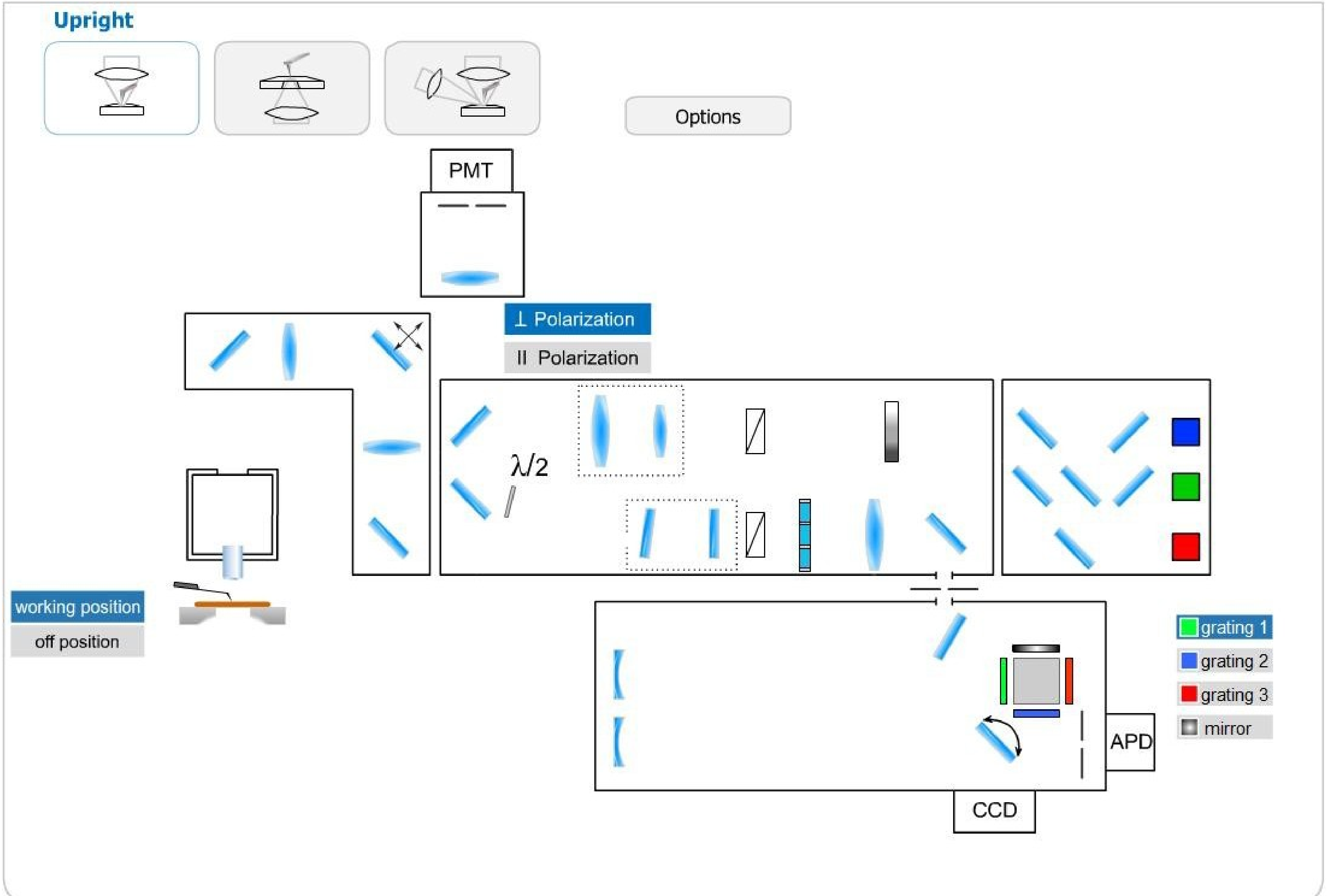
AFM – Confocal Raman / Fluorescence – SNOM – TERS

Spectra optical scheme



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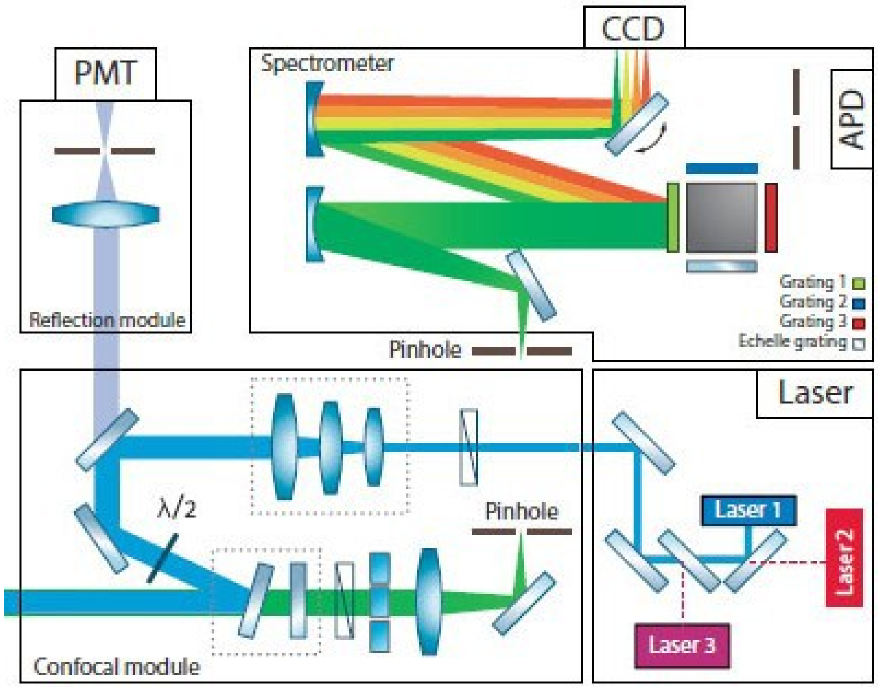
Optical scheme of Spectrometer



- True confocal design. Motorized confocal pinhole.
- Diffraction limited resolution guaranteed (e.g. 200 nm for blue laser, immersion optics)
- Extremely high optical throughput (~70-80 % for spectrometer, ~40-50% sample-to-detector)
- Fully motorized laser change (up to 3 / 5 lasers). UV – VIS – IR region
- Fully motorized: polarization optics, zoom beam expander, pinhole, 4 gratings
- Can be equipped by fastest and most sensitive detectors available (FI/BI CCD, EMCCD, DD-CCD etc.)
- Zoom beam expander – to guarantee diffraction limited laser spot to every objective
- Three optical ports for detectors: two in monochromator, one in separate channel

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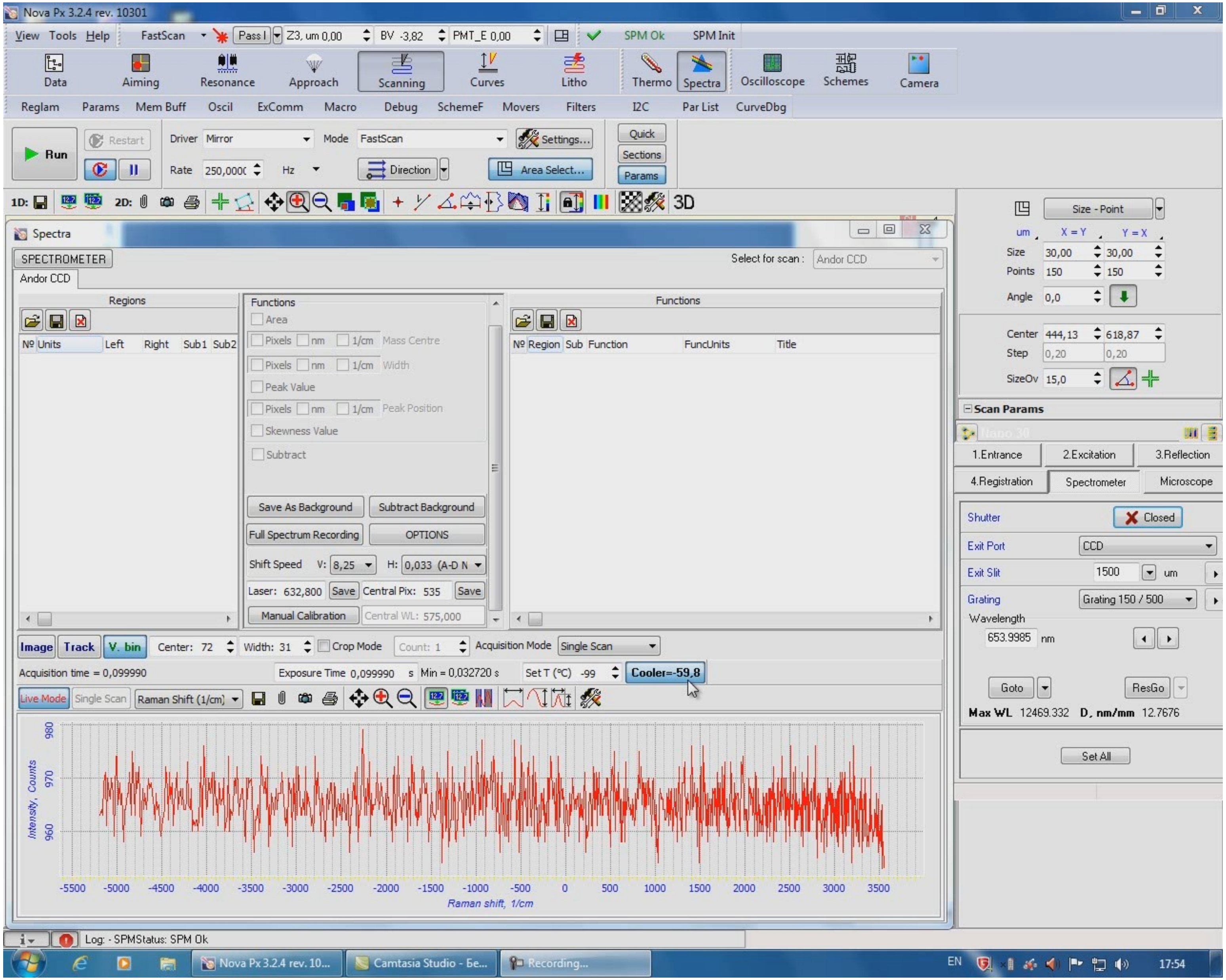
Fast scanning: 150x150 point for a 2 seconds (~50 us/point)



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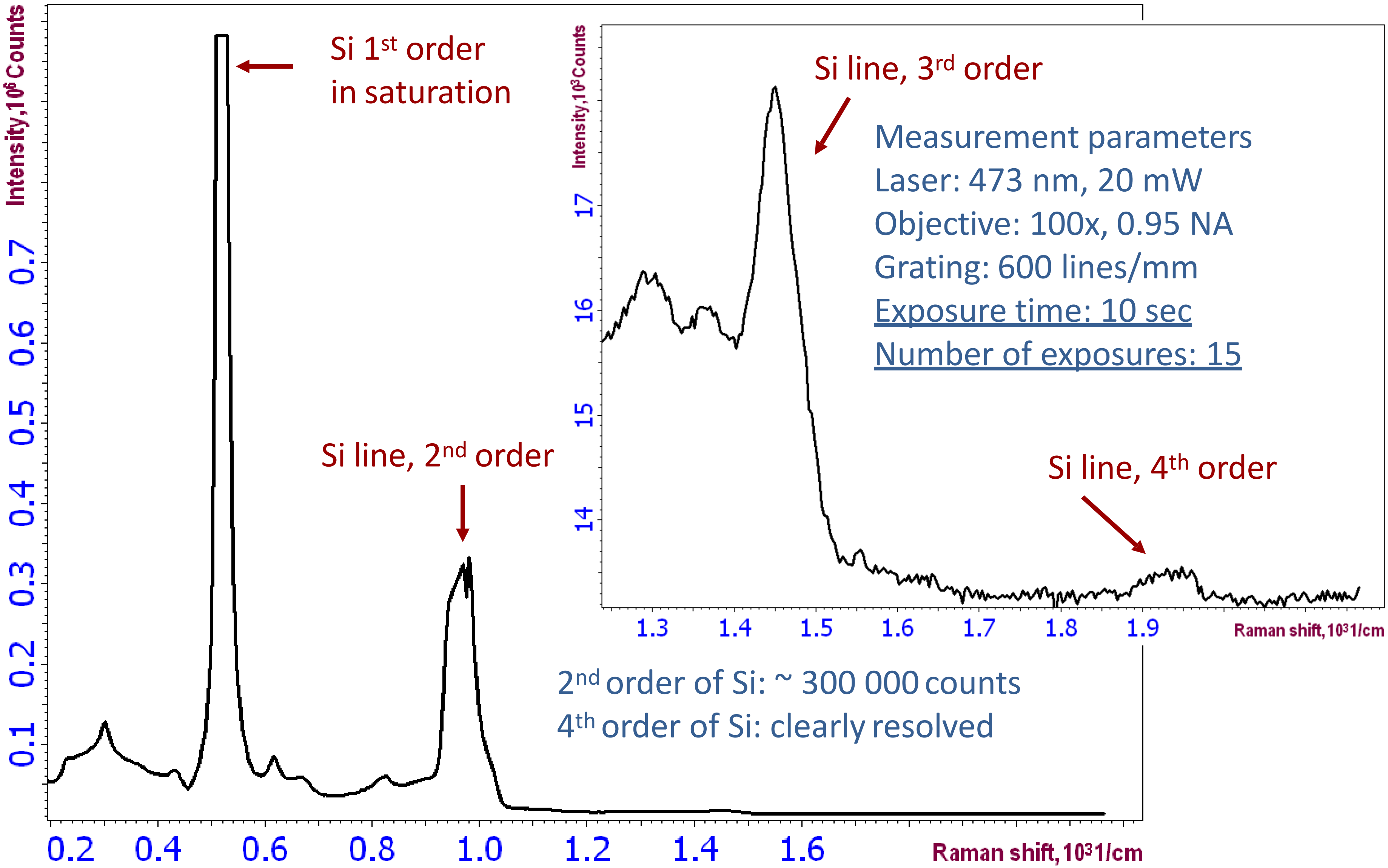
Sensitivity: 4th order of Si Raman band is clearly resolved



Measurement parameters
Laser: 473 nm, 20 mW
Objective: 100x, 0.95 NA
Grating: 600 lines/mm
<u>Exposure time: 10 sec</u>
<u>Number of exposures: 15</u>

2nd order of Si: ~ 300 000 counts
4th order of Si: clearly resolved

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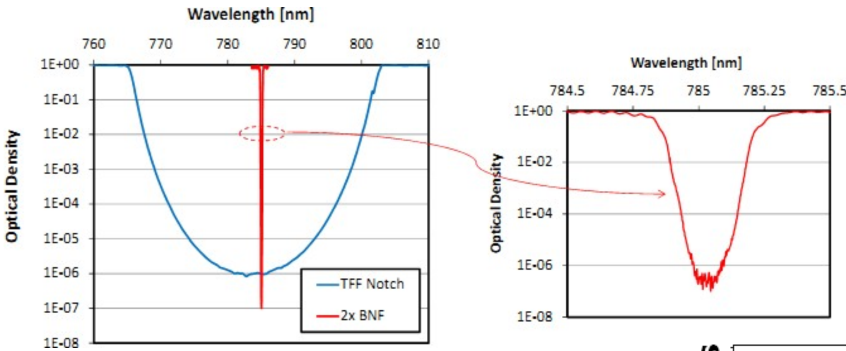
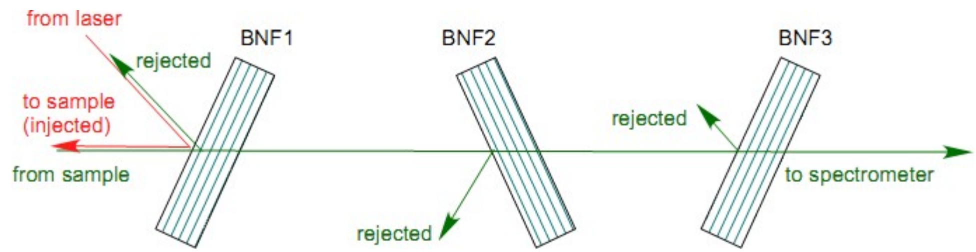
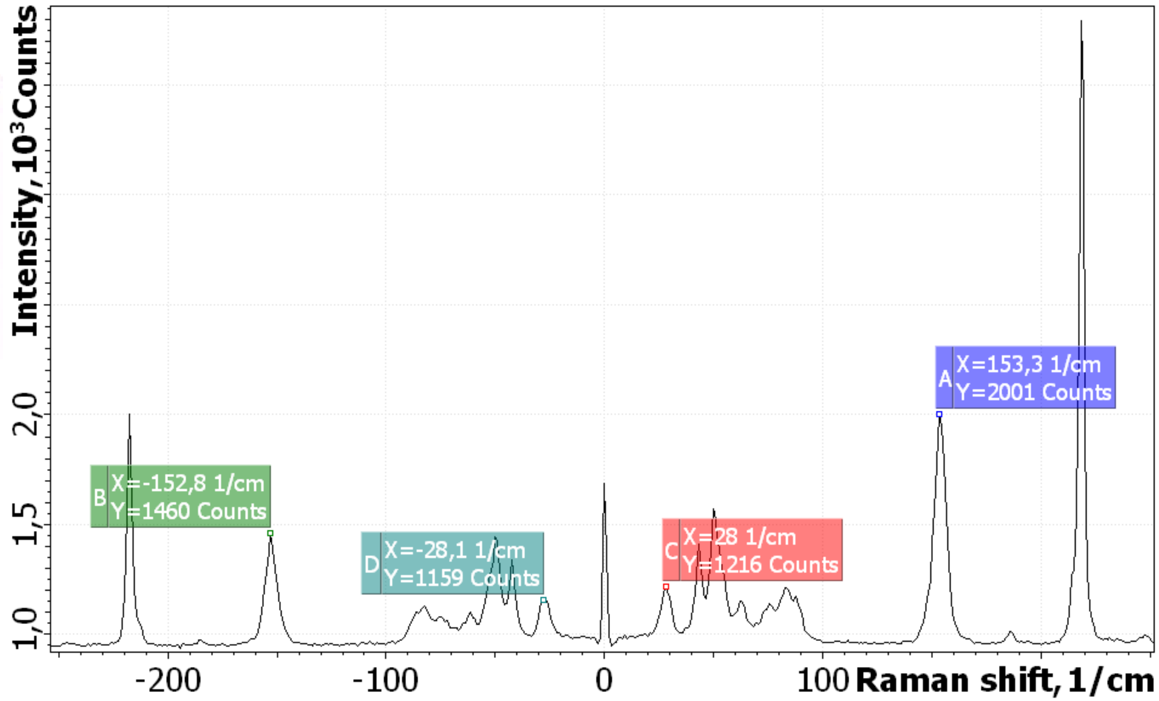
Low wavenumbers Raman spectra







Low wavenumbers Raman spectrum of sulfur. Cut-off at 10 1/cm
488 nm laser, 1800 lines/mm grating.

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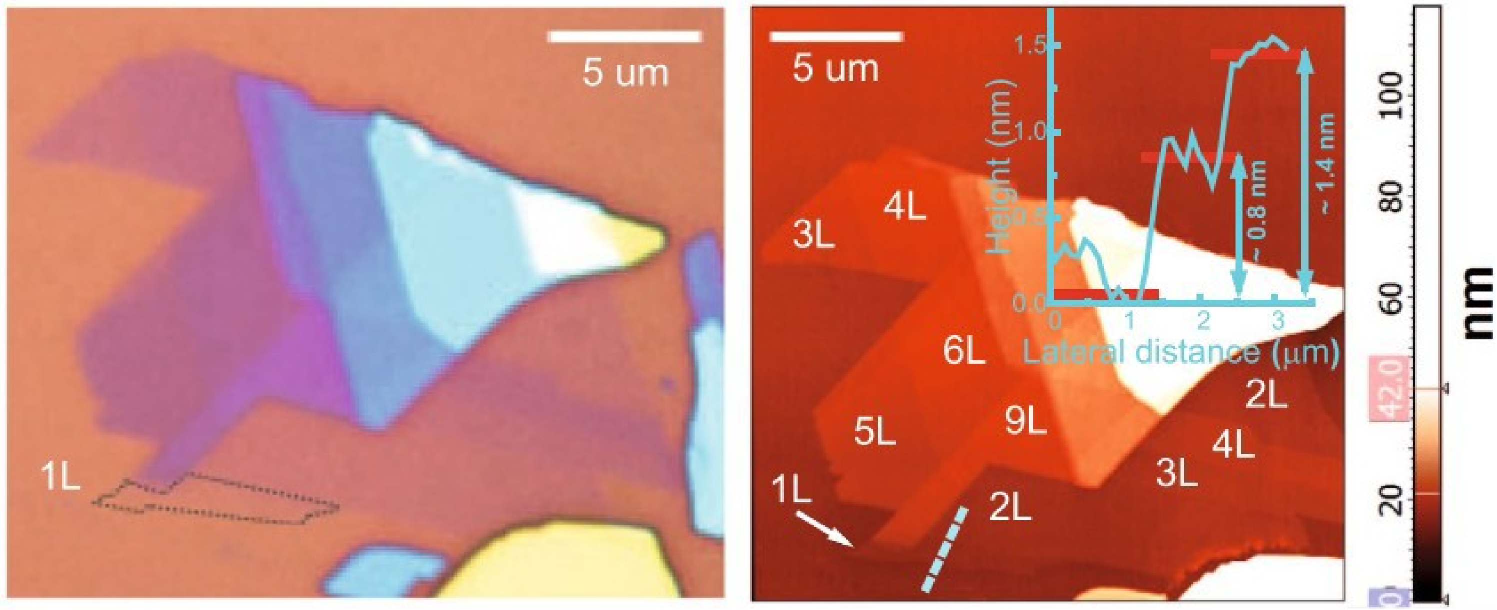
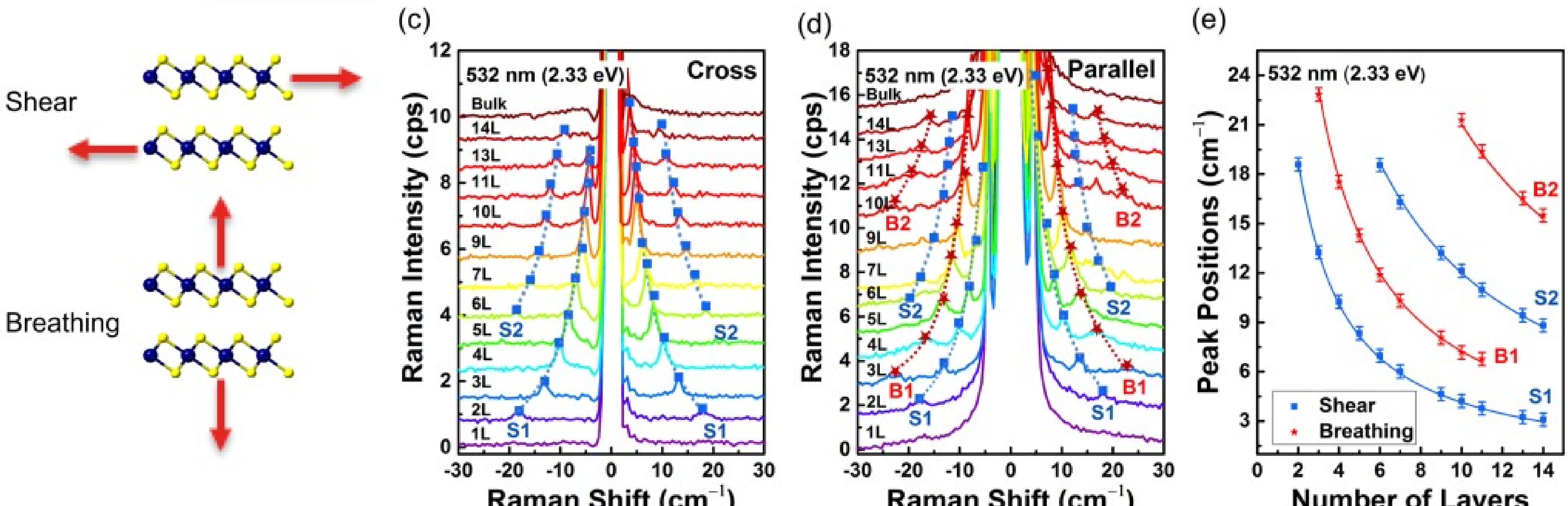
Defining number of 2H SnS2 layers





Sriv, T., Kim, K. & Cheong, H. Low-Frequency Raman Spectroscopy of Few-Layer 2H-SnS2. *Sci. Rep.* **8,** 2–8 (2018).

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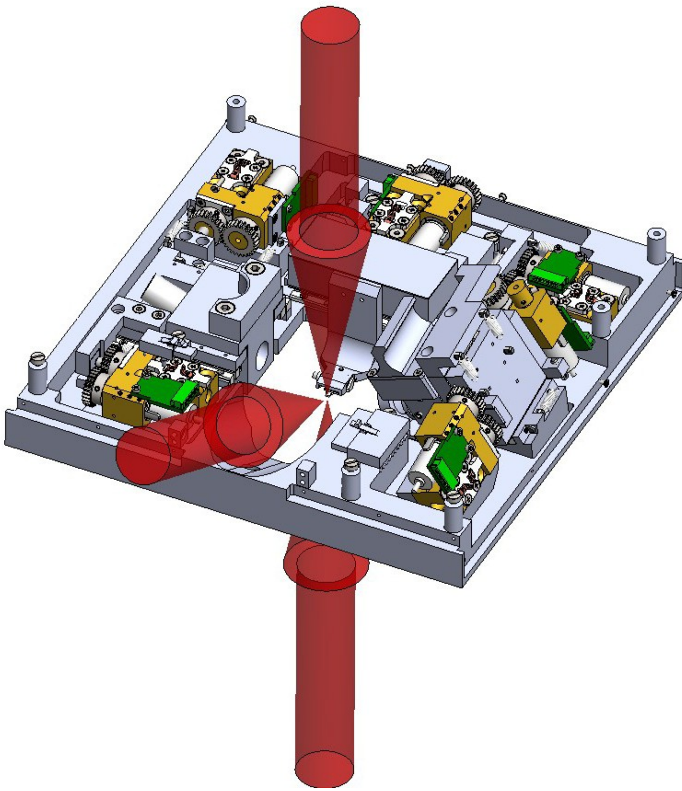
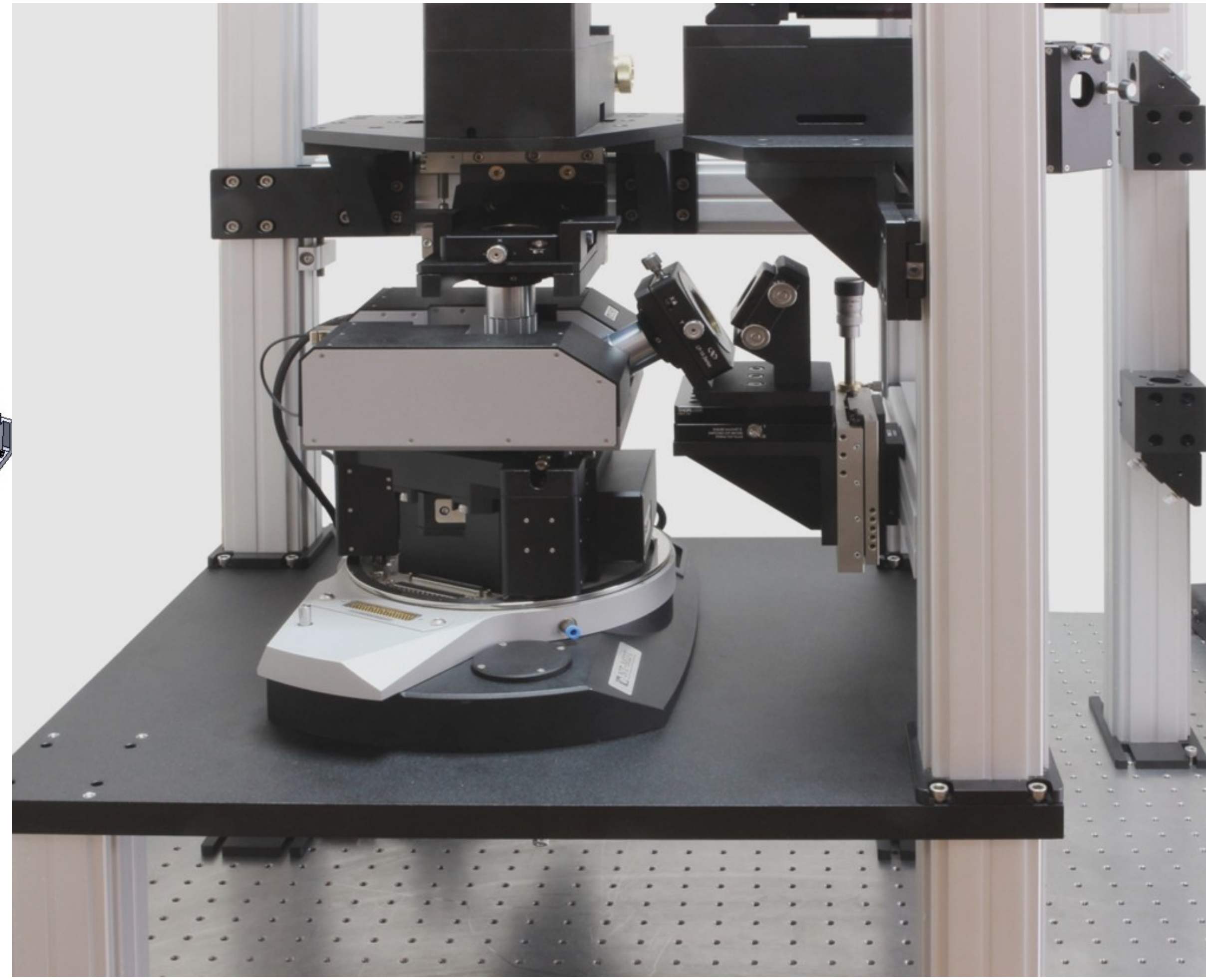
Optical access from Top, Bottom and Side

Access for **Mitutoyo** long working distance objective for top illumination



Access for bottom Illumination objective



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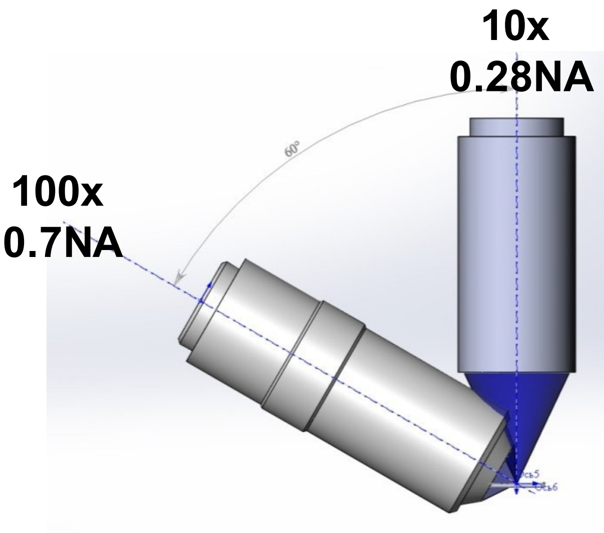
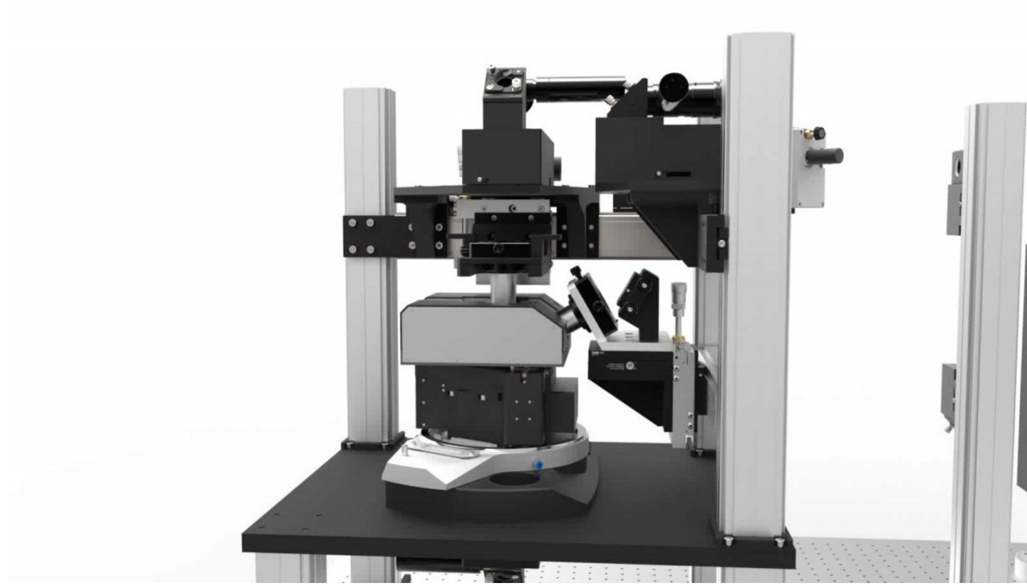
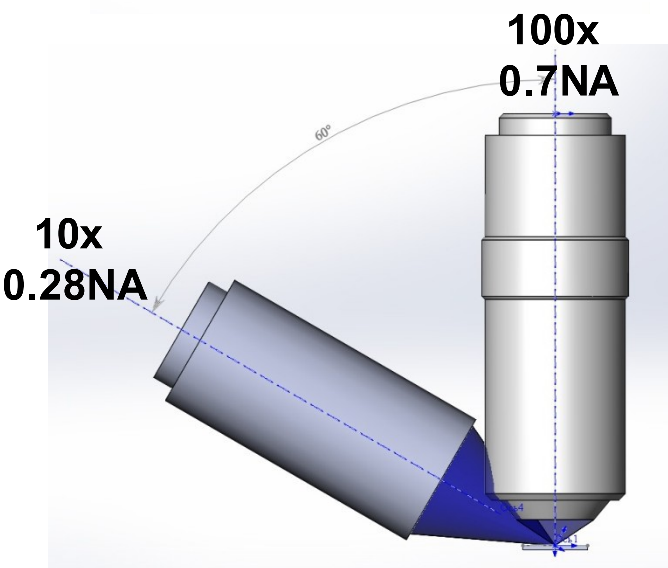
Excitation-collection configurations







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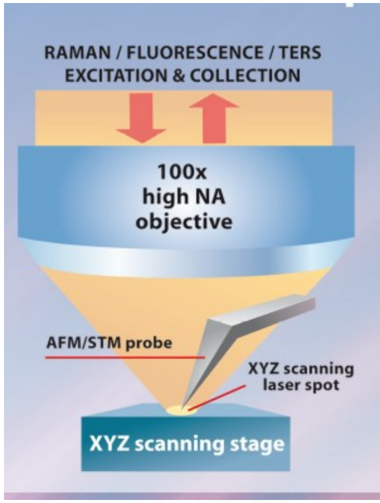
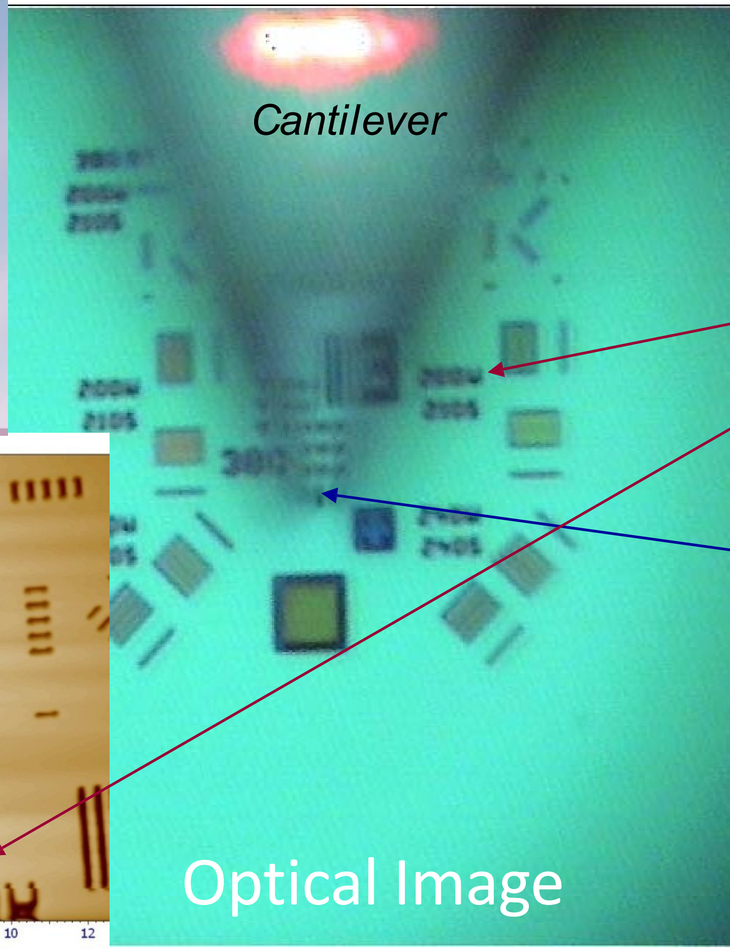
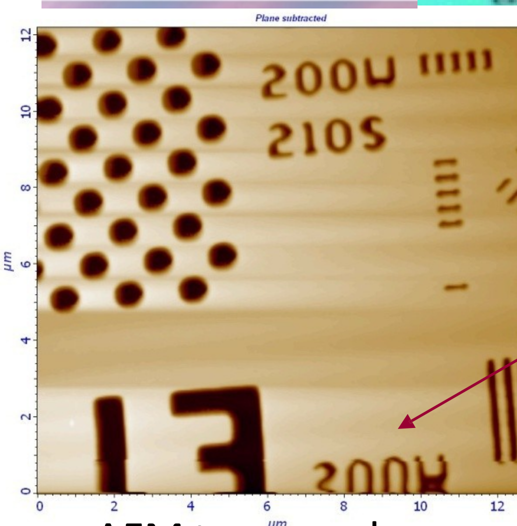
Top optical access to the AFM probe with 100x objective







AFM topography

1 µm height letters are readable – thanks to 100x objective (see next slide for AFM)

*Black spot at the apex of cantilever is the **exact** point there the tip touches substrate*

AFM probe over a structured Si substrate. View through 0.7NA 100x objective

Apex of opaque Si tip looks transparent on the image!

This unique observation is due to high aperture (0.7 NA) of the imaging objective

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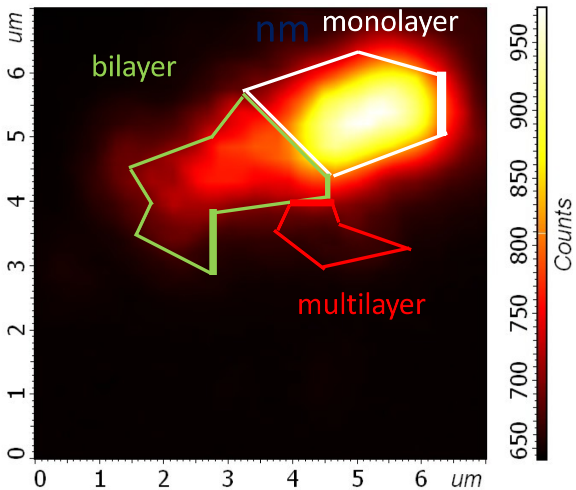
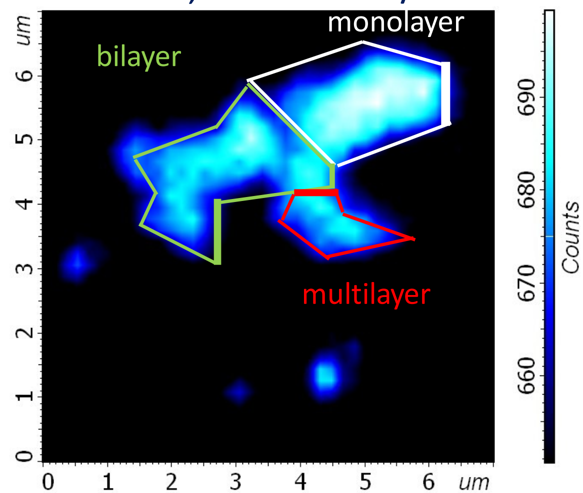
$MoSe_2$ flakes

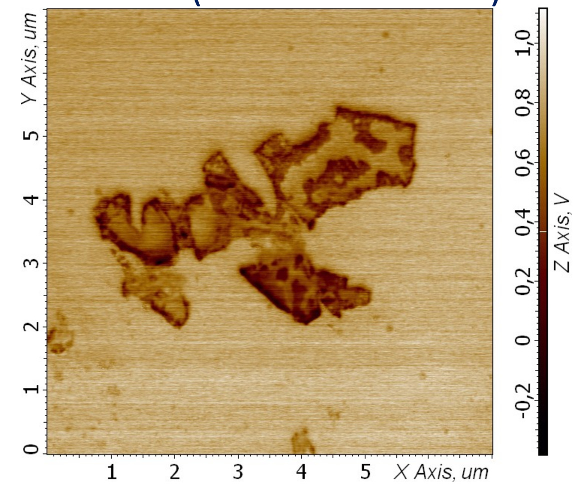
μ-Photoluminescence, ~ 800 nm



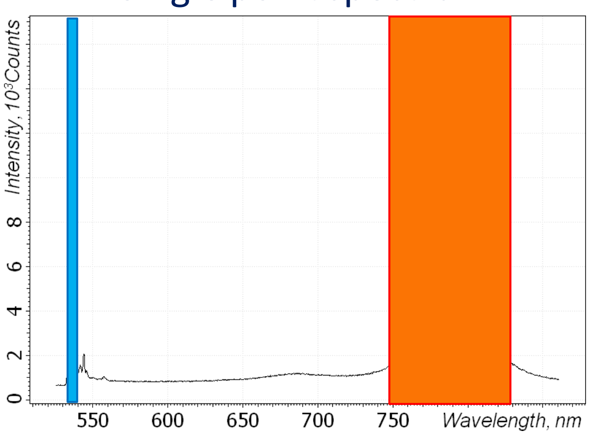
Raman, ~220-250 1/cm



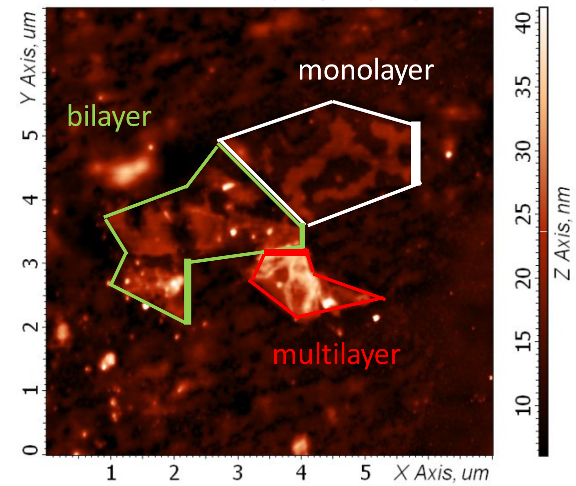
KPFM (Surface Potential)



Single point spectrum



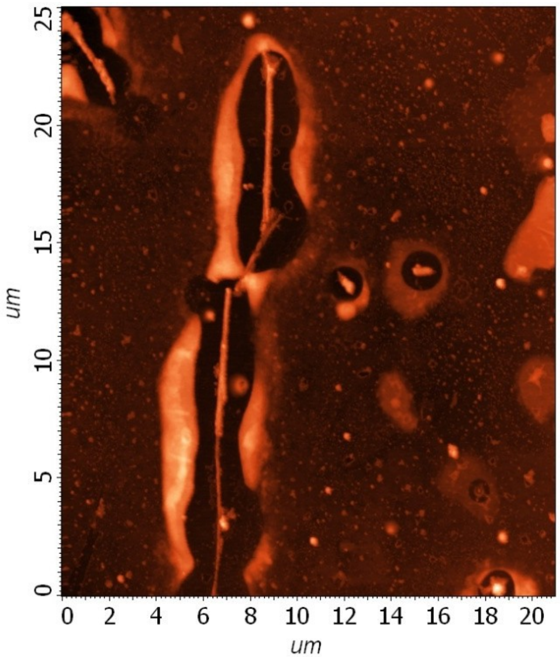
AFM Topography



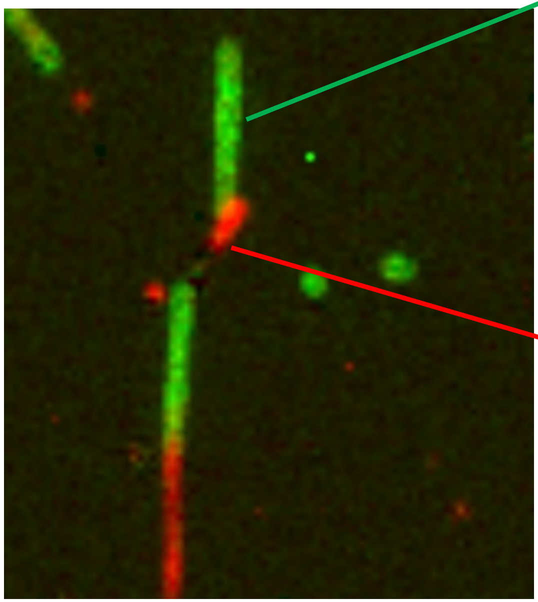
Wolfgang Mertin, Gerd Bacher, Artem Shelaev, Sergey Lemeshko, Universität Duisburg & NT-MDT

CdS-Polyaniline nanowires: AFM – Raman mapping

Topography

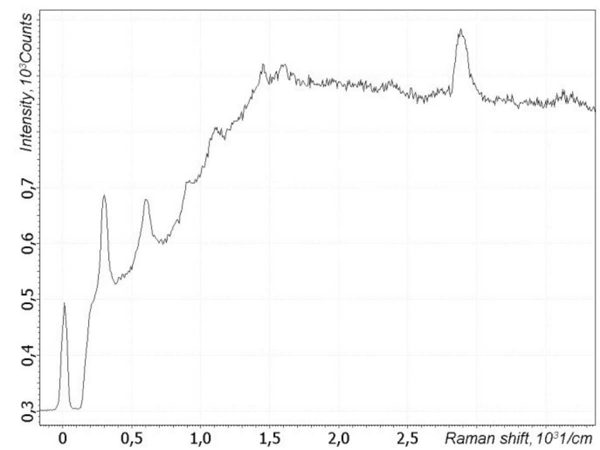


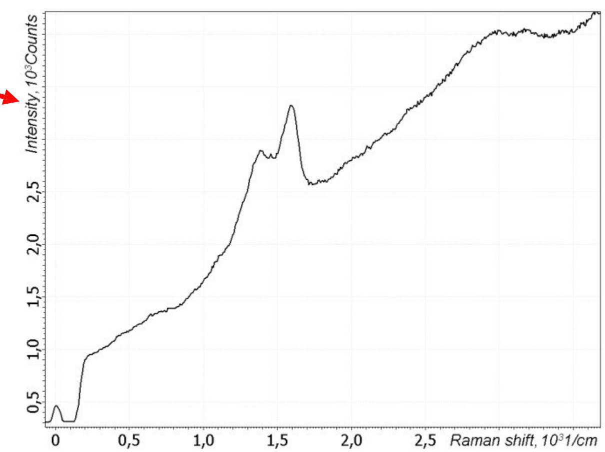
Raman mapping



Polyaniline

CdS





Single point unprocessed spectra.
Exposure time 20 sec.
473 nm excitation.

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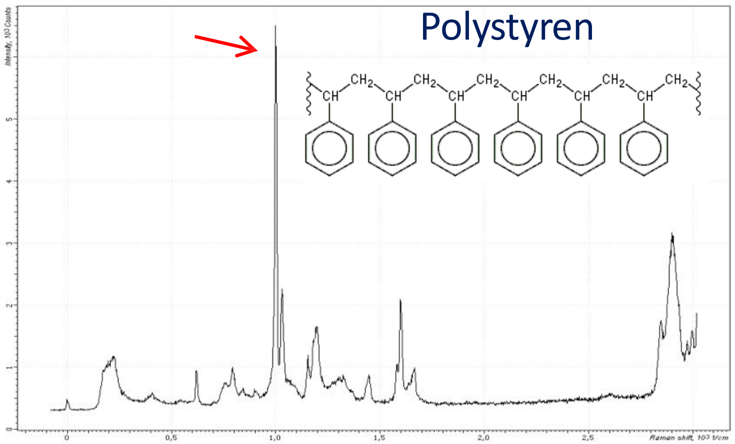
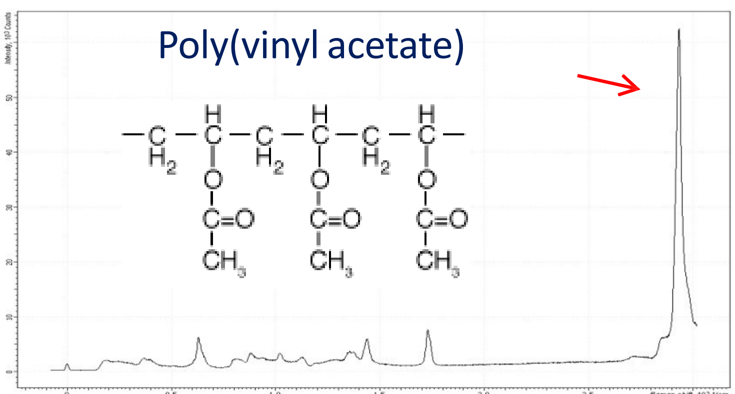
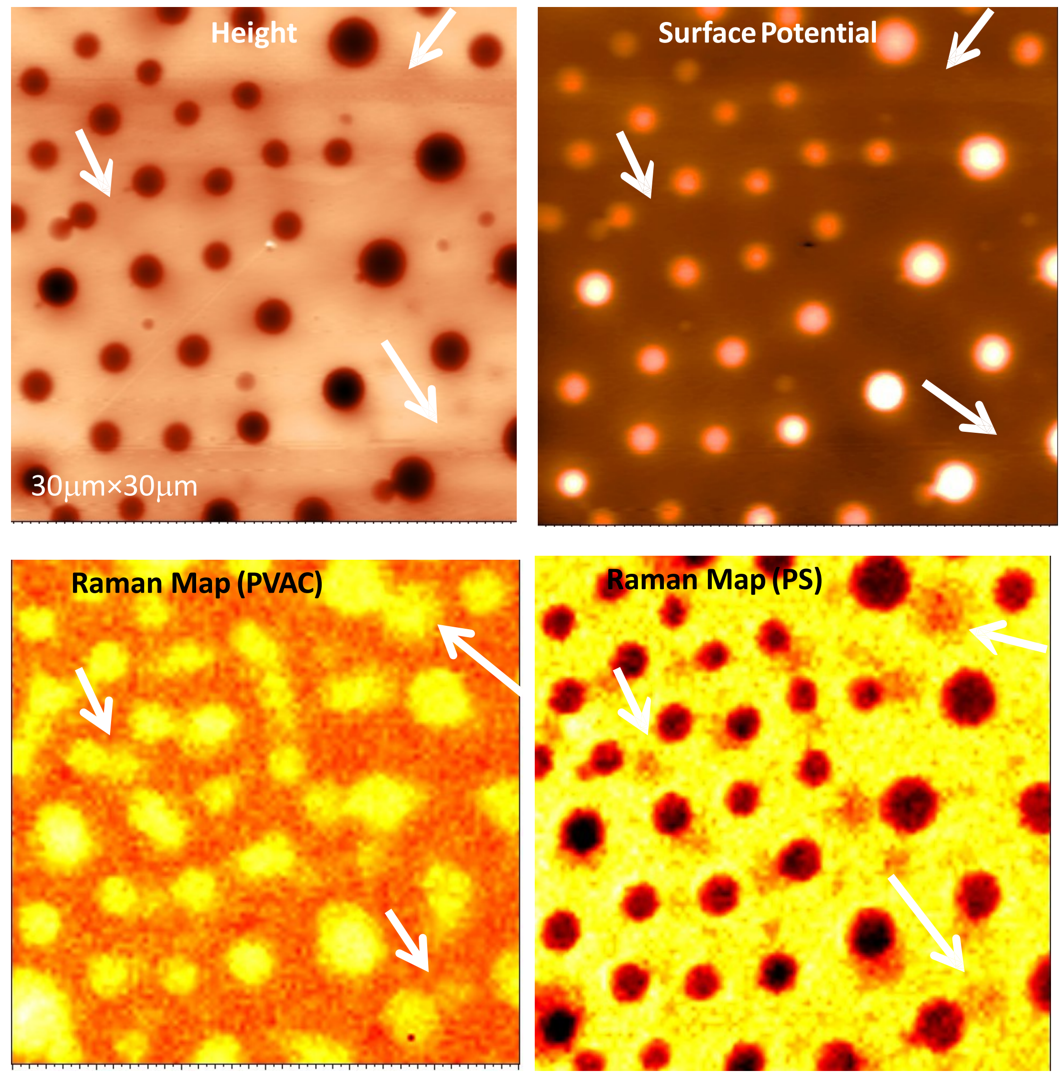
KPFM-Raman Studies of Polymer Blends

Polymer Blend PS-PVAC: Thick Film on ITO glass







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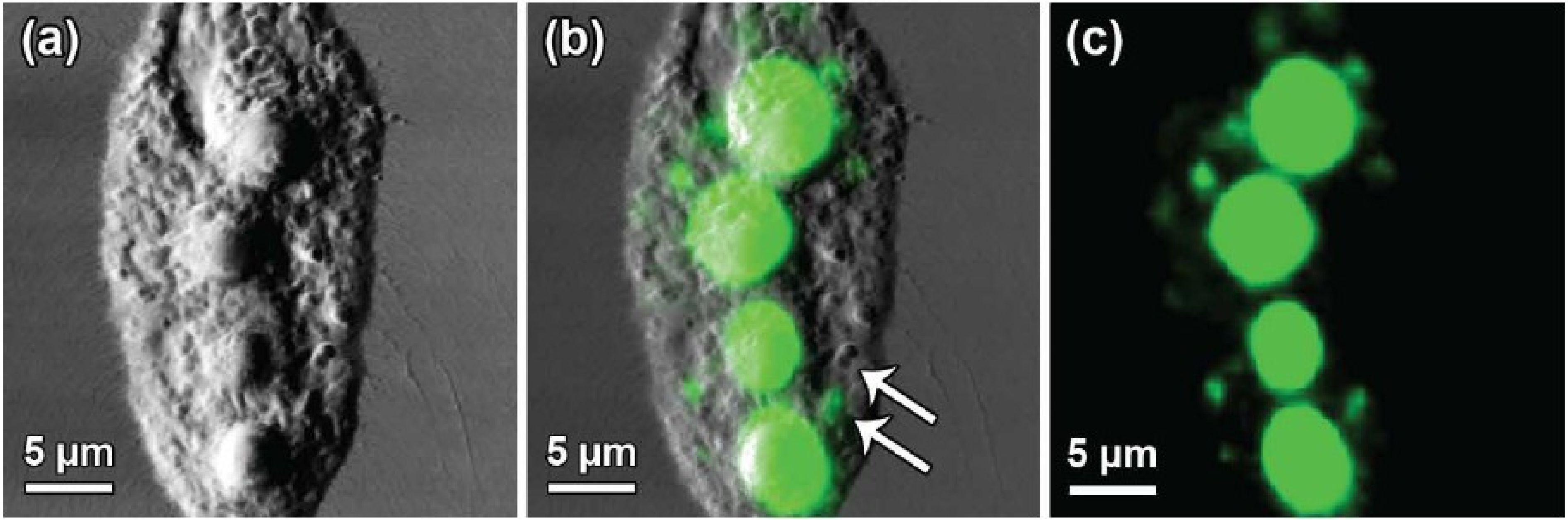
Cyanobacteria biofilm: AFM and Raman mapping



Combined study of cyanobacteria biofilm by means of atomic force microscopy and confocal Raman microscopy. AFM image in phase contrast (left) gives an image with nm resolution, however, does not contain any chemical information. Raman map (right) corresponds to the distribution of beta-carotene. Resolution Raman map is limited by the optical limit and is 400-500 nm. Beta-carotene is the pigment contained in cyanobacteria which perform photosynthesis. Overlay of two images (center) provides the chemical identity and relate it to the AFM image of high resolution.

Data courtesy: Thomas Schmid, Pawel L. Urban, Andrea Amantonico, Renato Zenobi ETH Zurich, Switzerland

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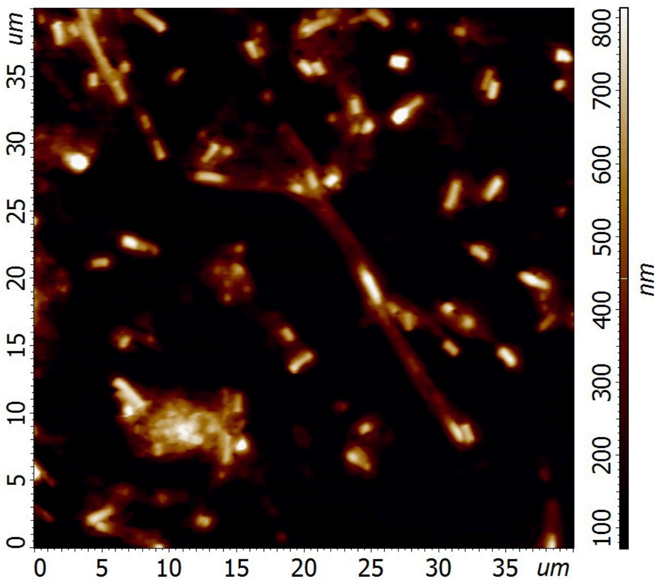
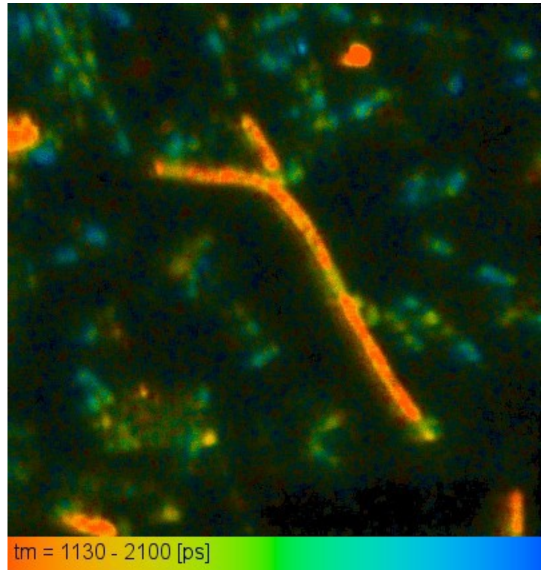
Topography and FLIM image of e-coli

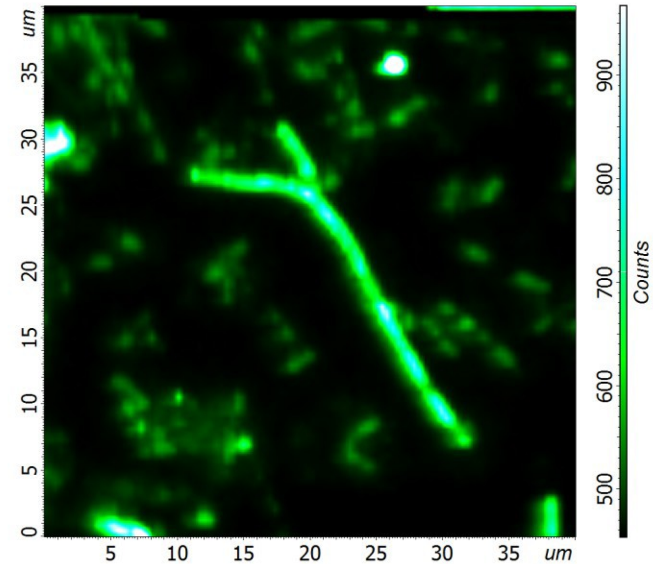
AFM Topography

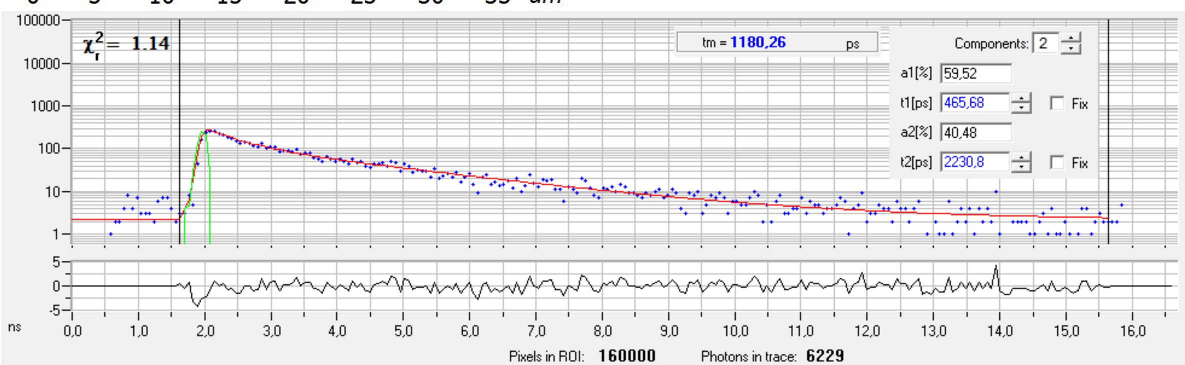


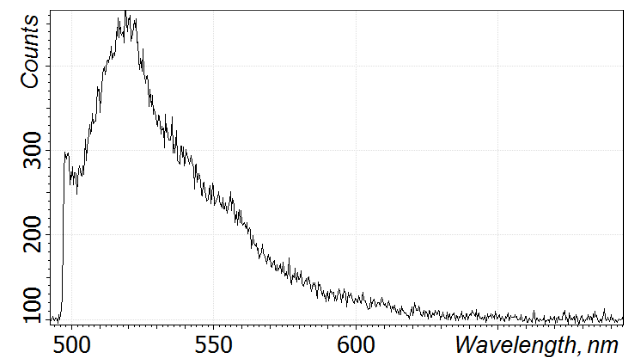
Lifetime map 525-540 nm



Fluorescence 525-540 nm







Topography (left) and FLIM mapping of 525-540 nm band (center) and fluorescence intensity (right). Decay curve on the bottom left image and fluorescence spectrum on the bottom right one. Different FLIM signals come from different fluorescent proteins, which produced by e-coli genetically modified in different ways. Spectrum shape is very similar. Intensity and lifetime is different. AFM + Spectrometer + FLIM provides sufficient information to identify different proteins in bacteria.

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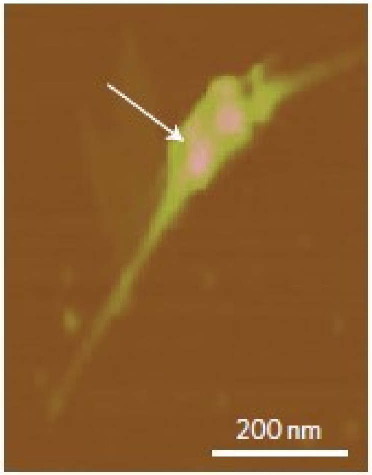
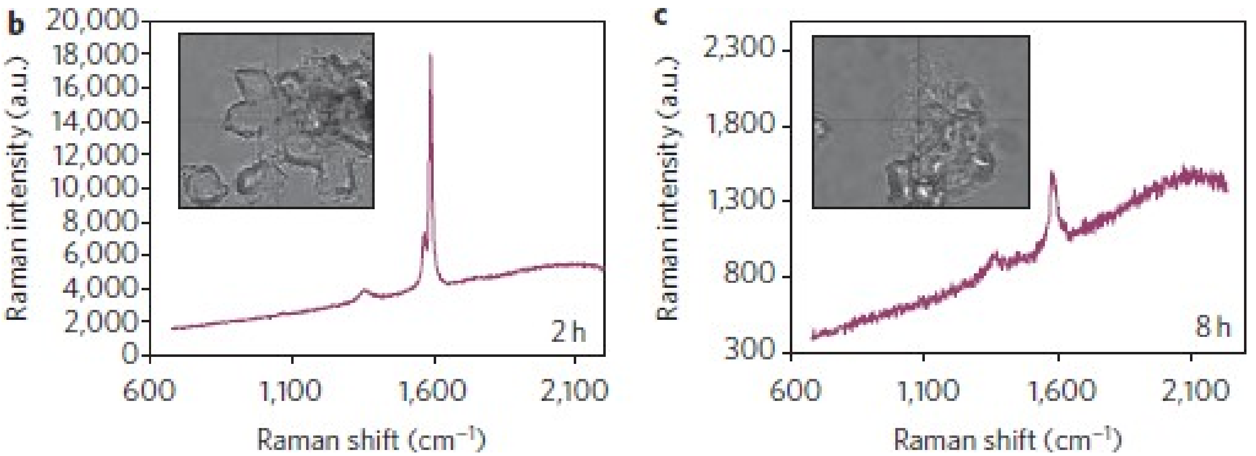
Biodegradation of carbon nanotubes





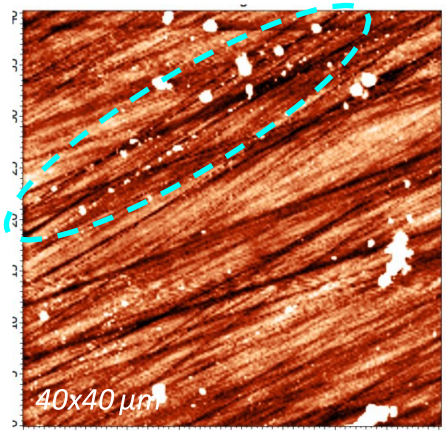
AFM image showing the capture of a single nanotube by living cell of immune system (neutrophils).

Raman spectra of neutrophil with IgG-nanotubes after 2 hours (b) and 8 hours (c). Reducing the intensity of G- and D-bands of carbon nanotube indicates biological degradation of single nanotubes. Thus, neutrophils were successfully processed and excreted objects such as carbon nanotubes

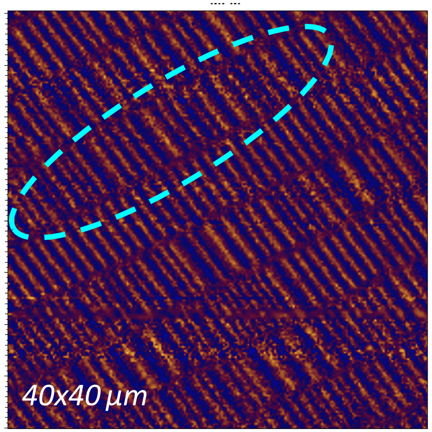
Y. Volkov et all // Carbon nanotubes degraded by neutrophil myeloperoxidase induce less pulmonary inflammation, Nature Nanotechnology, 2010

NT-MDT Spectrum Instruments

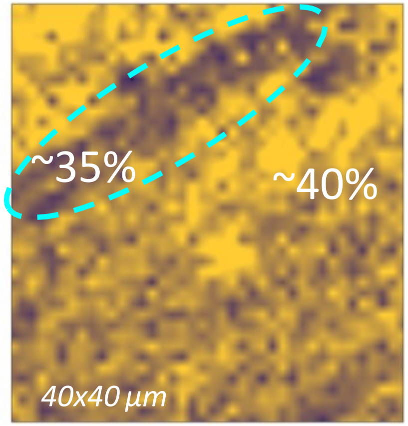
DLC Protective Layer of Hard Disk Drive



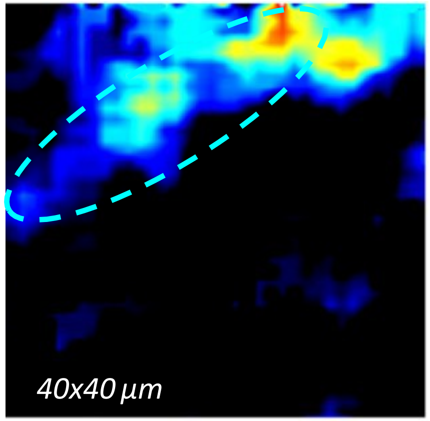
AFM topography
Nearly parallel scratches in DLC protective layer are produced by low-flying magnetic head. Bumps are signatures of erosion of Co magnetic layer.



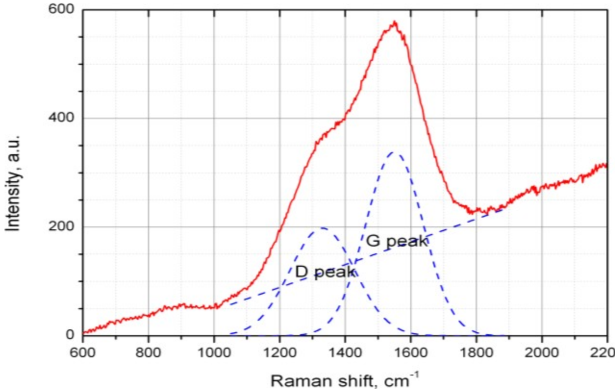
MFM image
Magnetic domains are not damaged yet.



Raman map,
sp3 (diamond-type) bonding fraction
ωG = 1580.



Raman map,
ID/IG ratio
Increased fraction of sp2 bonds and defects.



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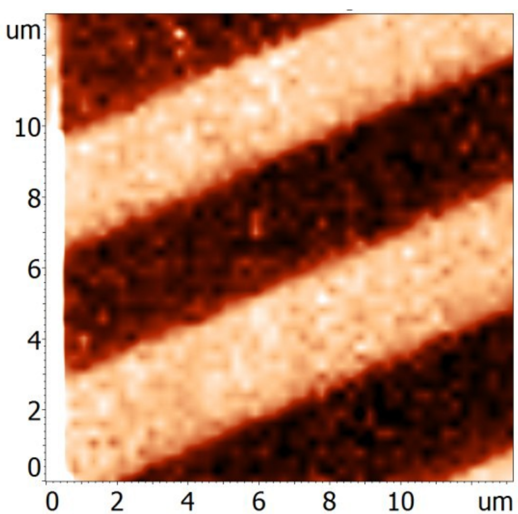
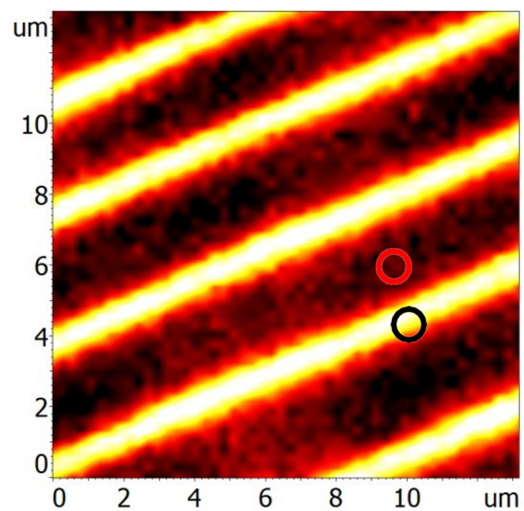
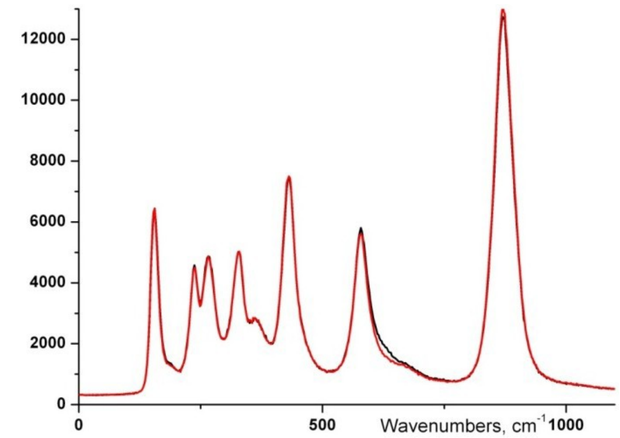
Simultaneous PFM and Raman mapping

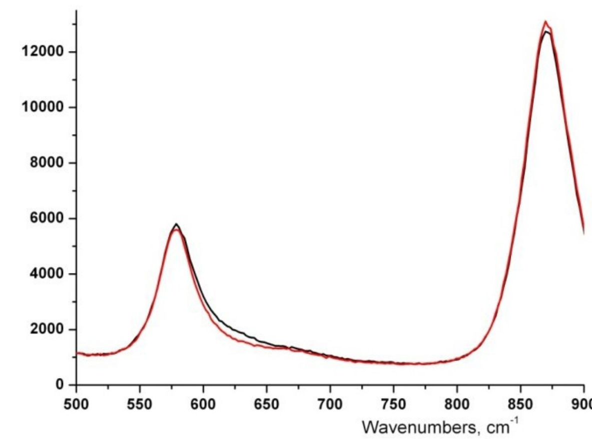
PFM



Raman map of band
553-599 1/cm







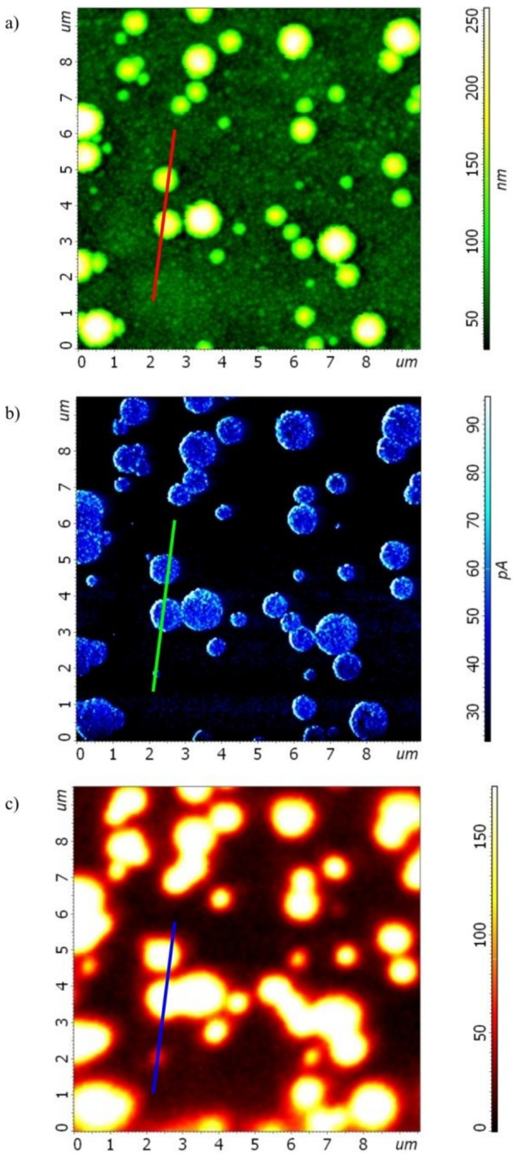
PFM mapping and Raman mapping of 553-599 1/cm band Lithium Niobate. Changes of Raman bands intensities appears on the border of domains

100x0,7 objective used. ~8 mW of 473 nm laser used.
Exposure time 1 s/points and 50x50 points scan size.

L. Eng, A. Shelaev & NT-MDT

NT-MDT Spectrum Instruments

Photocurrent mapping under localized optical excitation



Topography map

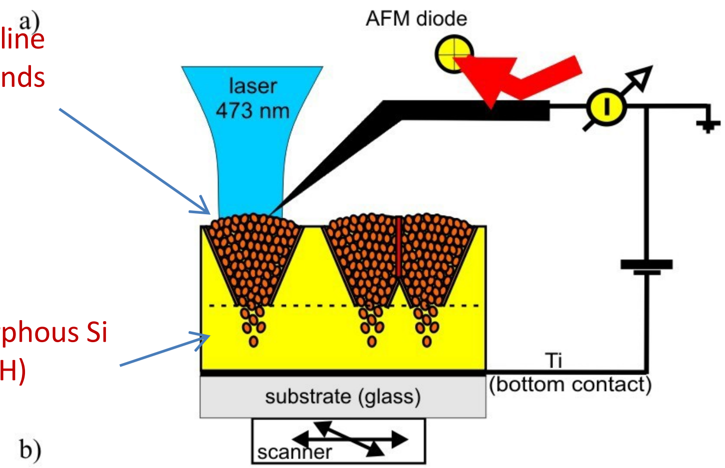
Local photoconductivity map

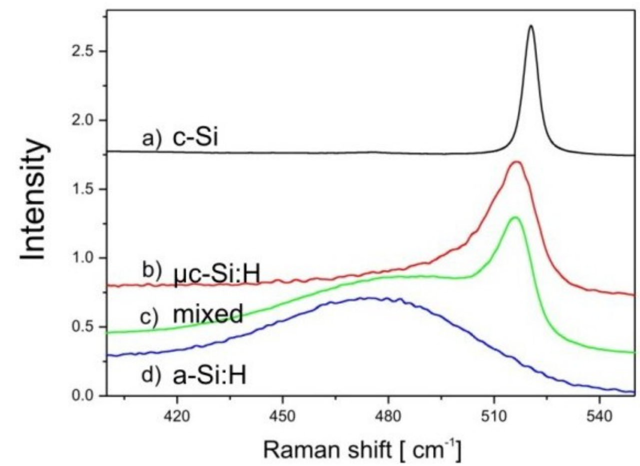
Raman map (µc-Si:H)

microcrystalline Si thin film in amorphous Si

Microcrystalline (µc-Si:H) islands

Fully amorphous Si layer (a-Si:H)





Martin Ledinský, Antonín Fejfar, Aliaksei Vetushka and Artem Shelaev

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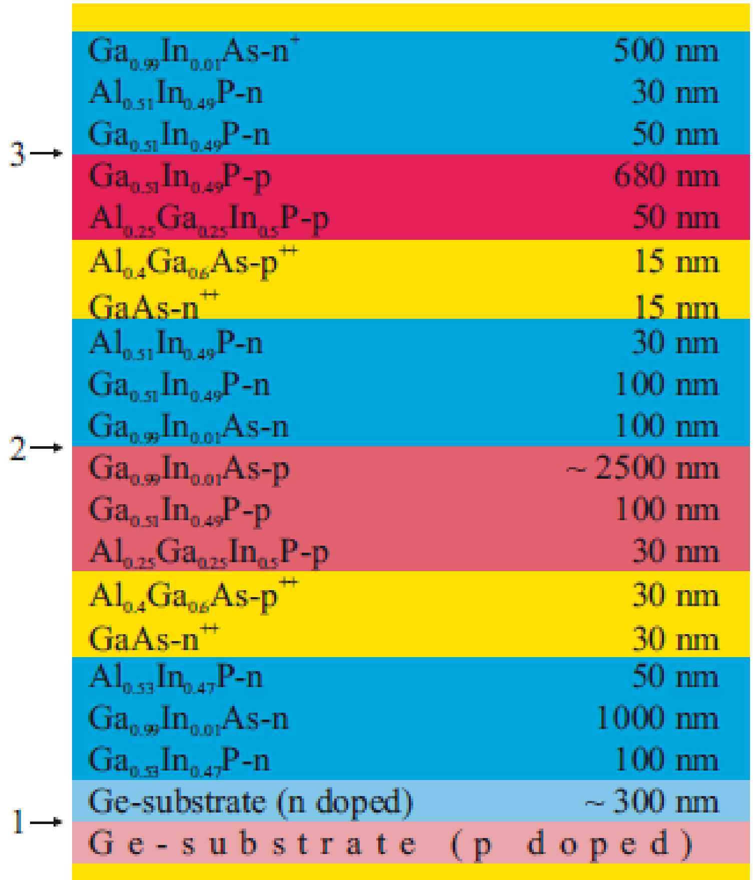
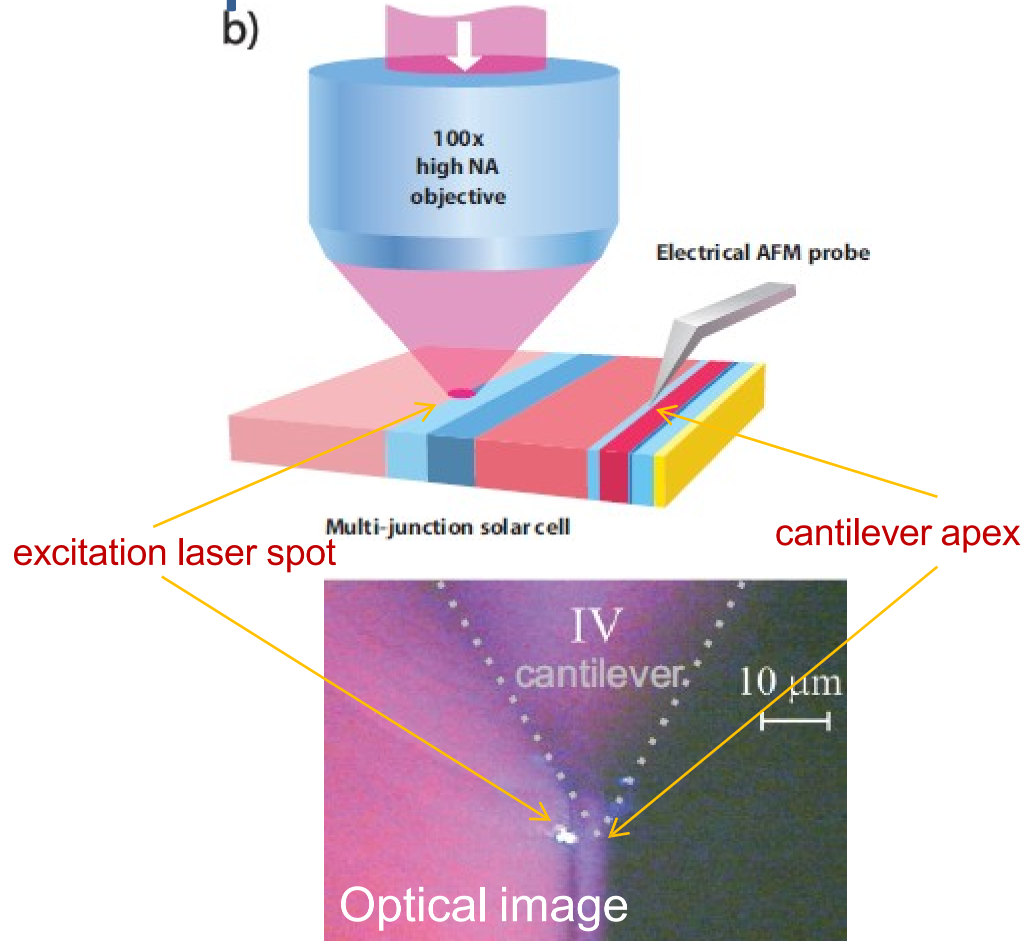
Solar cell diagnostics by combination of Kelvin probe microscopy with local photoexcitation



Multijunction solar cell structure.
Digits 1,2,3 show p-n junctions.
Blue: n-type layers, pink: p-type layers, yellow: highly conductive layers

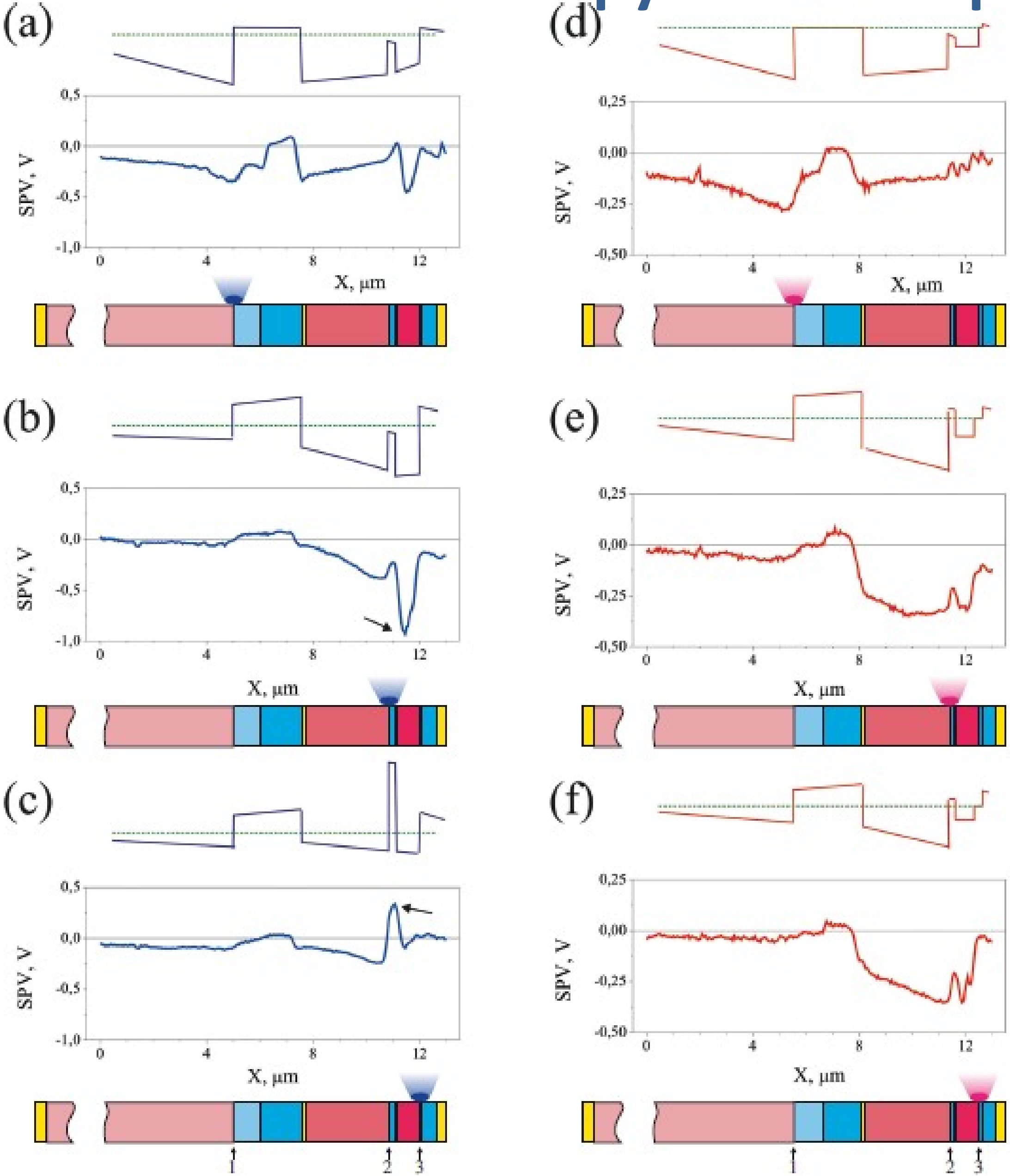


Individual p-n junction is locally excited by a 400 nm laser spot. Variation of surface potential is measured by cantilever (Kelvin prove microscopy)

A. Ankoudinov, A. Shelaev Ioffe Institute & NT-MDT

NT-MDT Spectrum Instruments

Solar cell diagnostics by combination of Kelvin probe microscopy with local photoexcitation



Surface potential variation for local excitation by 473 nm laser (left row: a,b,c) and 785 nm laser (right row: d,e,f).

Different individual p-n junctions are locally excited.

Experimental results correspond well to numerical simulation

A. Ankoudinov, A. Shelaev Ioffe Institute & NT-MDT

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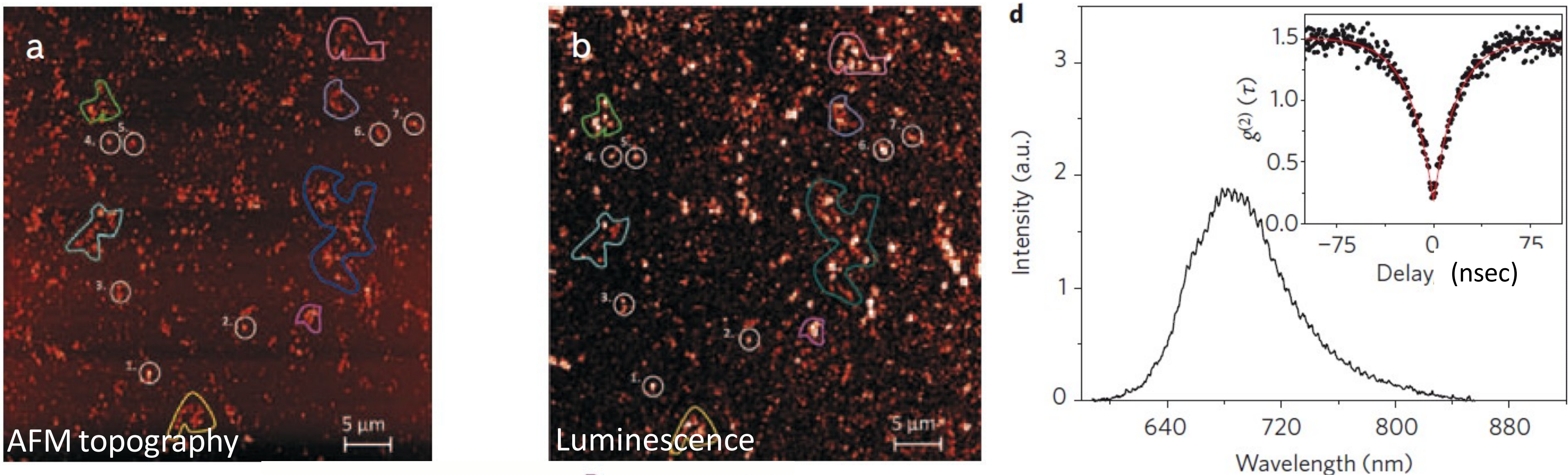
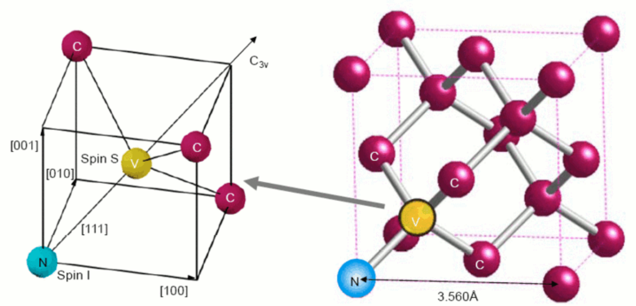
Nitrogen vacancy color centers in nanodiamonds

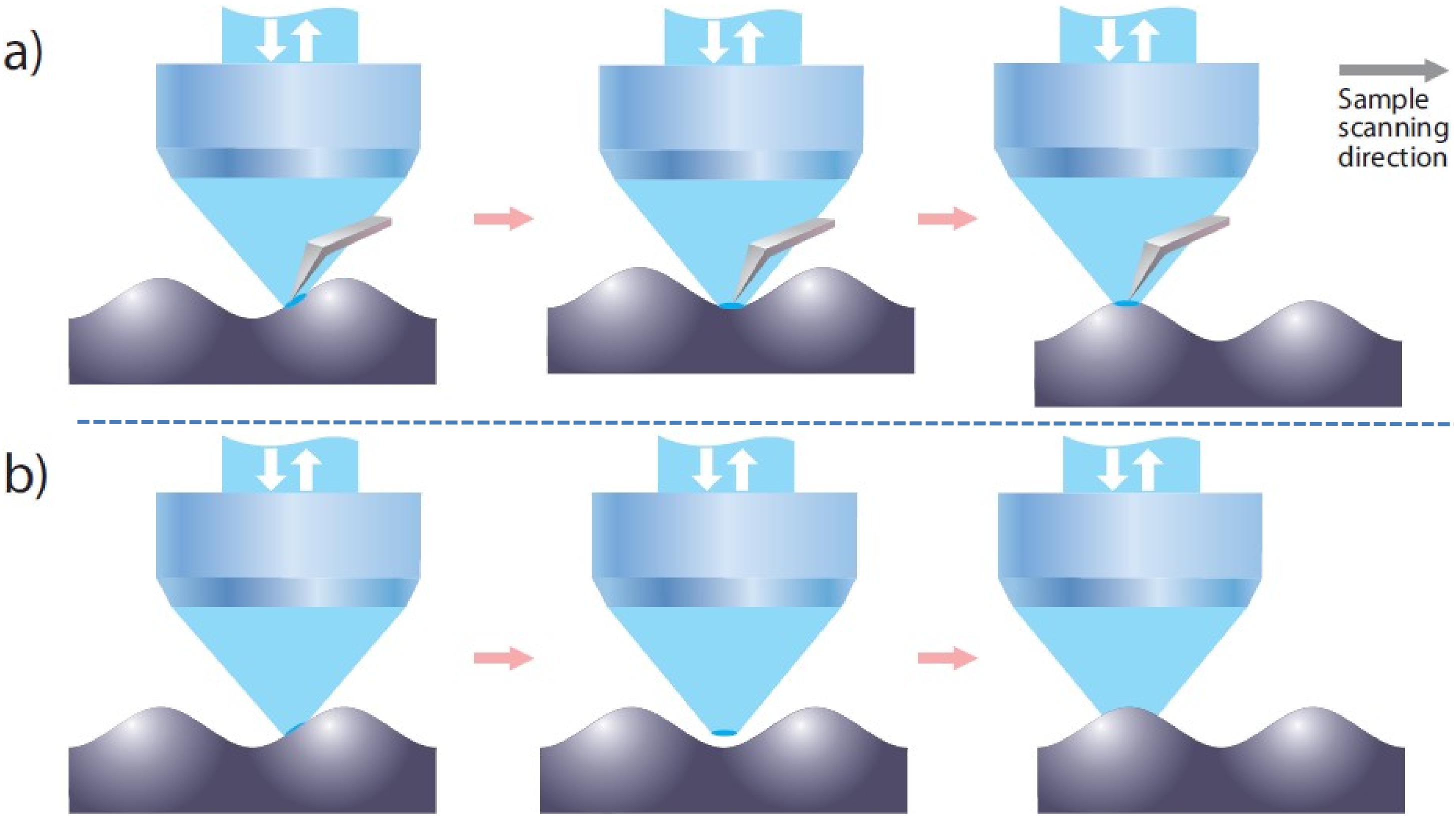




Observation of nitrogen-vacancy (NV) color centers in *discrete* detonation nanodiamonds
(a) AFM topography image; smallest particles observed are discrete isolated nanodiamonds of ~5 nm size. (b) Confocal luminescence map of the same sample area; nitrogen-vacancy luminescence from isolated nanodiamonds is clearly seen. (c) Luminescence spectrum of individual NV center in a 5 nm crystal host.

C. Bradac et al., *Nature Nanotechnology* 5, 345 - 349 (2010)

Focus track feature of integrated AFM - confocal Raman/fluorescence instrument



With focus track. Sample surface is always in focus

Without focus track. Sample surface getsout of focus for rough / inclined samples.

(a)Integrated AFM-Raman instrument and its “focus track” feature. Sample surface always stays in focus due to AFM feedback mechanism. This provides true information about sample chemical composition even for very rough surfaces.

(b) Standard confocal Raman/fluorescence imaging – sample is scanned in X&Y directions; Sample gets out of focus, providing incorrect data about optical properties of the surface.

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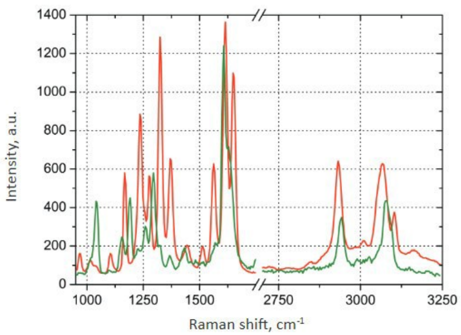
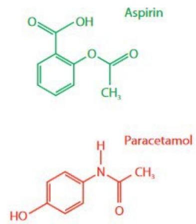
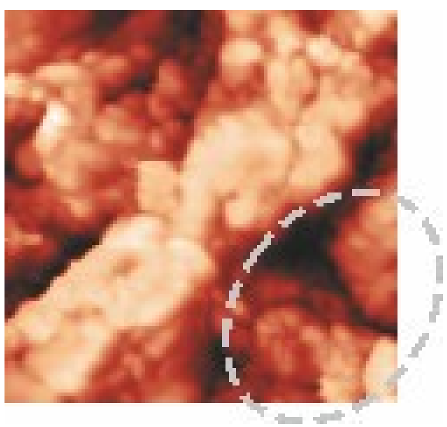
Focus track feature of integrated AFM - confocal Raman/fluorescence instrument

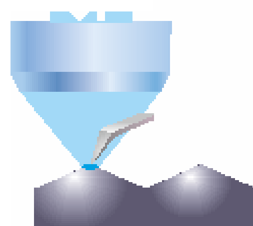


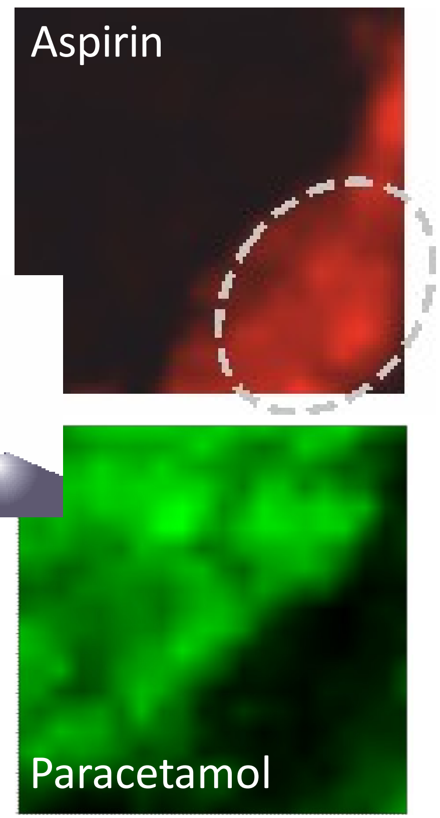


Raman mapping of a pharmaceutical tablet

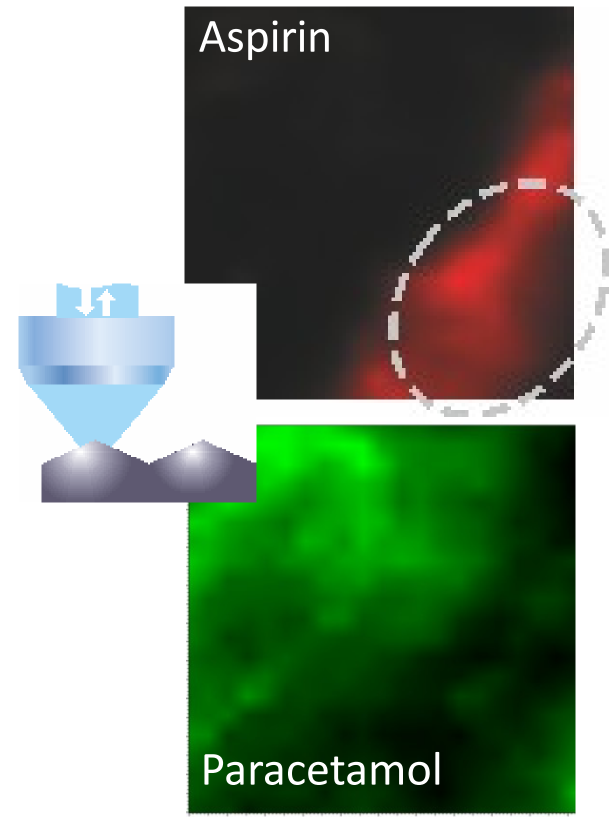


AFM image topography
Total height variation: ~ 6 µm





Raman maps
WITH focus track



Raman maps
WITHOUT focus track

Size of images: 20x20 µm

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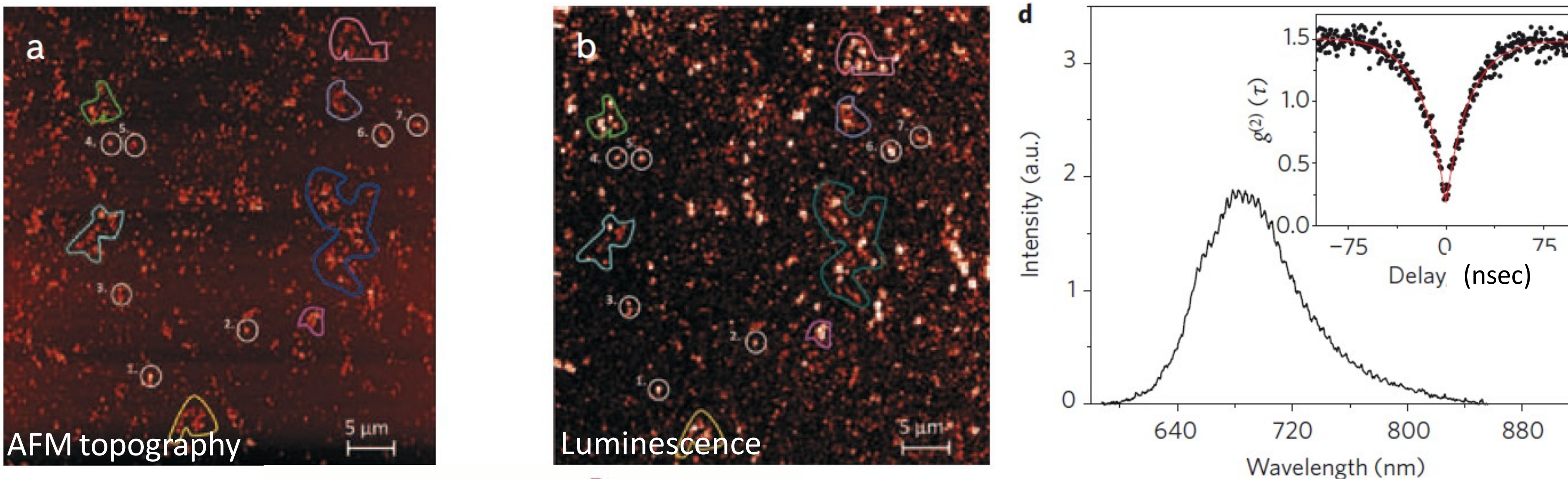
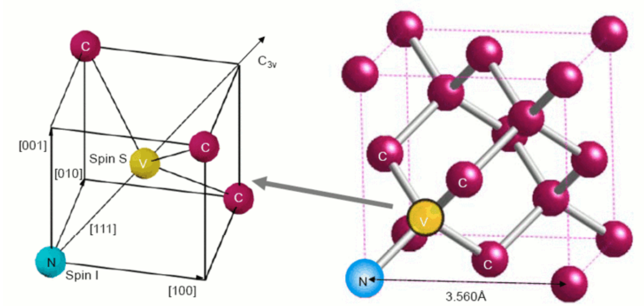
Nitrogen vacancy color centers in nanodiamonds





Observation of nitrogen-vacancy (NV) color centers in *discrete* detonation nanodiamonds
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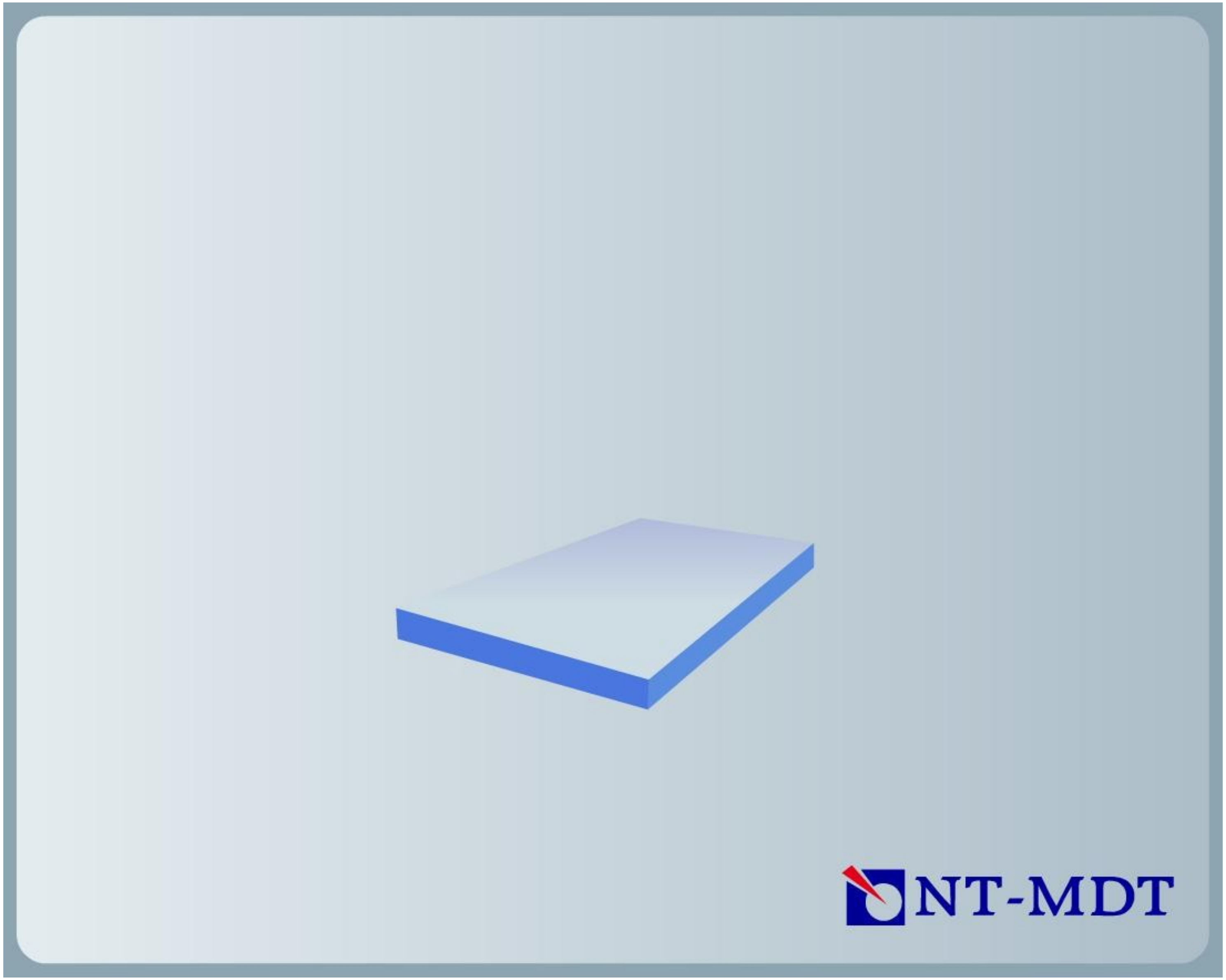
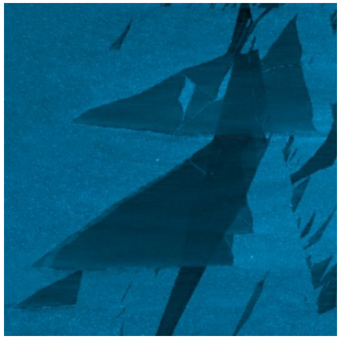
C. Bradac et al., *Nature Nanotechnology* 5, 345 - 349 (2010)

Graphene, AFM + Confocal Raman

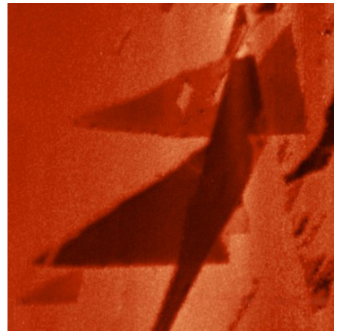


Real time simulation. Scanning area of 100x100 pixels, 50 sec scanning time

Graphene, AFM + Confocal Raman

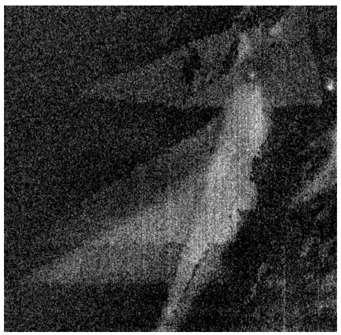


Lateral Force Microscopy
(friction)

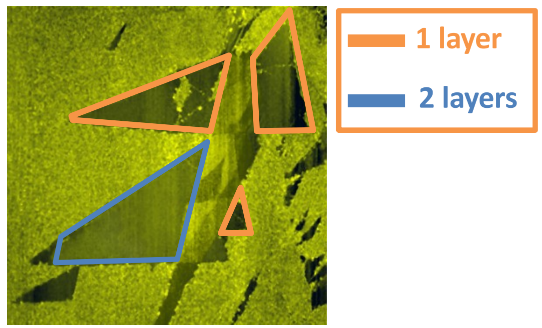


Electrostatic Force Microscopy
(charge distribution)

Force Modulation Microscopy
(elasticity)



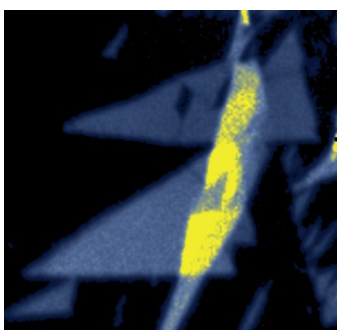
Capacitance Microscopy



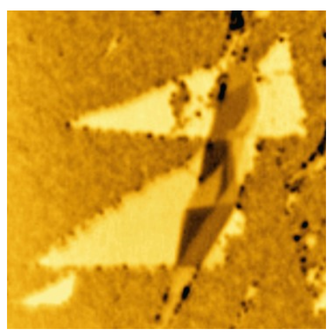
AFM Topography

Size: 30*30 µm

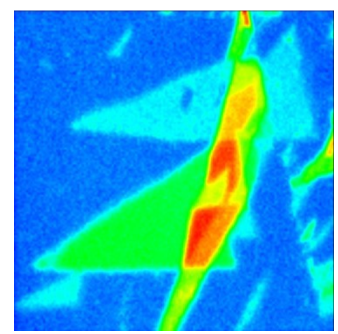
Scanning Kelvin Probe Microscopy
(surface potential)



Raman Map, 2D Band position



Confocal Rayleigh Microscopy



Raman Map, G-band Intensity

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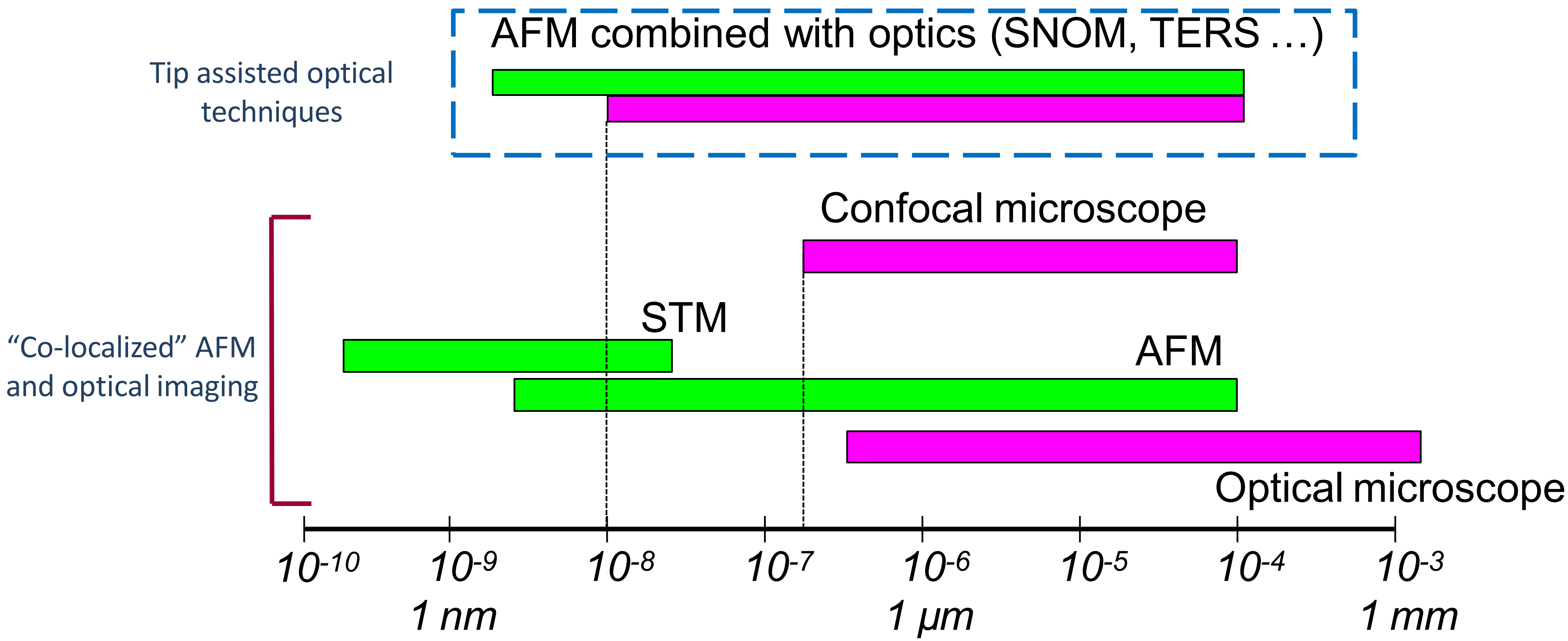
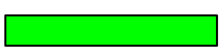
Resolution and capabilities of different techniques

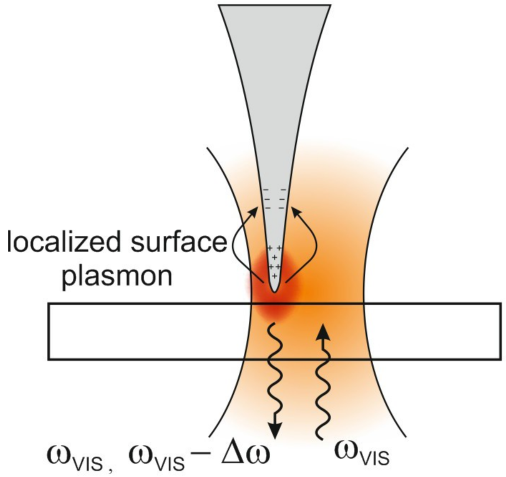



Optical techniques (color imaging, physical & chemical analysis)


Scanning probe microscopy (topography, mechanical, electrical, magnetic and other properties of the surface)

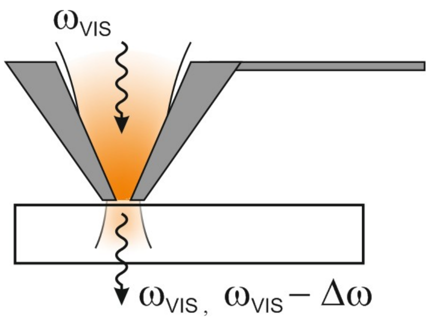

AFM (STM) + Optical techniques = Dramatic increase of resolution and sensitivity

Super-resolution imaging using scanning optical antennas



Tip enhanced near-field optical microscopy

Light localization and enhancement by localized surface plasmon



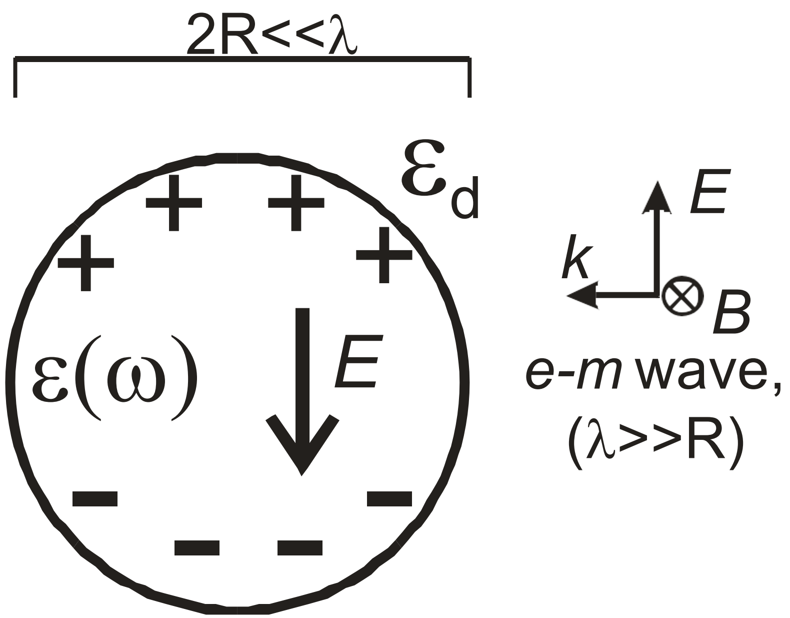
Aperture scanning near-field optical microscopy (SNOM)

Light transmission through non-resonant subwavelength aperture

Optical antenna: a device designed to efficiently convert free-propagating optical radiation to localized energy, and vice versa.

- *L. Novotny, N. van Hulst, Nature photonics 5, 89 (2011)*
- *P. Bharadwai, B. Deutch, L. Novotny, Adv. In Opt. Phot. 1, 438 (2009)*
- *Pohl D. W., Optics, Principles and Applications (World Scientific, 2000).*

Localized surface plasmon resonance in metal nanoparticles (0D geometry)



metal spherical nanoparticle
in dielectric medium

$$\alpha = 4\pi R^3 \frac{\varepsilon(\omega) - \varepsilon_d}{\varepsilon(\omega) + 2\varepsilon_d}$$

Nanoparticle polarizability

Resonant interaction with light at:

$$\varepsilon(\omega_{res}) = -2\varepsilon_d$$

(Fröhlich mode)

Drude model: $\varepsilon'(\omega) = 1 - \omega_p^2 / \omega^2$

$$\omega_{pe} = \sqrt{\frac{4\pi n_e e^2}{m}}$$

$$\boxed{\omega_{res} = \omega_p / \sqrt{3}}$$

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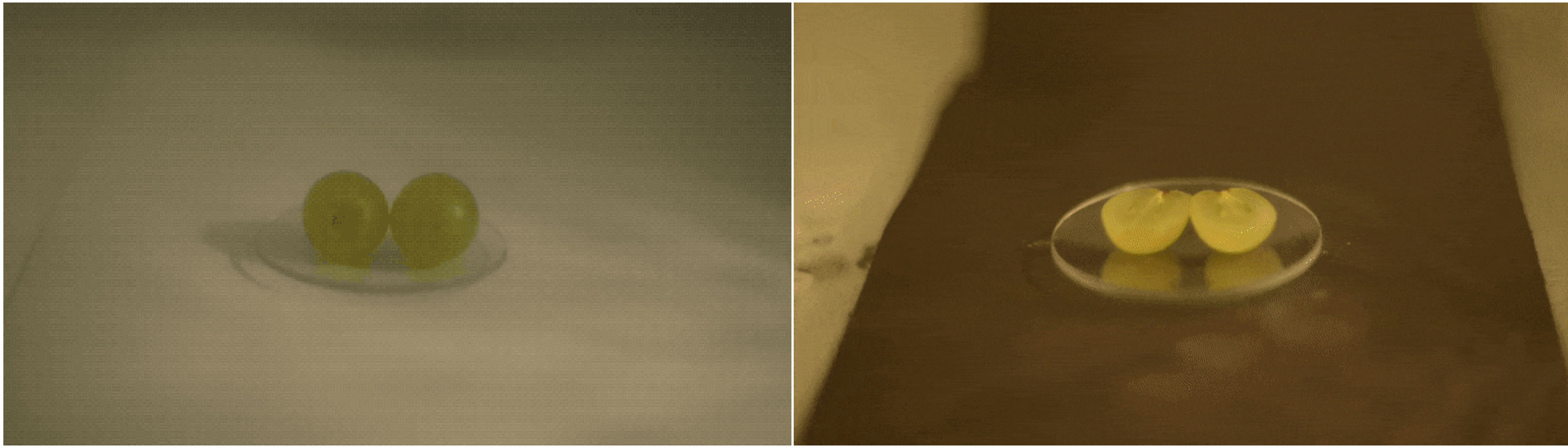
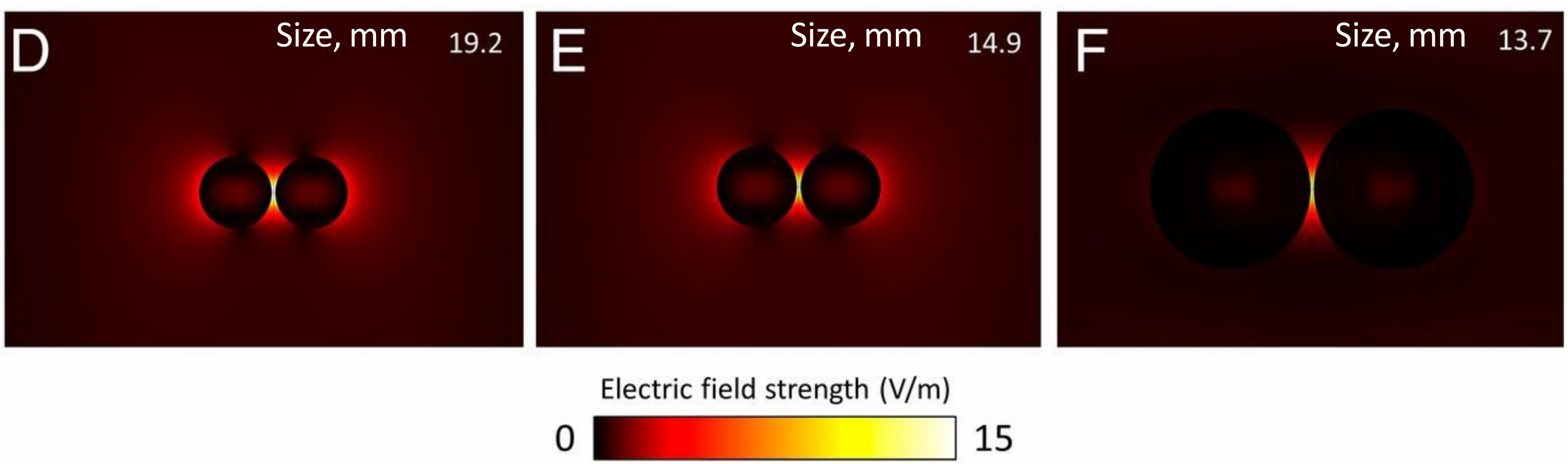
Localized EM field in macroobjects



Video of plasma created by EM irradiation of grapes in a commercial microwave oven in the traditional manner.



Proceedings of the National Academy of Sciences Mar 2019, 116 (10) 4000-4005; DOI:10.1073/pnas.1818350116

TERS: Importance of light polarization

"Z-polarized" light (with electrical field polarized along the tip axis) light experiences the largest enhancement at the tip apex

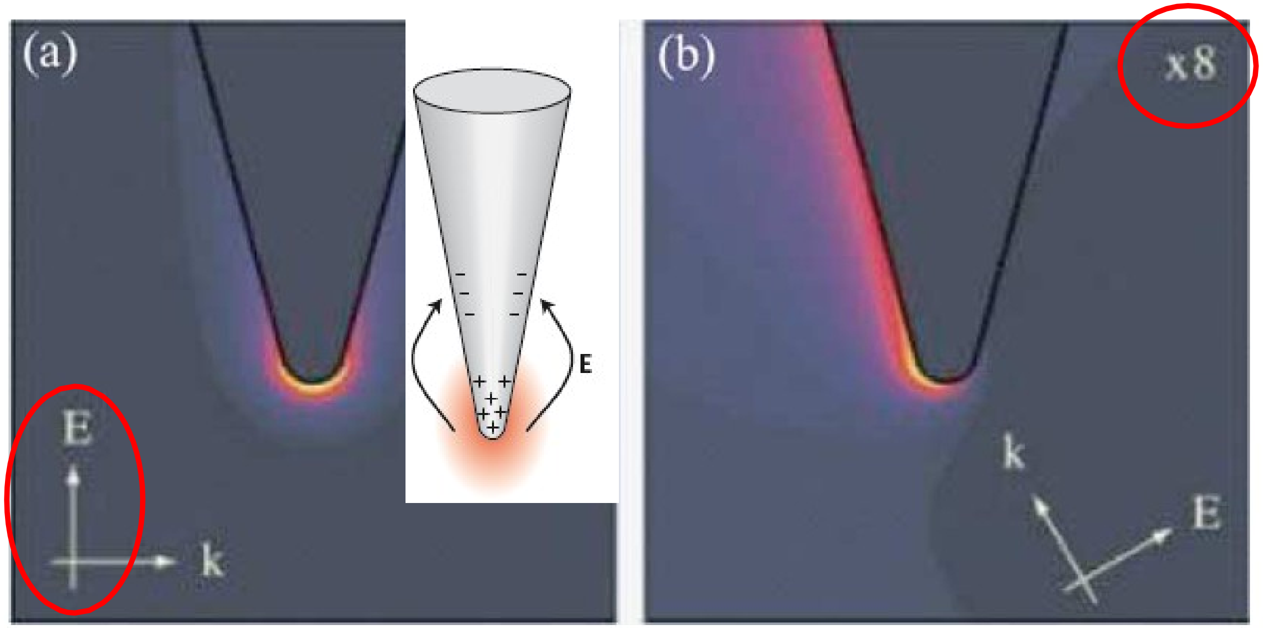


Fig. 1 Calculated field distribution at a sharp Au tip with a diameter of 5 nm. (a) Field distribution for an incident electric field vector parallel to the tip shaft showing localization of the electric field at the tip apex. (b) Field distribution for an incident electric field orientated nonparallel to the tip shaft. The field is no longer confined to the tip apex.

Taken from: N. Anderson, A. Hartschuh, L. Novotny, Materials Today (2005)

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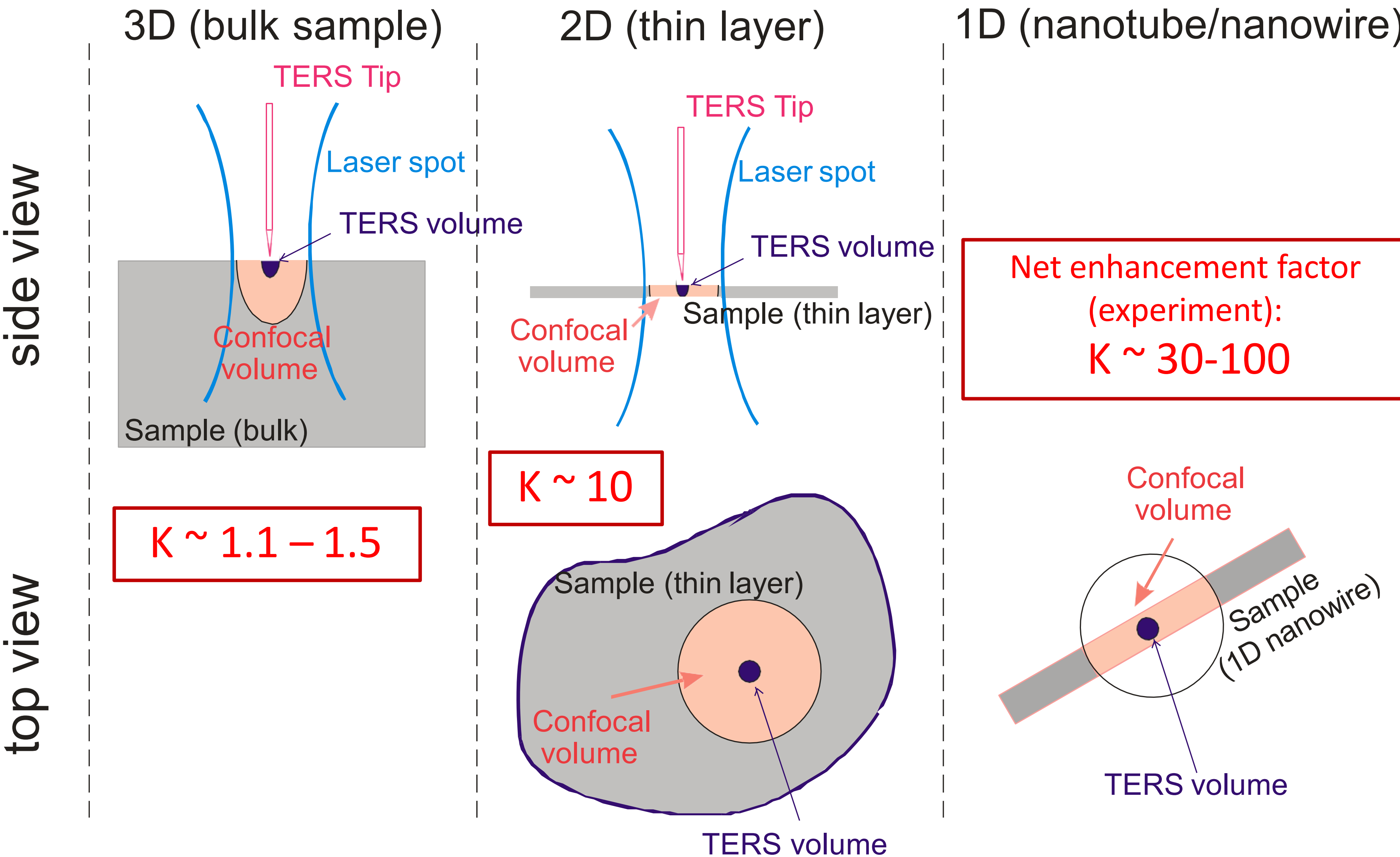
Spectrum Instruments

TERS enhancement in different geometries (1D, 2D, 3D)



Far field to near field volume ratio decreases with decreasing dimension – lower dimensions are more advantageous for TERS

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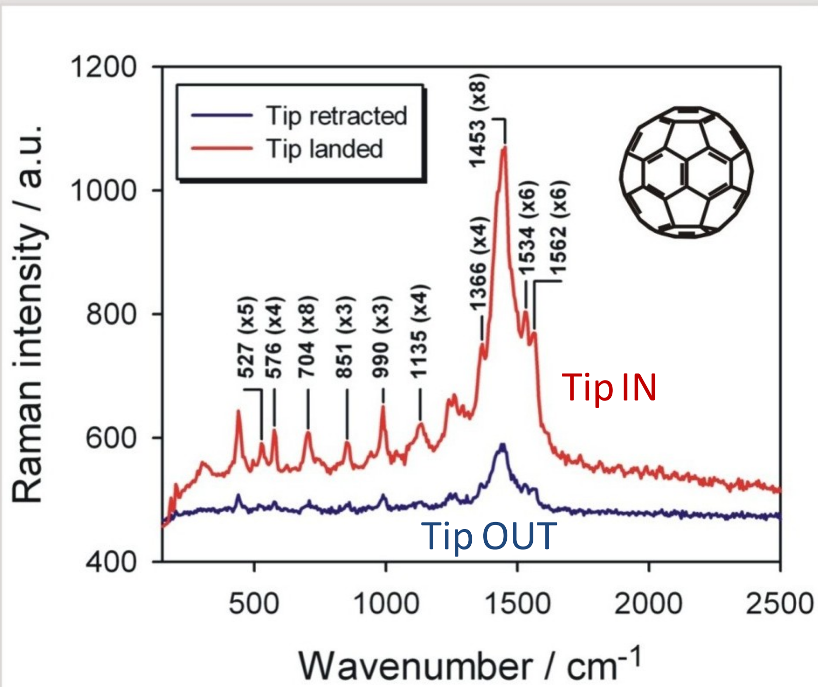
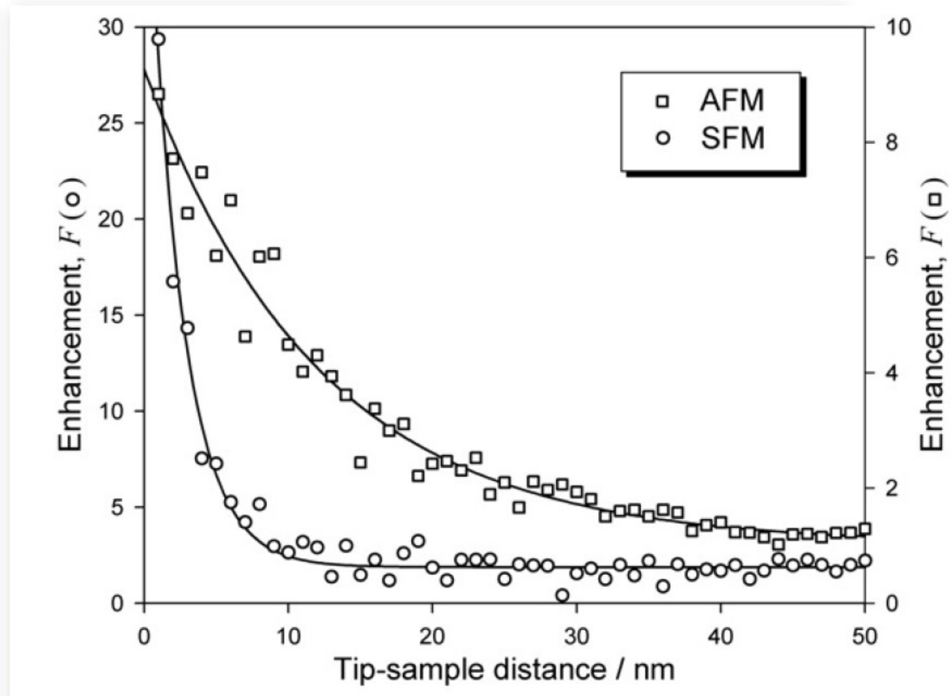
TERS enhancement factor as function of tip-sample distance
Fullerene thin film

Laser: 633 nm
Tip: Au etched wire & Au coated cantilever
Mode: Shear force & non-contact mode

Enhancement factor: ~ 5–10x



Signal enhances >10 times after tip is approached



Signal enhancement versus tip-sample distance: proof of plasmonic near-field nature of the effect

Data courtesy of S. Kharintsev, J. Loos, G. Hoffman, G. de With, TUE, the Netherlands

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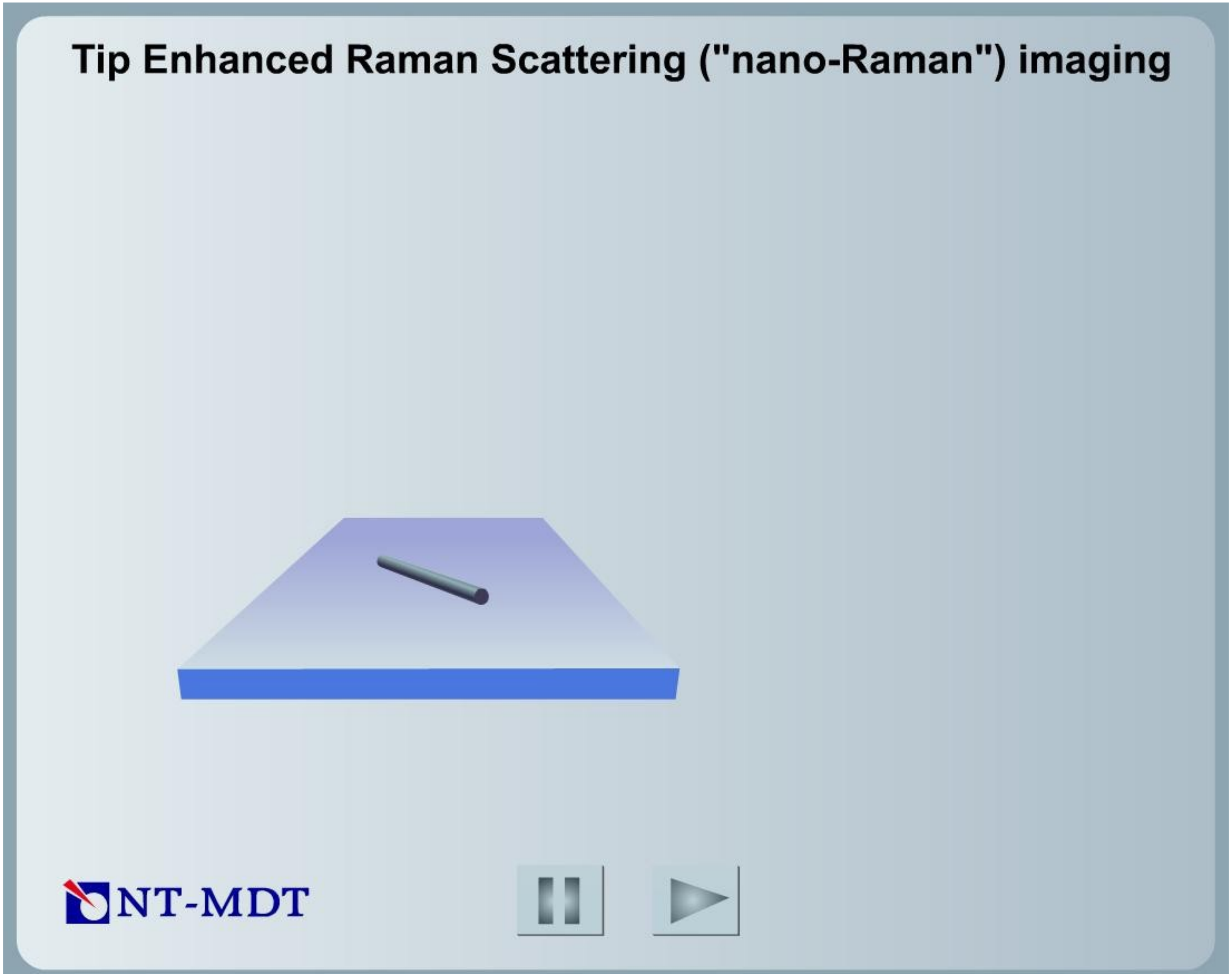
TERS on carbon nanotubes
All data – using NT-MDT instrument



NT-MDT
Spectrum Instruments

TERS on carbon nanotubes
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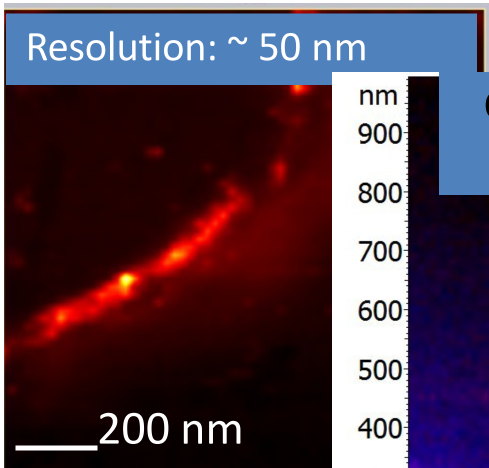
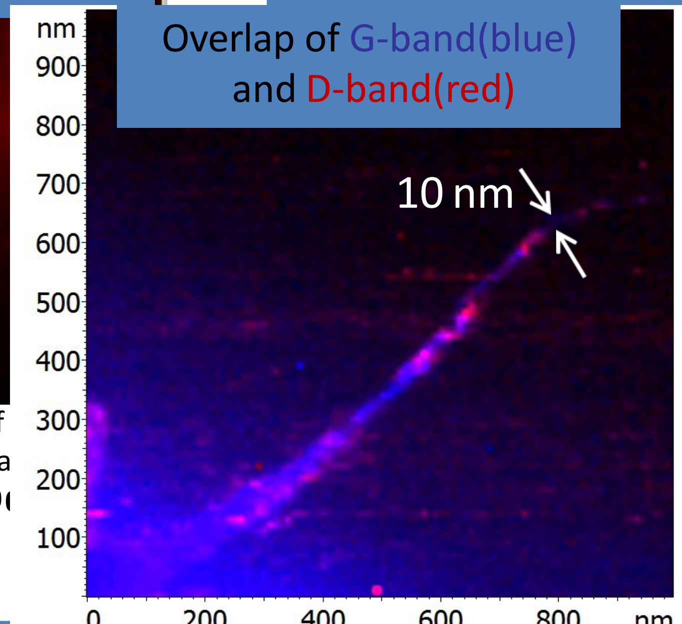
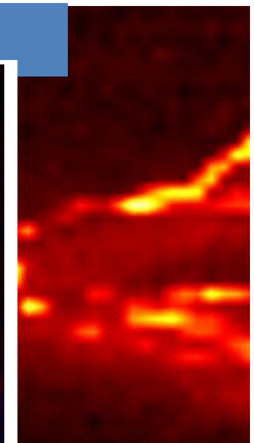
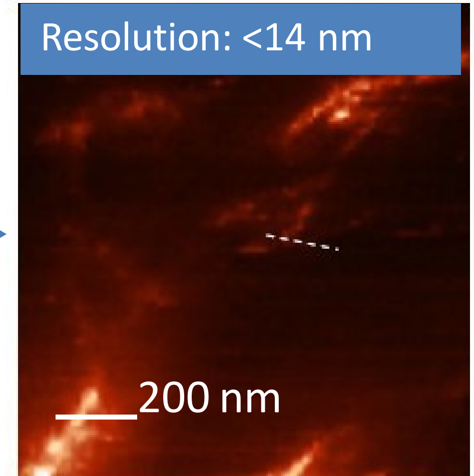


S.S. Kharintsev, G. Hoff
Dorozhkin, G. de With, a
Nanotechnology 18 **(20**

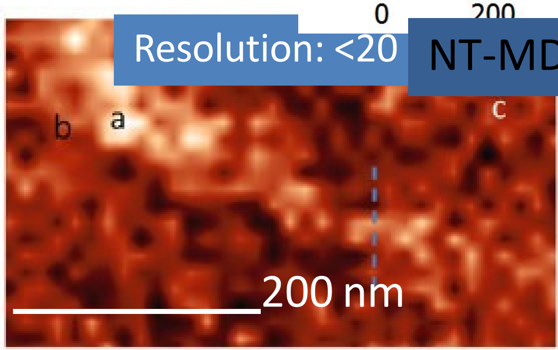




os, R. Zenobi
)08)

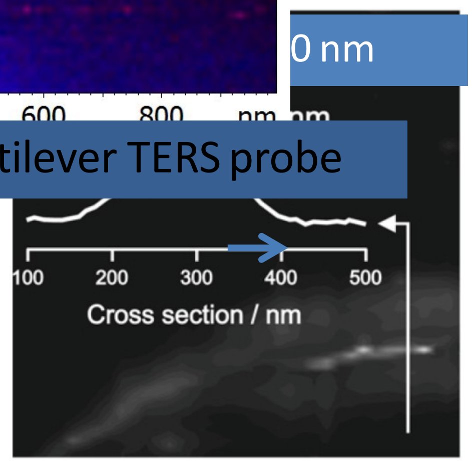


Chan K.L., Kazarian S.G., Nanotechnology 21, 445704 **(2010)**

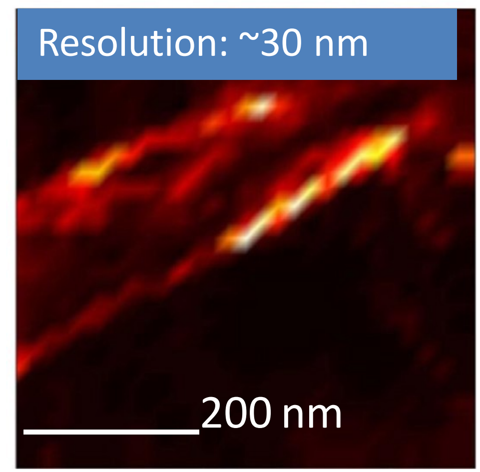


Chan K.L., Kazarian S.G., Nanotechnology 22, 175701 **(2011)**

NT-MDT, Cantilever TERS probe

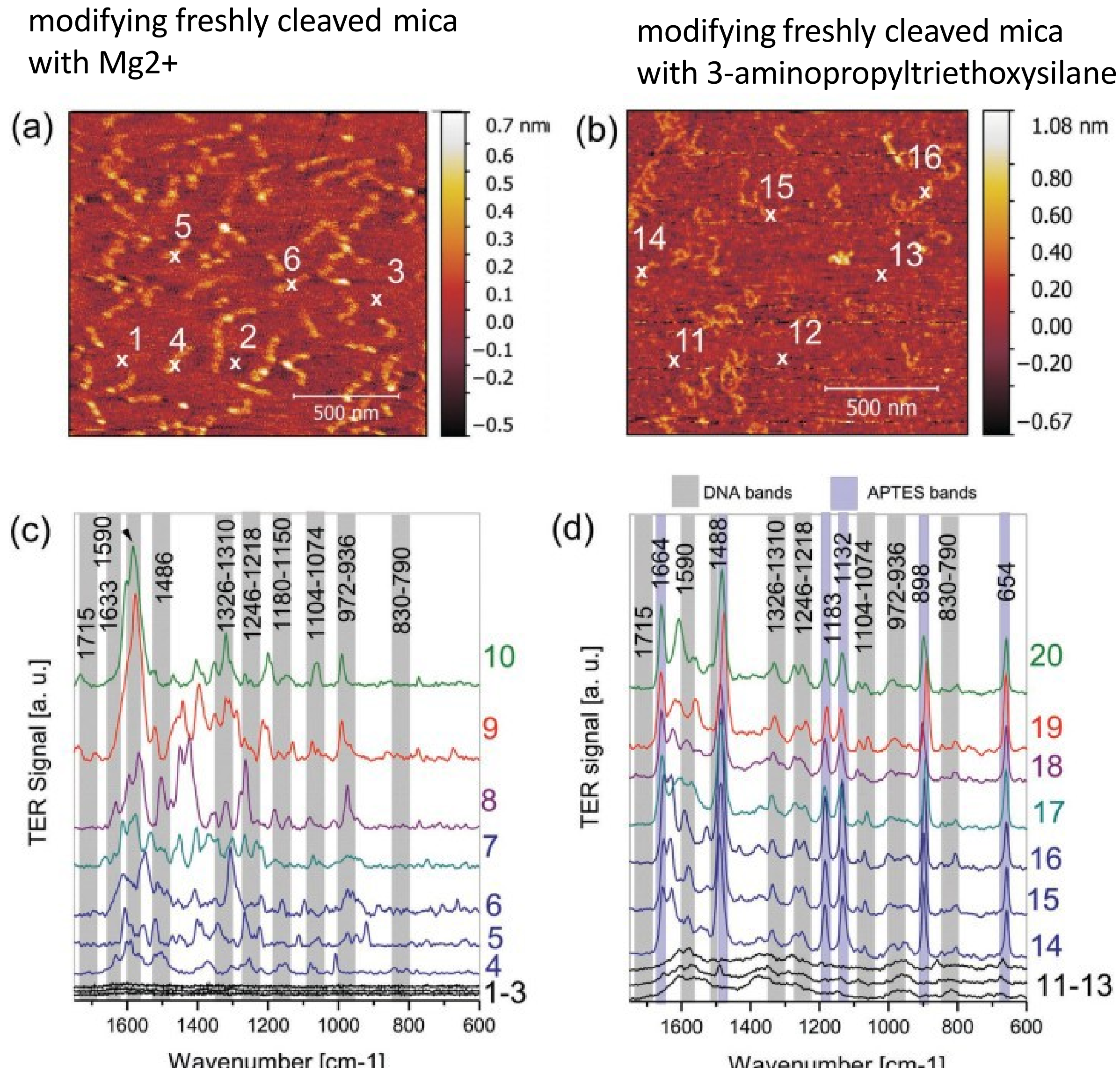


S. Kharintsev, G. Hoffmann, A. Fishman. & M. Salakhov J. Phys. D: Appl. Phys. 46 **(2013)** 145501



M. Zhang, J. Wang, Q. Tian, Optics Communications 315, 164 **(2014)**

TERS spectroscopy of single DNA molecules



Lipiec, E., Japaridze, A., Szczerbiński, J., Dietler, G. & Zenobi, R. Preparation of Well-Defined DNA Samples for Reproducible Nanospectroscopic Measurements. *Small* **12,** 4821–4829 (2016).

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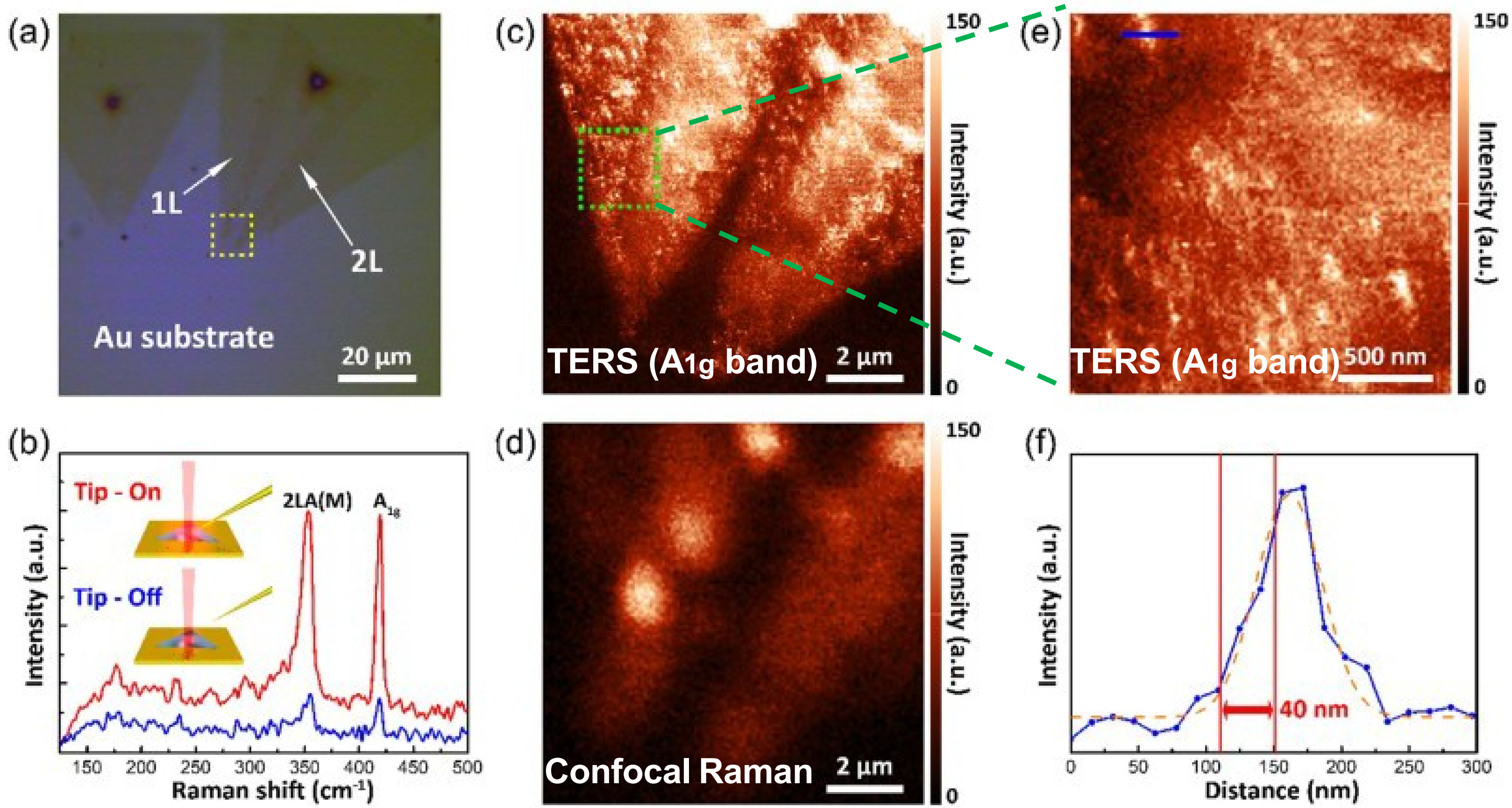
TERS spectra and images of mono/bilayer WS_2 flake



C. Lee *et al.*, "Tip-Enhanced Raman Scattering Imaging of Two-Dimensional Tungsten Disulfide with Optimized Tip Fabrication Process," *Sci. Rep.*, vol. 7, no. September 2016, p. 40810, Jan. 2017.

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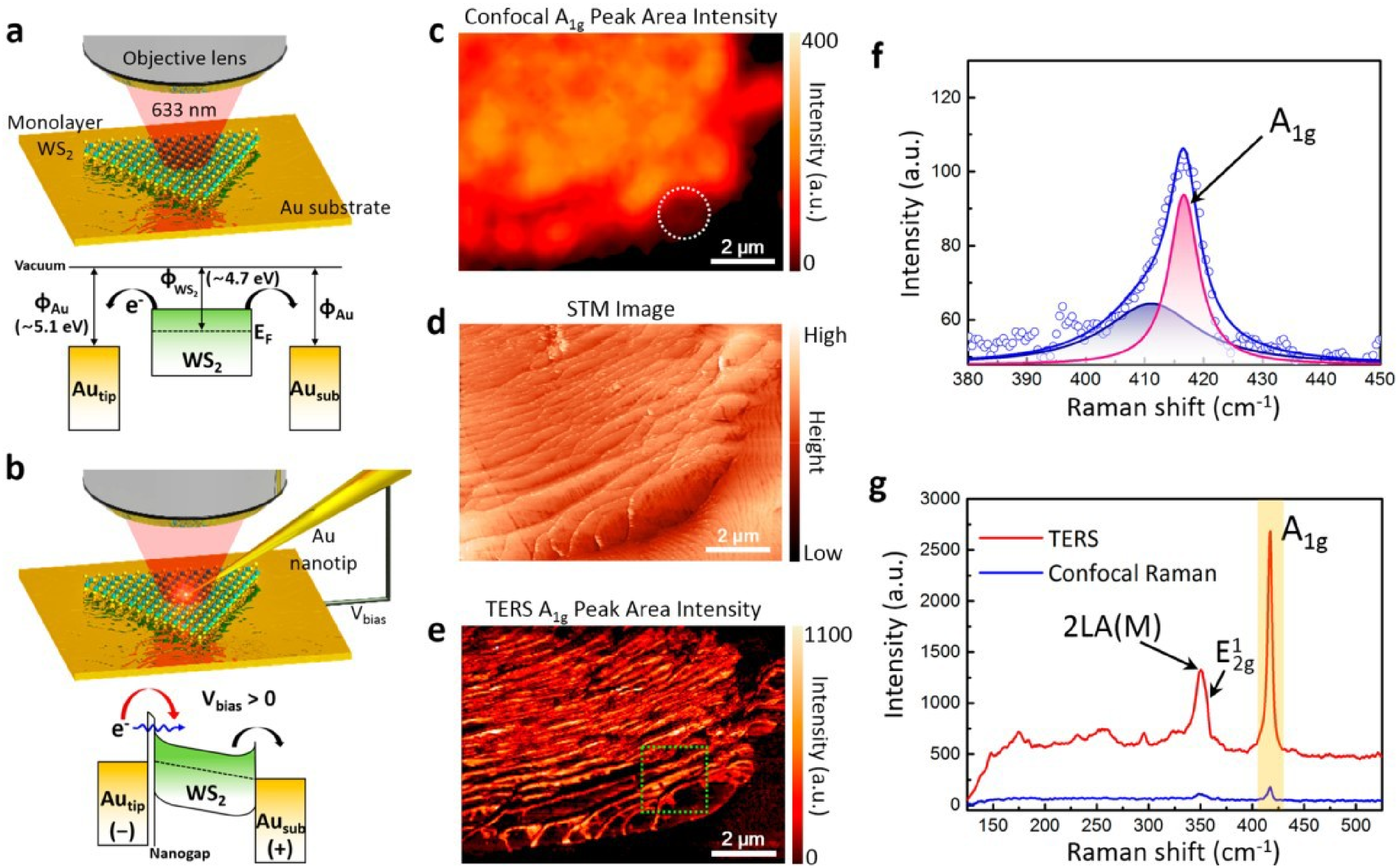
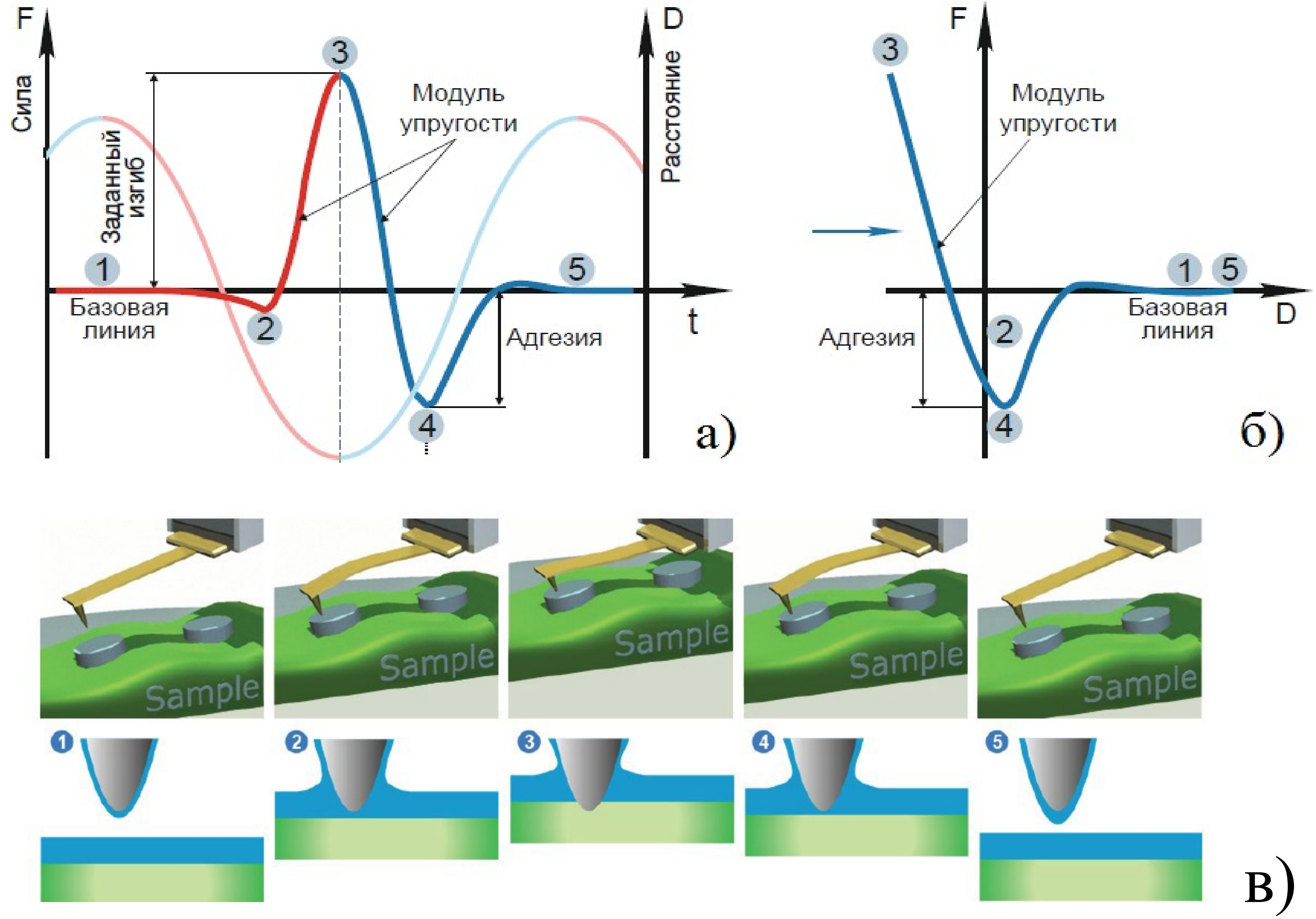
STM TERS of monolayer WS_2



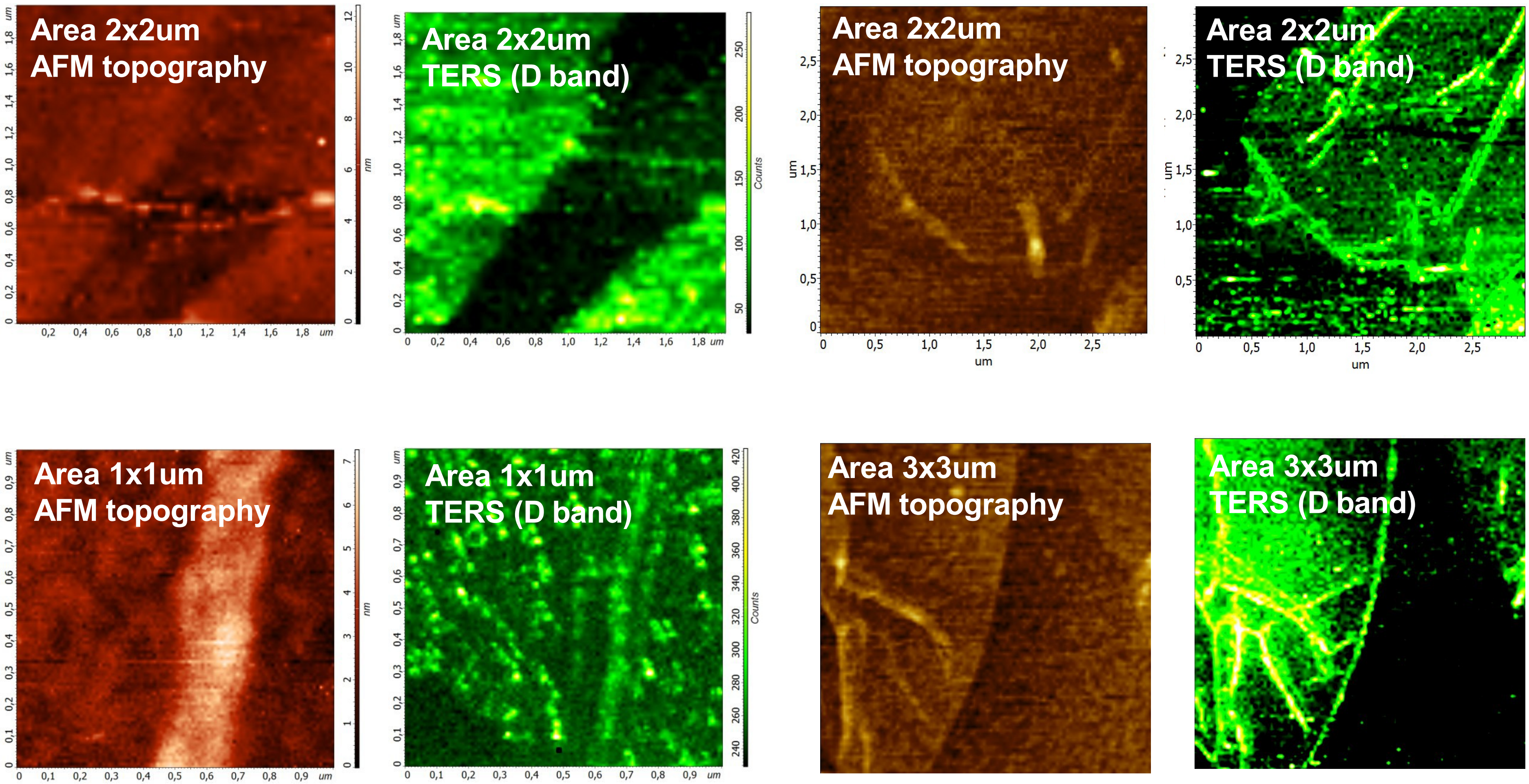
Lee, C. *et al.* Unveiling Defect-Related Raman Mode of Monolayer WS2 via Tip-Enhanced Resonance Raman Scattering. *ACS Nano* **12,** 9982–9990 (2018).

NT-MDT Spectrum Instruments

Hybrid mode of feed back loop



TERS on Graphene Oxide
AFM TERS cantilevers, HYBRID regime



Typical TERS resolution with AFM TERS probes: ~ 20 – 40 nm.

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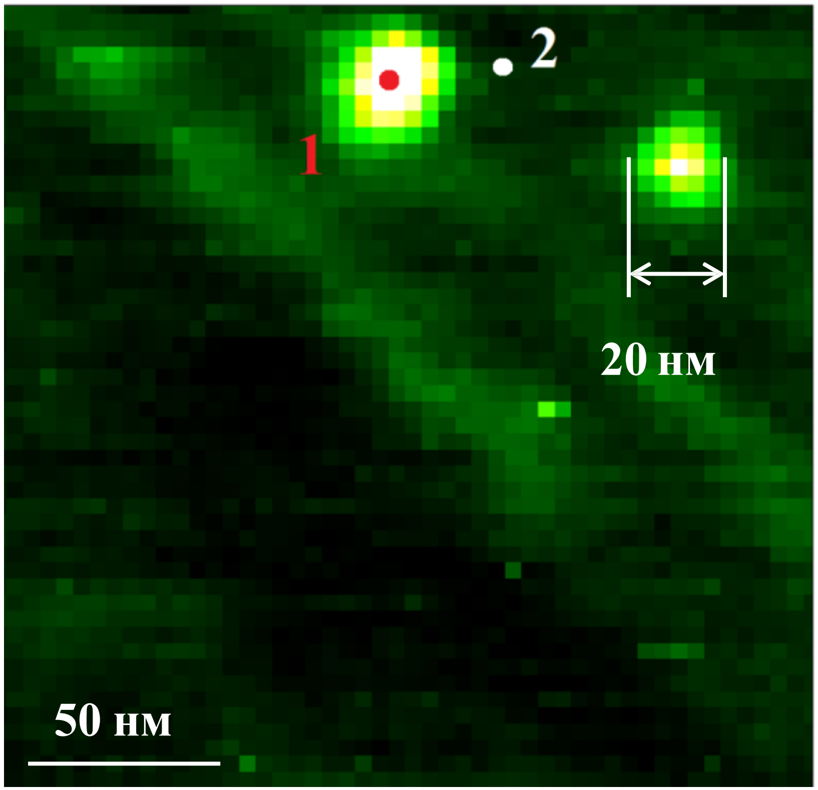
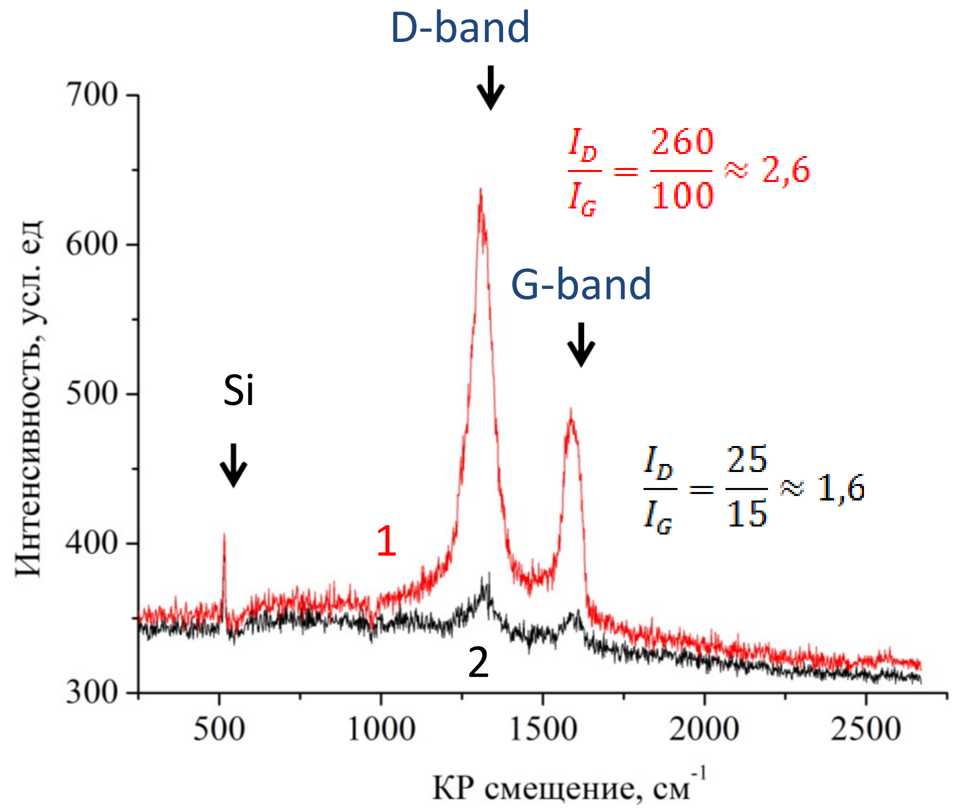
TERS map of single defects in Graphene oxide (GO). HybriD mode.

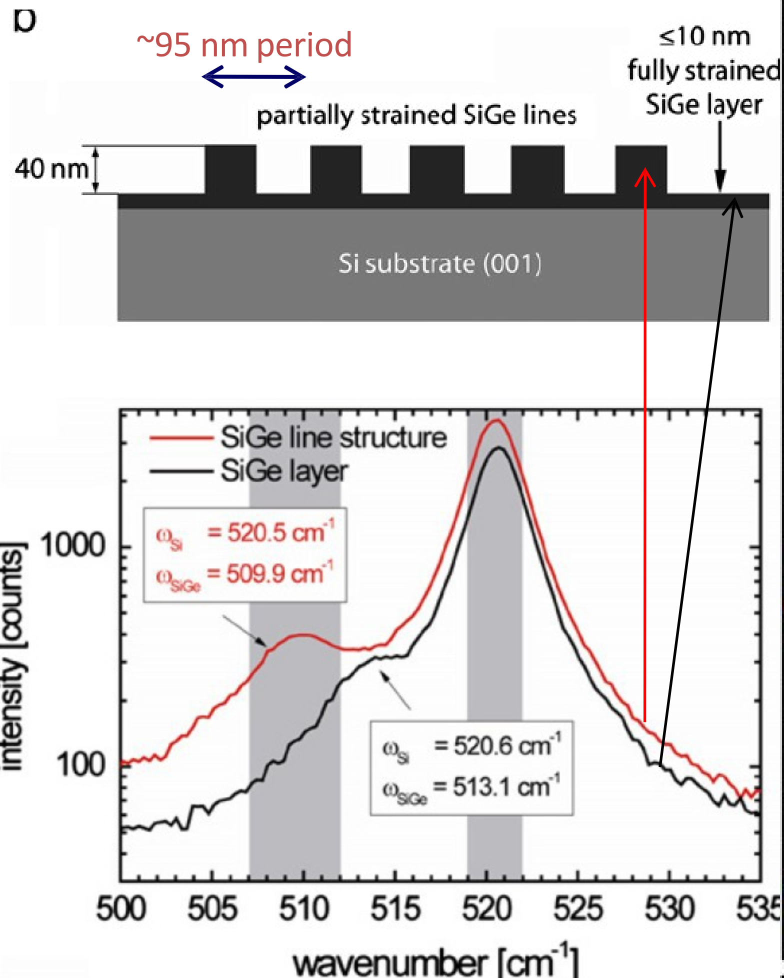
TERS map, G-band

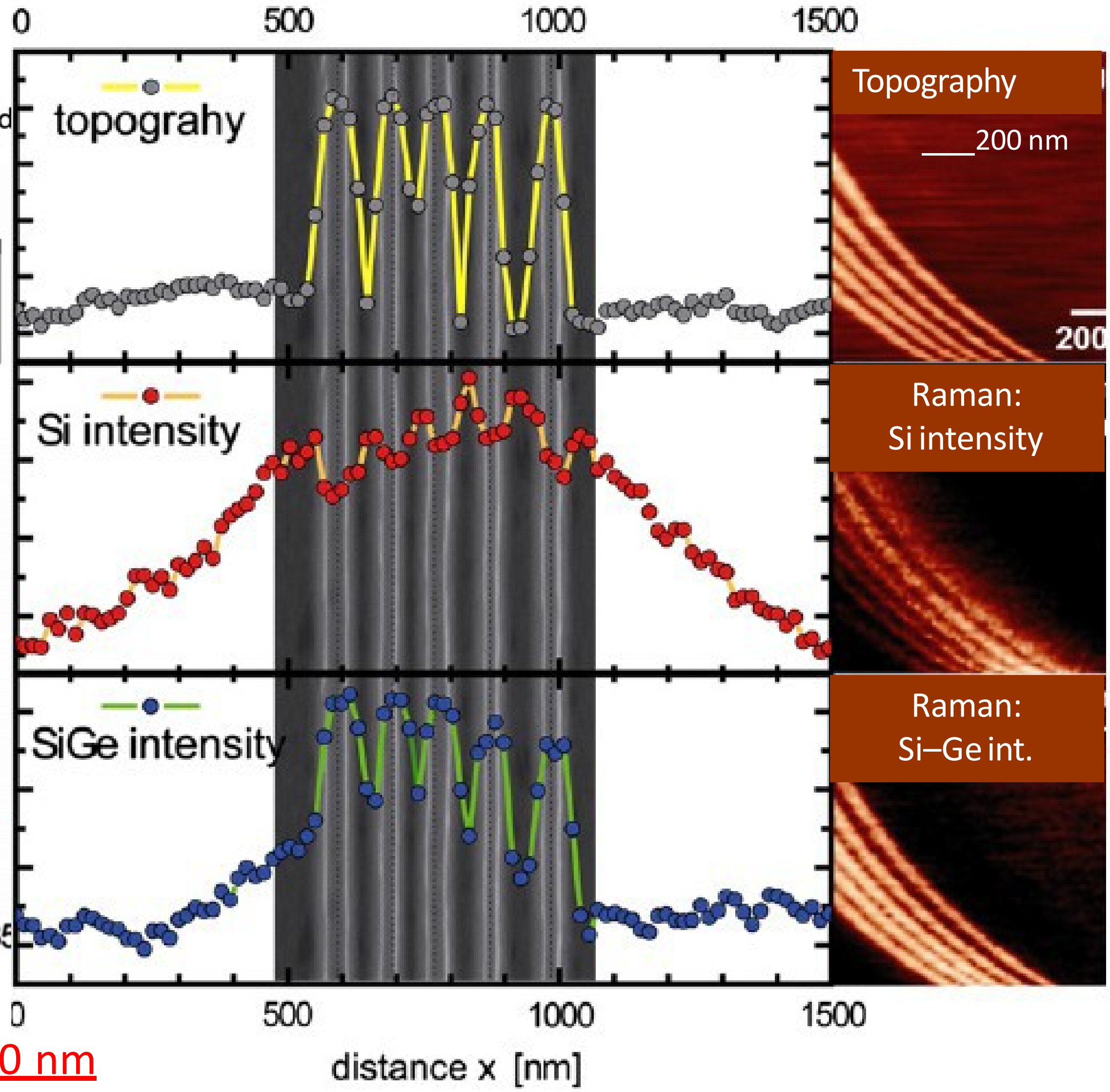




TERS of single defects in GO flakes. Distance between point 1 and 2 is ~25 nm. Spectra from 1 and 2 points are shown on the graph

TERS ("nano-Raman") on periodic Si-Ge structure resolution ~50 nm



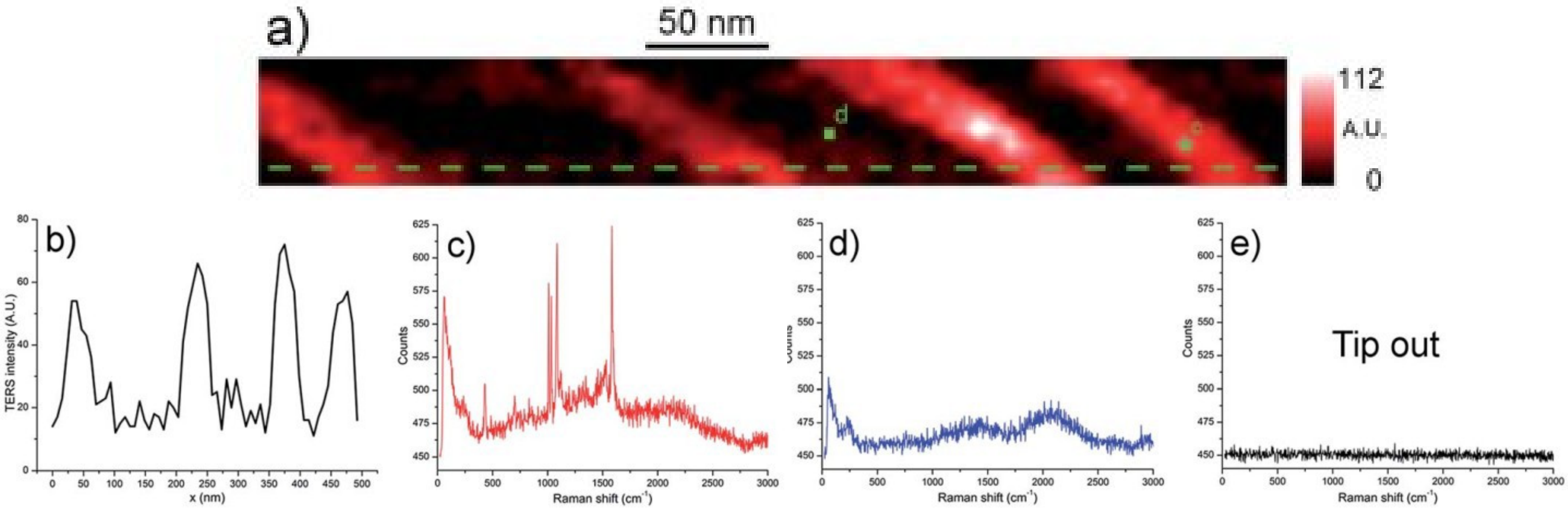


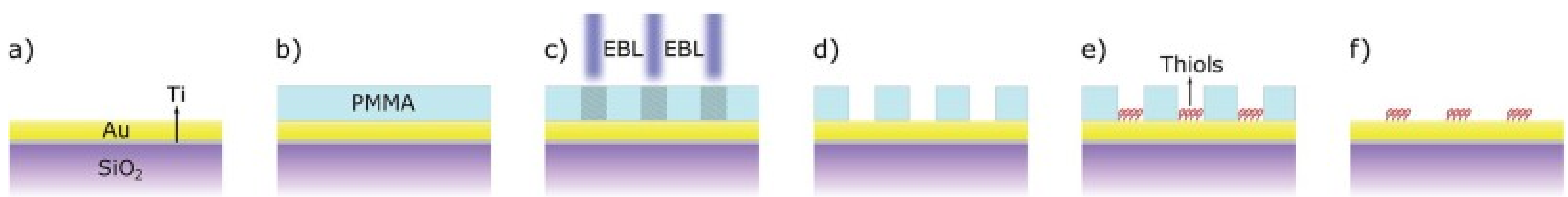
Lateral resolution of Raman maps: <u>≤50 nm</u>

P.Hermann, M. Hecker, D. Chumakov, M. Weisheit, J. Rinderknecht, A.Shelaev, P. Dorozhkin, L.M.Eng, Fraunhofer CNT & AMD, Dresden; NT-MDT. Ultramicroscopy 111, 1630 (2011)

NT-MDT Spectrum Instruments

TERS on periodic Thiols structure as a reference sample resolution ~10 nm

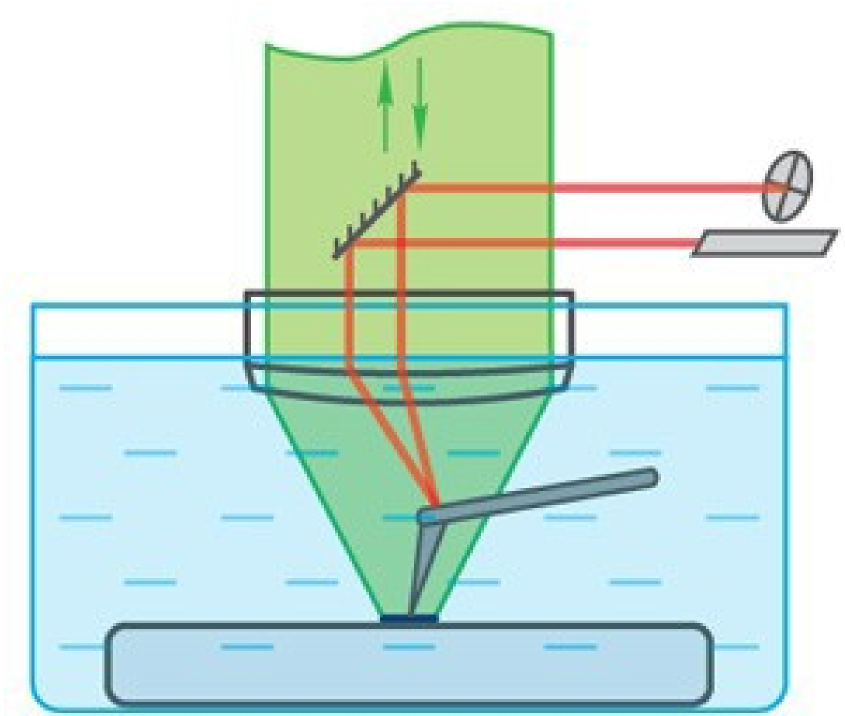


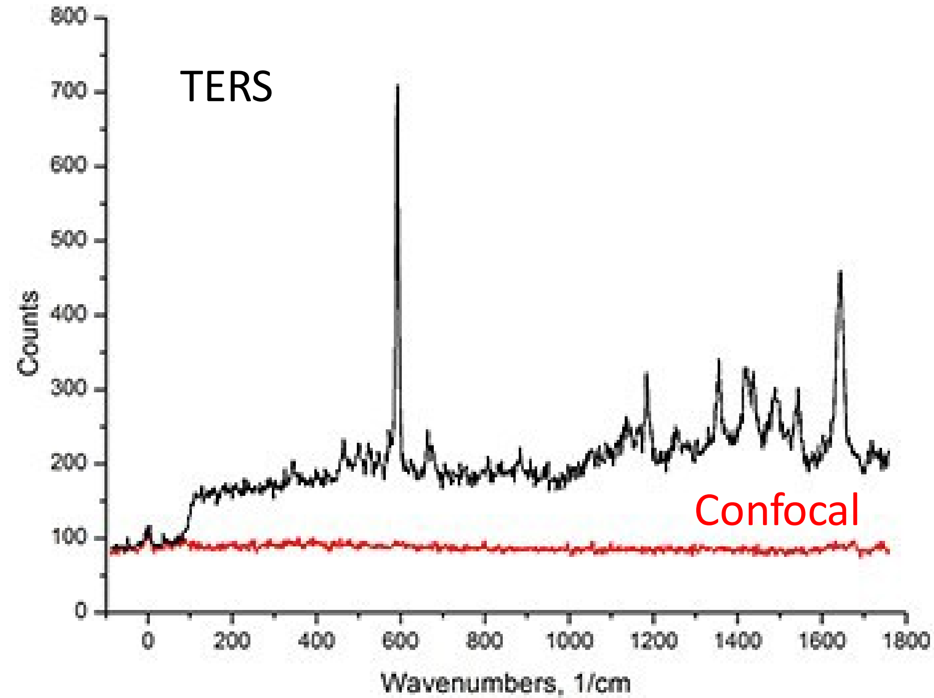


Sacco, A., Imbraguglio, D., Giovannozzi, A. M., Portesi, C. & Rossi, A. M. Development of a candidate reference sample for the characterization of tip-enhanced Raman spectroscopy spatial resolution. *RSC Adv.* **8,** 27863–27869 (2018)

NT-MDT Spectrum Instruments

TERS in the liquid environment, HD mode





In the experiment, in an optical AFM head a polarized exciting laser (λexc = 632.8 nm) was focused on the tip of the AFM TERS probe through a 60× immersion objective (working length: 2 mm) with a high numerical aperture (N.A. = 1).
The enhancement of Raman scattering signal was about 200x

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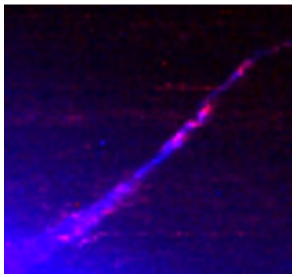
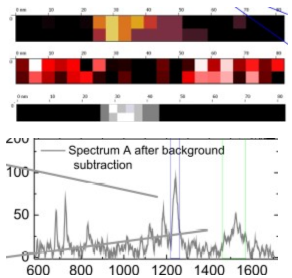
Spectrum Instruments

Tip Enhanced Raman Scattering

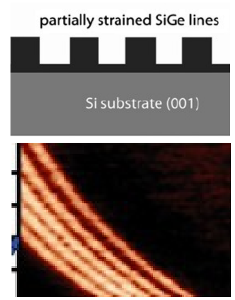
Various types samples. Proven by multiple publications by NT-MDT customers.



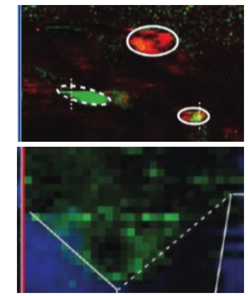
Carbon nanotubes
Resolution: ~10 nm
Nanotechnology, 2011
& ~10 other papers



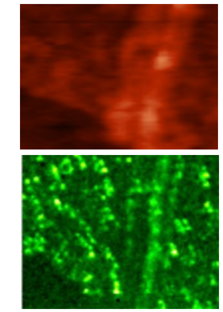
DNA molecule
Resolution: ~15 nm
Ang. Chem. Int., 2014,
E. Lipiec et. al



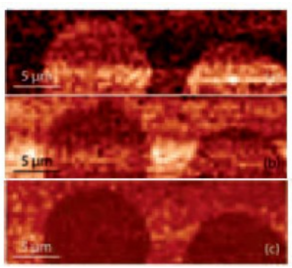
Si/SiGe structures
Resolution: <50 nm
Ultramicroscopy, 2011
P. Hermann et al.



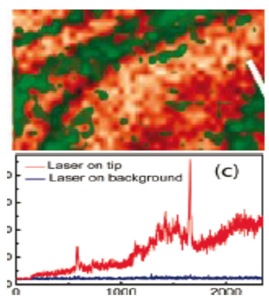
Graphene
Resolution: ~12 nm
ACS Nano, 2011
R. Zenobi et. al.



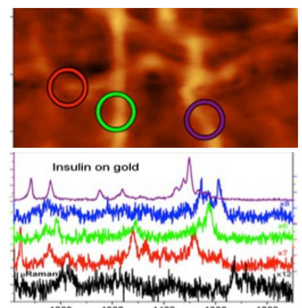
Graphene Oxide
Resolution: ~15 nm
A. Shelaev, et. al.,
2014



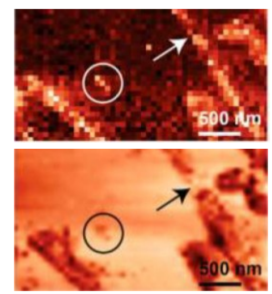
Thiol monolayers
Resolution: ~10 nm
Beilstein J. Nano, 2011
R. Zenobi et. al.



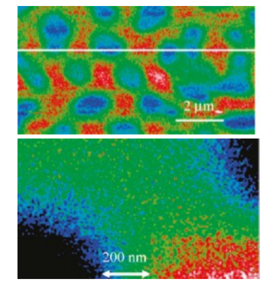
Thin molecular layers
Resolution: ~15 nm
NanoLett., 2010
R. Zenobi et. al.



Amyloid fibrils
Resolution: ~50 nm
Plasmonics, 2012
E. Di Fabrizio et. al.



Peptide nanotapes
Resolution: ~50 nm
ACS Nano, 2013
R. Zenobi et. al.

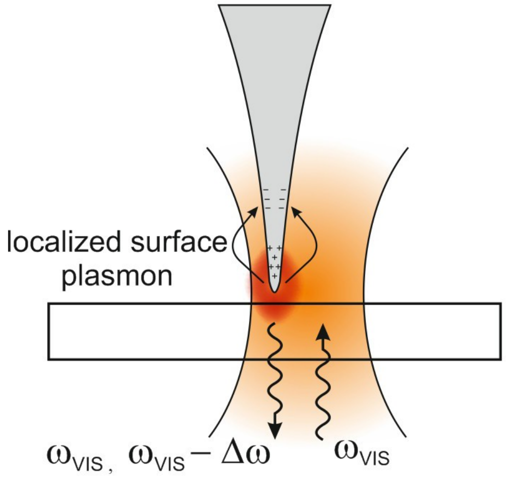


Polymers
Resolution: ~50 nm
Macromol., 2011
G. Hoffmann et al.

More than 100 publications.

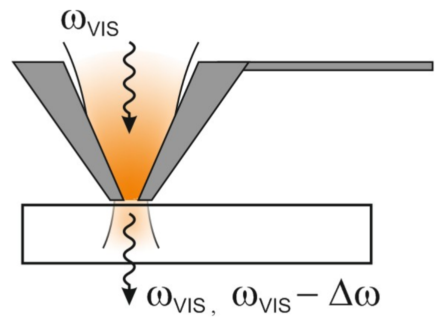
NT-MDT
Spectrum Instruments

Super-resolution imaging using scanning optical antennas



Tip enhanced near-field optical microscopy

Light localization and enhancement by localized surface plasmon



Aperture scanning near-field optical microscopy (SNOM)

Light transmission through non-resonant subwavelength aperture

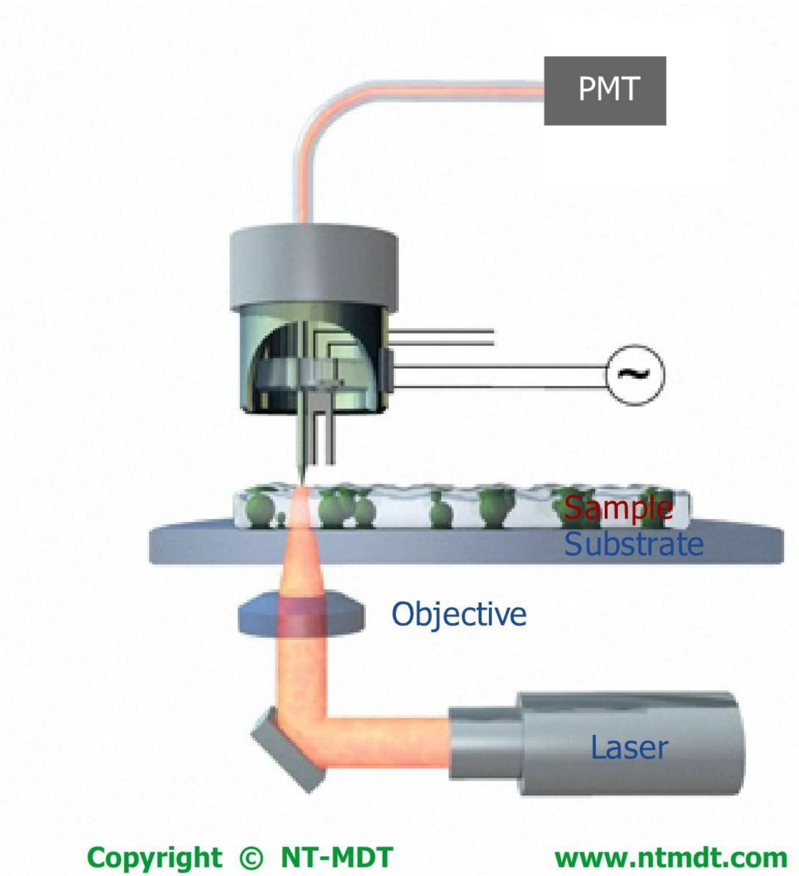
Optical antenna: a device designed to efficiently convert free-propagating optical radiation to localized energy, and vice versa.

- *L. Novotny, N. van Hulst, Nature photonics 5, 89 (2011)*
- *P. Bharadwai, B. Deutch, L. Novotny, Adv. In Opt. Phot. 1, 438 (2009)*
- *Pohl D. W., Optics, Principles and Applications (World Scientific, 2000).*

NT-MDT Spectrum Instruments

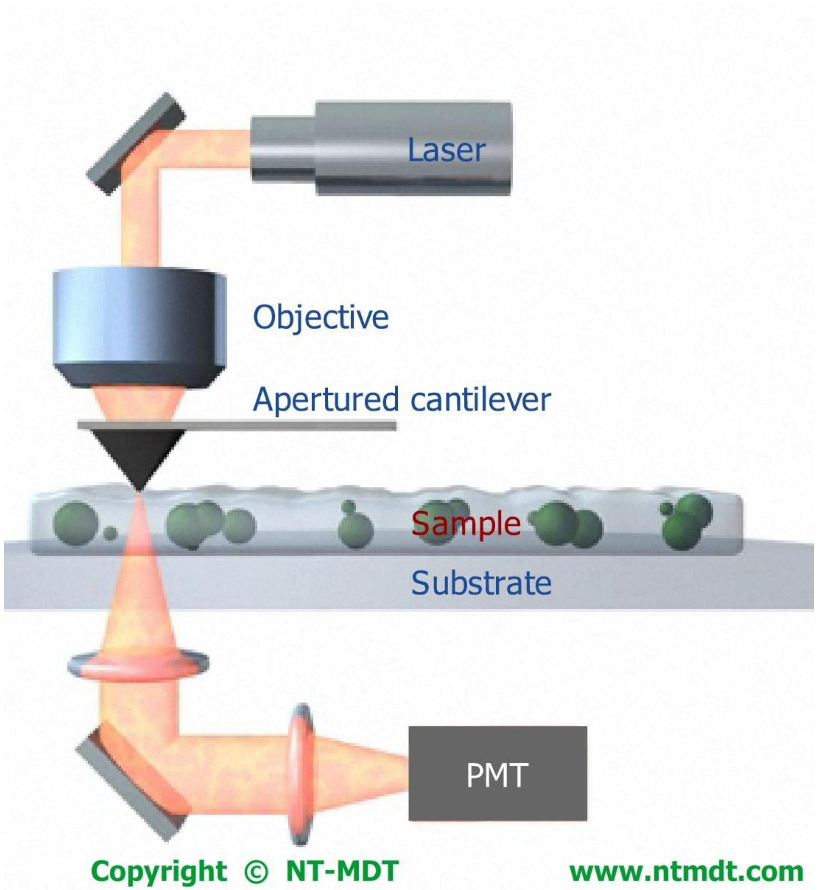
Two major types of SNOM

FIBER SNOM



Example shows
SNOM collection mode
(laser signal)

CANTILEVER SNOM



Example shows
SNOM Transmission mode
(laser signal)

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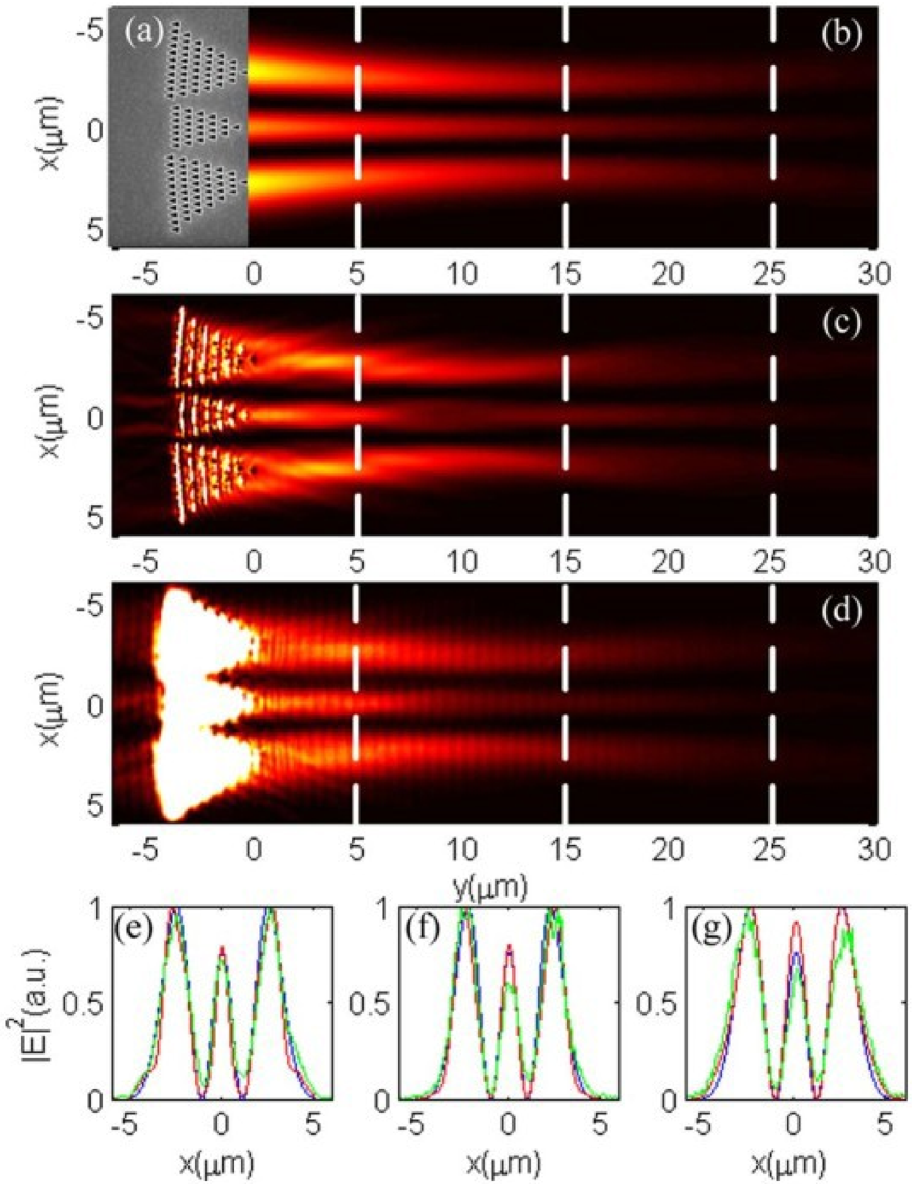
Generating unidirectional SPP beams



Required shape

Numerical simulation for calculated Delta-shape structures

Experiment, SNOM data

Profiles at different distances

You, O., Wang, Q., Bai, B., Wu, X. & Zhu, Z. A simple method for generating unidirectional surface plasmon polariton beams with arbitrary profiles. *Opt. Lett.* **40,** 5486 (2015).

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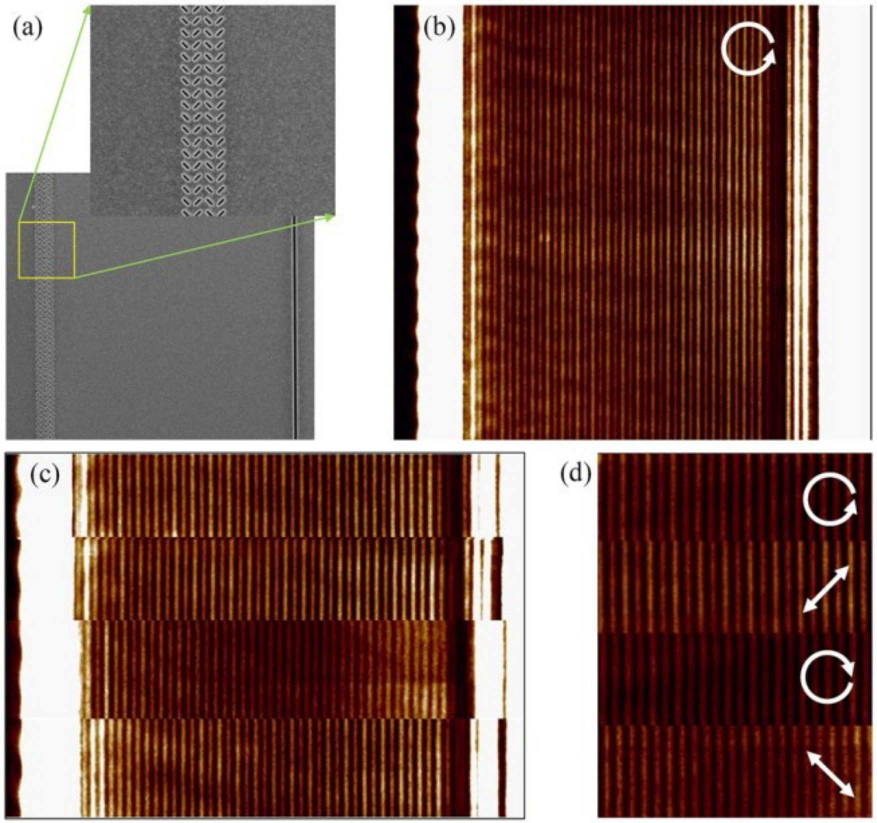
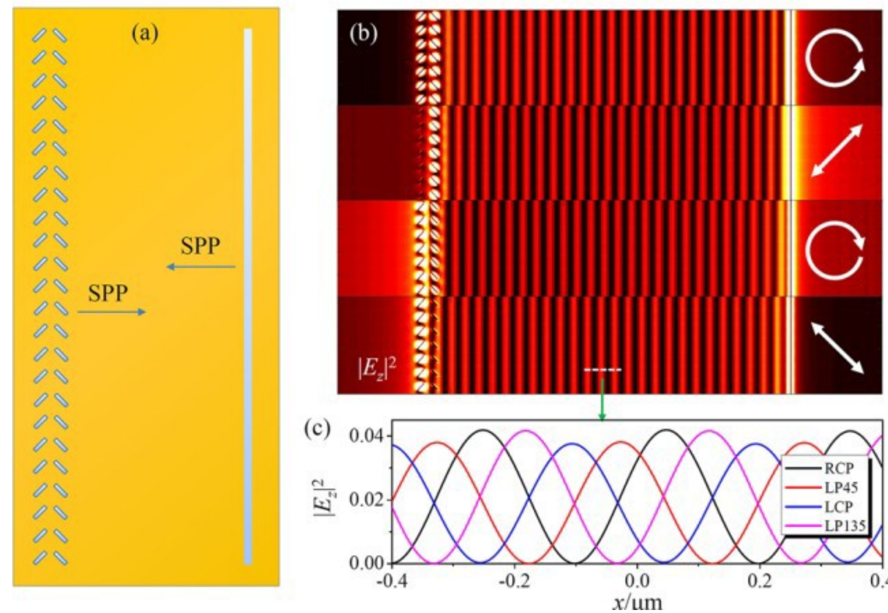
Plasmons Generation

Experiment, SNOM data

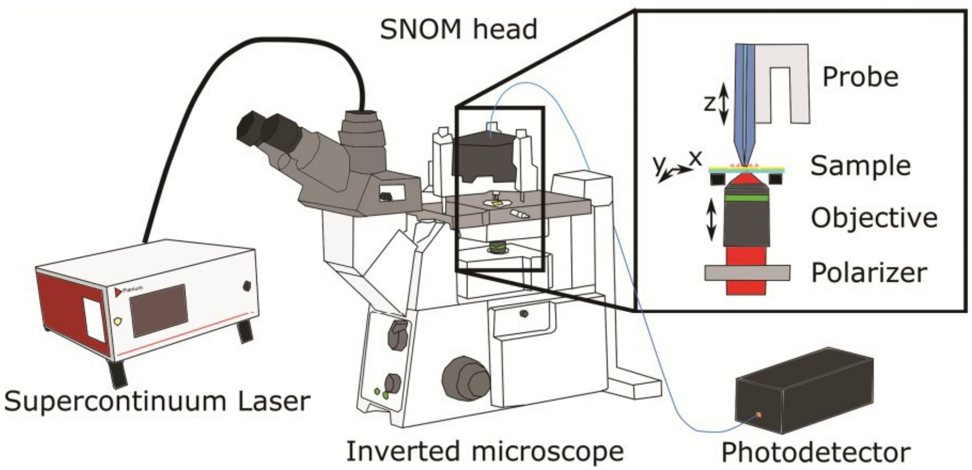


Simulation

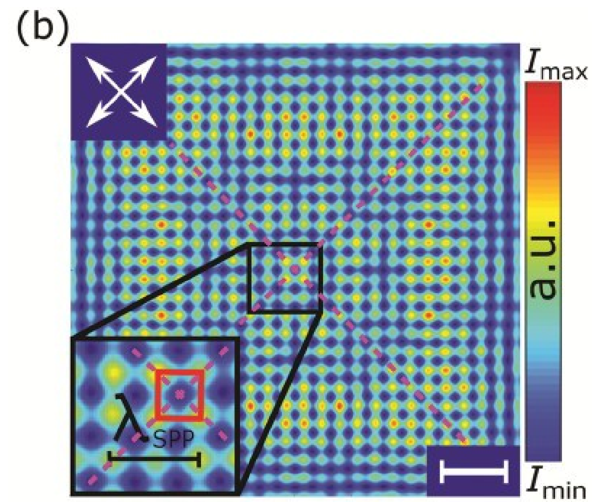


Zhang, C. *et al.* Polarization-to-Phase Coupling at a Structured Surface for Plasmonic Structured Illumination Microscopy. *Laser Photonics Rev.* **12,** 1–7 (2018).

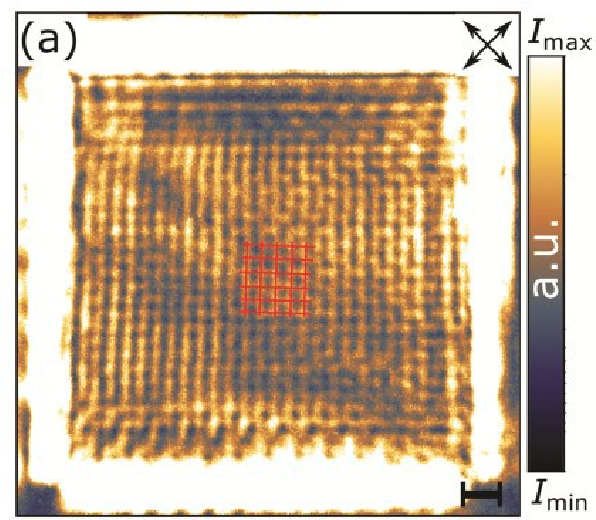
SPP interference studied by SNOM

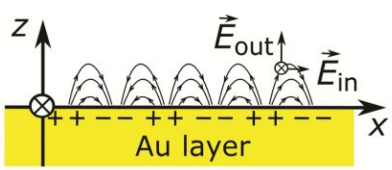


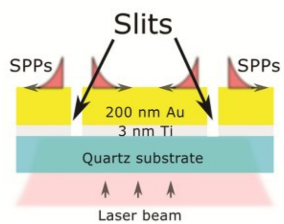
Numerical simulation

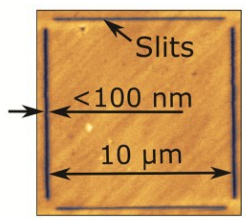


Experiment









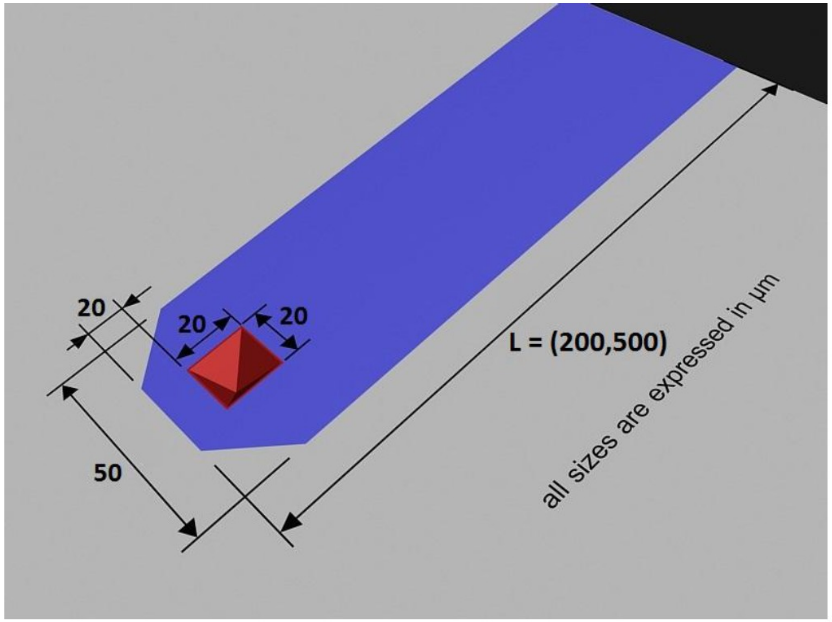
Kvapil, M. *et al.* Imaging of near-field interference patterns by aperture-type SNOM – influence of illumination wavelength and polarization state. *Opt. Express* **25,** 16560 (2017).

NT-MDT Spectrum Instruments

NT-MDT cantilever SNOM: contact AND non-contact probes

Probe	Resolution	TR@ 473
1 contact	150 nm	~3*10-4
1 contact	???	0.3*10-4
1 noncontact	110 nm	~0.16*10-4
2 noncontact	120 nm	~0.5*10-4
3 noncontact	135 nm	~0.7*10-4
4 noncontact	100 nm	~0.2*10-4
5 noncontact	150 nm	~1.6*10-4

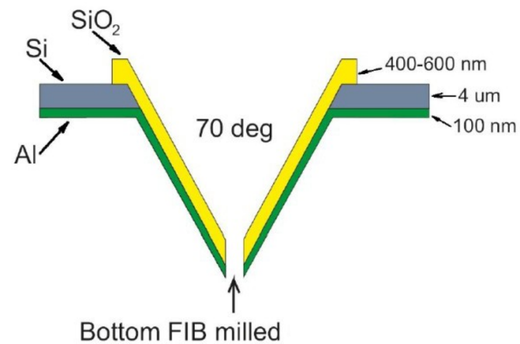
1) Lever sizes and the pyramid position:



Pyramid LxWxH = 20x20x13 (70 deg)

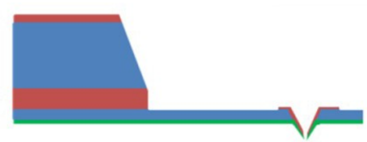
	Spring Constant (N/m)			Frequency (kHz)			Length (micron)			Width (micron)			Thickness (micron)		
	Nominal	Min	Max	Nominal	Min	Max	Nominal	Min	Max	Nominal	Min	Max	Nominal	Min	Max
NonContact	16.5	5.9	39.0	130	88	180	200	190	210	55	54	57	4	3	5
Contact	1.01	0.41	2.30	20.8	15	27	500	490	510	55	54	57	4	3	5

2) Tip shape and aperture size:



Pyramid (SiO2) thickness 400-600 nm

3) Coating: Al, about 100 nm, coating from bottom side. Bottom FIB milling is done after coating. Typical aperture diameter about 170 ±25nm.



Al deposition on tip side
FIB from pit side

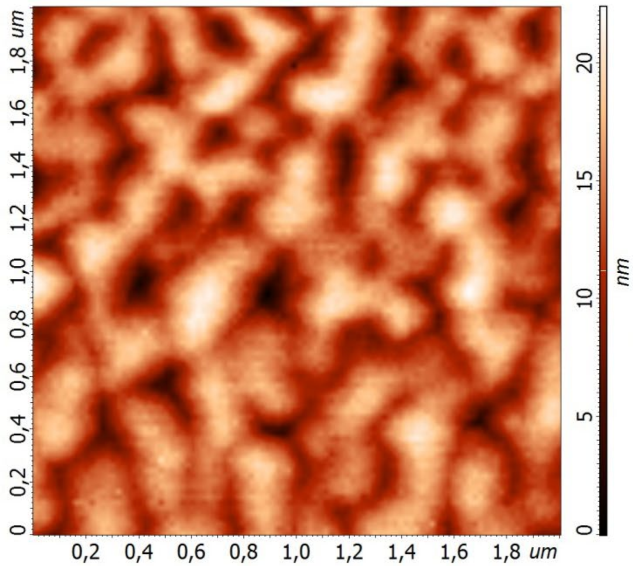
NT-MDT Spectrum Instruments

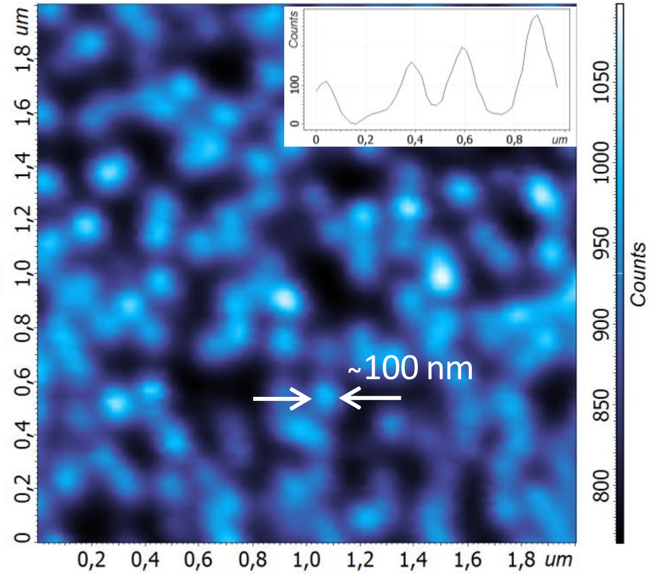
SNOM of InP/GaInP quantum dots with GaInP cap layer

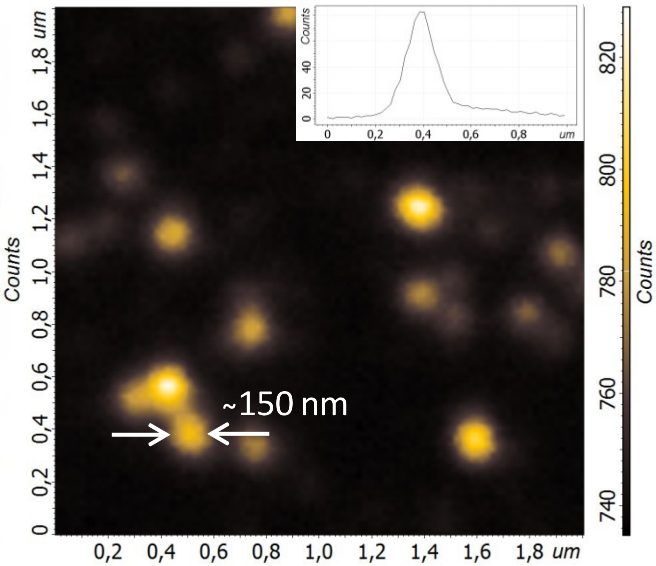
AFM Topography

PL SNOM, 700-770 nm

PL SNOM, 800-810 nm







Cap layer only (QDs not visible)

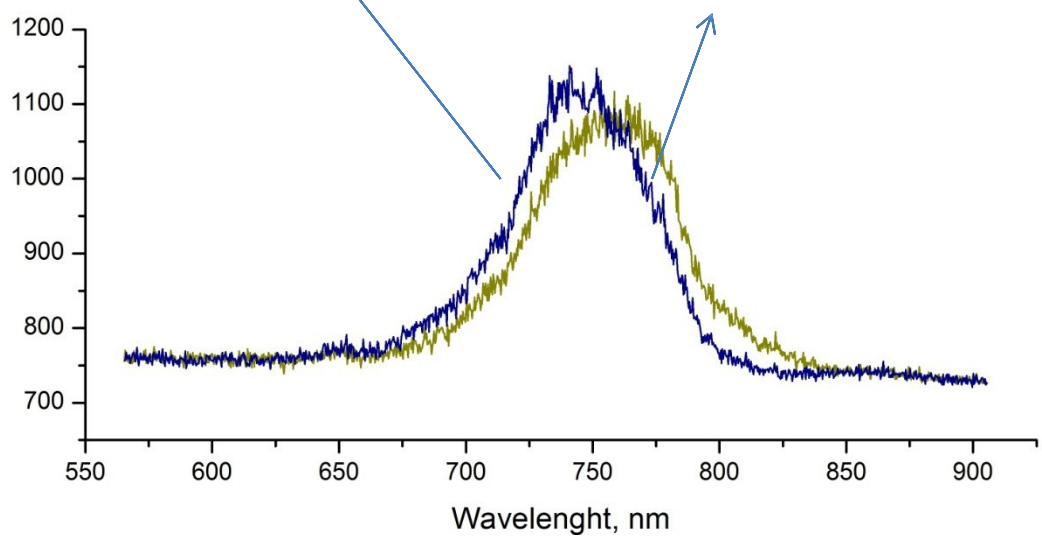
20-50 nm dia. QDs

100-200 nm dia. QDs

2x2 µm scans

Simultaneously obtained topography (left) and SNOM maps of photoluminescence (PL) in 700-770 nm (center) and 800-810 nm (right) spectral regions. 100x100 pixels, 0.1 s/point

Images obtained by cantilever based SNOM in with excitation and collection via the same SNOM aperture

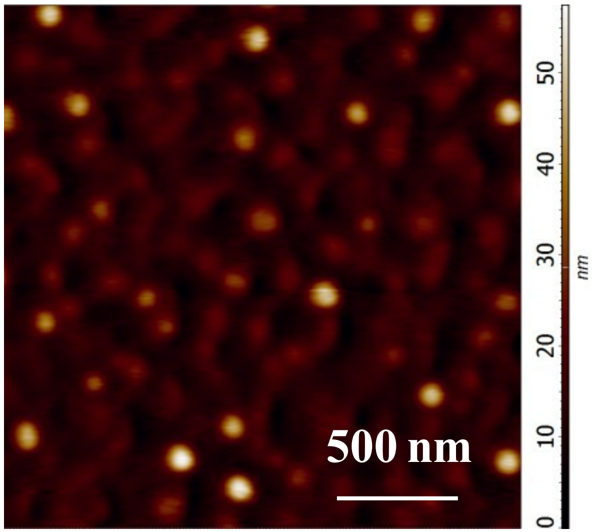


A. Mintairov, A. Ankudinov, A. Shelaev, P. Dorozhkin, Ioffe Institute & NT-MDT, 2016

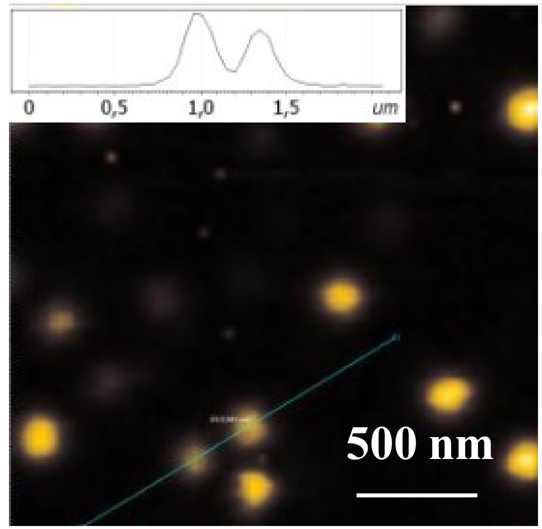
NT-MDT Spectrum Instruments

QD SNOM spectroscopy and topography

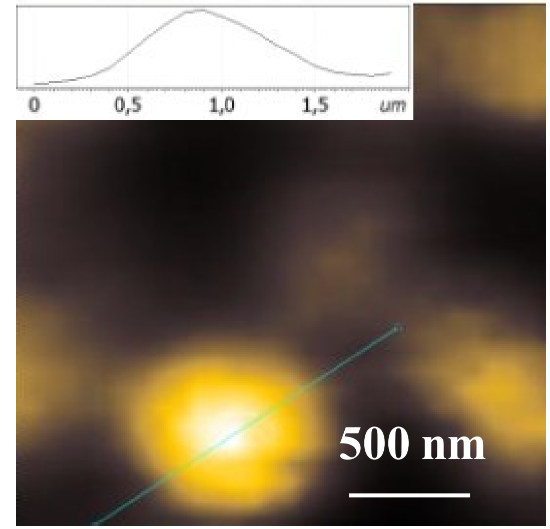
AFM Topography

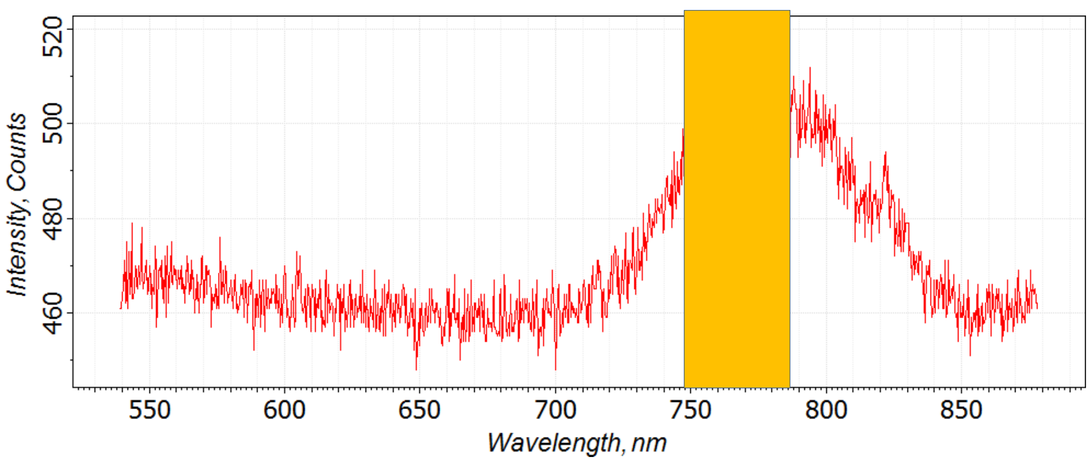


SNOM PL, 750-780 nm



Confocal map, 750-780 nm





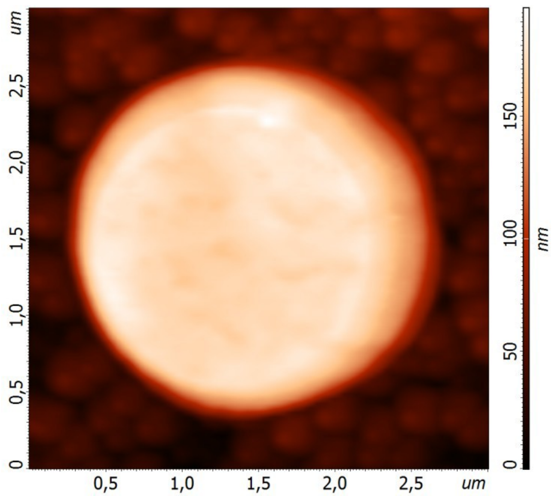
3x3 µm scans

Simultaneously obtained topography (left) and SNOM maps of photoluminescence (PL) in 750-780 nm band (center) and confocal map with the same spectral band (right). 100x100 pixels, 0.1 s/point. Images obtained by cantilever based SNOM in with excitation and collection via the same SNOM aperture. AFM tapping mode used.

Shelaev A. V., Mintairov A. M., Dorozhkin P. S., and Bykov V.A. Scanning near-field microscopy of microdisk resonator with InP/GaInP quantum dots using cantilever-based probes // J. Phys. Conf. Ser. 2016. Vol. 741. P. 12132.

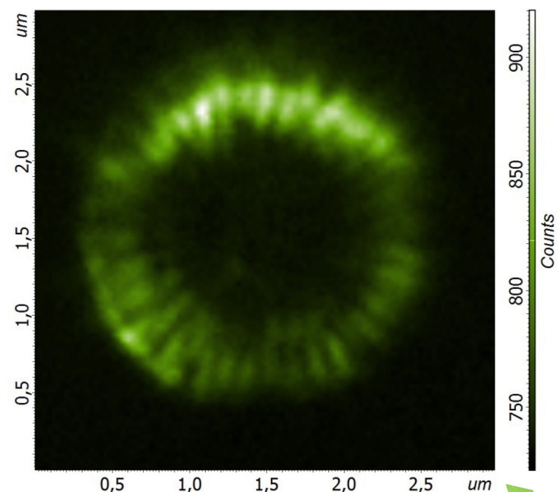
Whispering gallery light modes in microdisks with InP/GaInP self-organized quantum dots

Topography



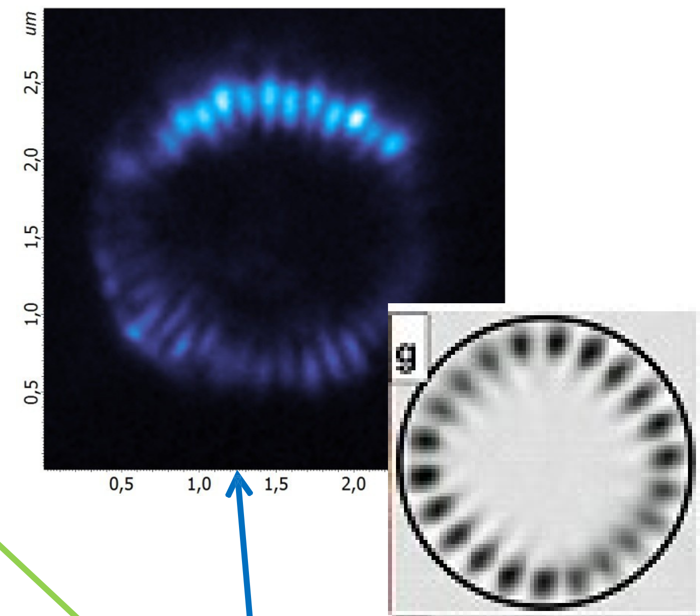
SNOM PL, 732-735 nm

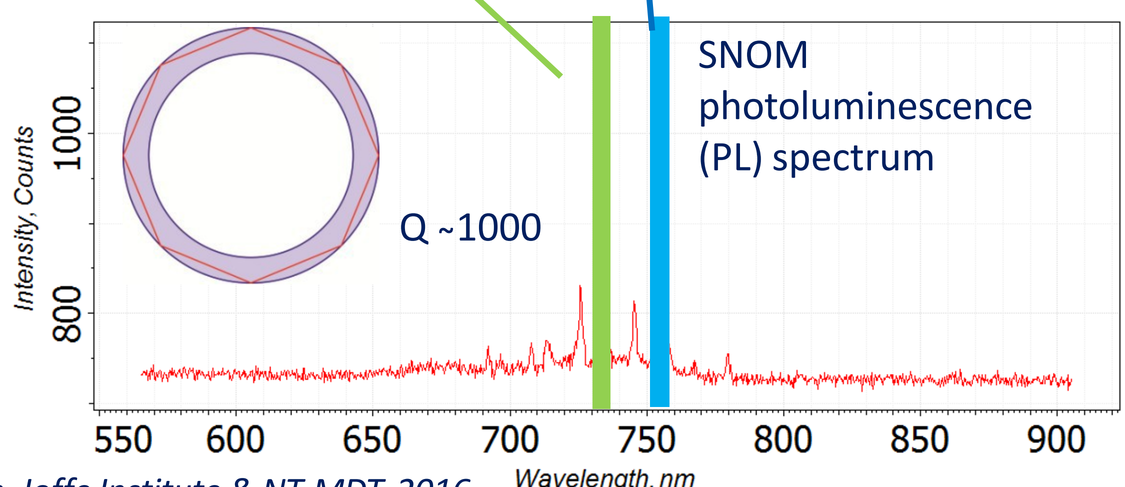
TE_{20} mode



SNOM PL, 753-757 nm

TE_{18} mode





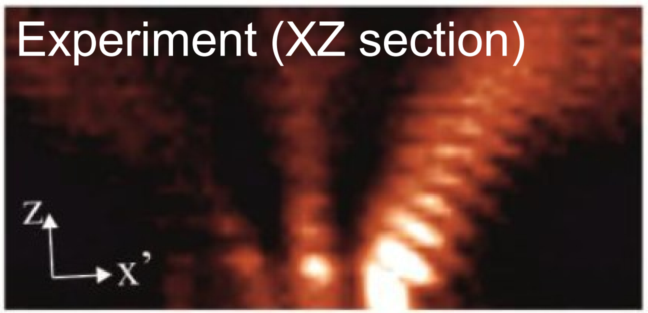
Simultaneously obtained topography (left) and SNOM maps of light whispering gallery modes in the ranges 753-757 nm band (center) and 732-735 nm (right). 100x100 pixels, 0.1 s/point

Images obtained by cantilever SNOM with side illumination

A. Mintairov, A. Ankoudinov, A. Shelaev, P. Dorozhkin, Ioffe Institute & NT-MDT, 2016

Laser emission in 3D studied by SNOM

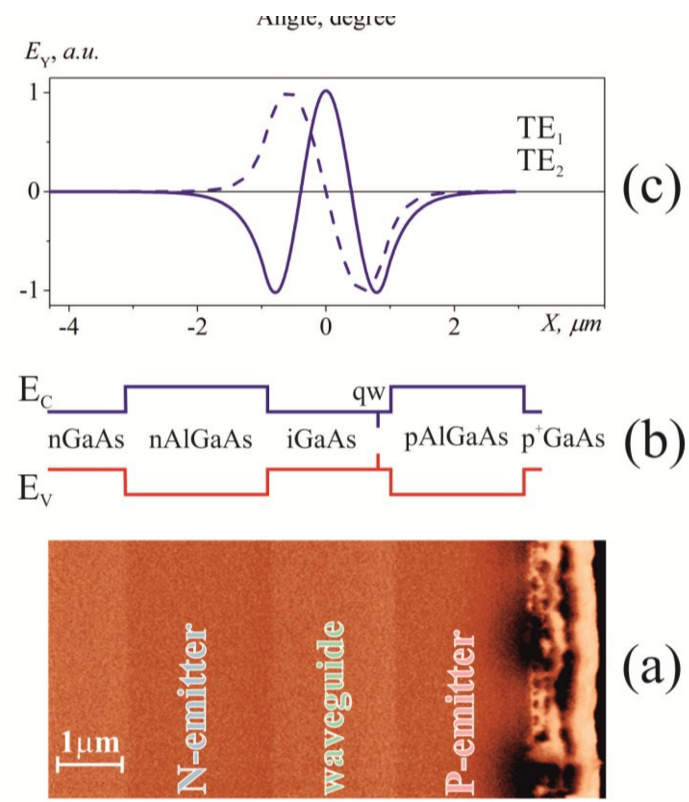
Cantilever SNOM operation at near IR region (~1.1 μm)



Far field (propagating e-m radiation)

Surface (near field)

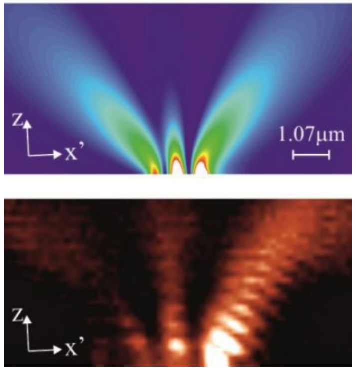
Surface (near field)



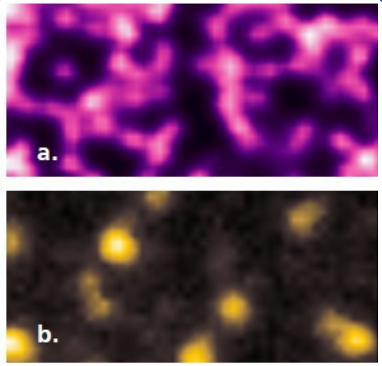
A.V. Ankudinov, P.S. Dorozhkin, A.A. Podoskin, A.V. Shelaev, S.O. Slipchenko, I.S. Tarasov, M.L. Yanul
Ioffe Physical Institute; NT-MDT Co. & ITMO

NT-MDT Spectrum Instruments

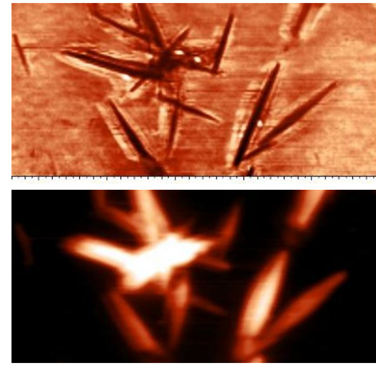
Aperture SNOM applications (NT-MDT instrumentation)



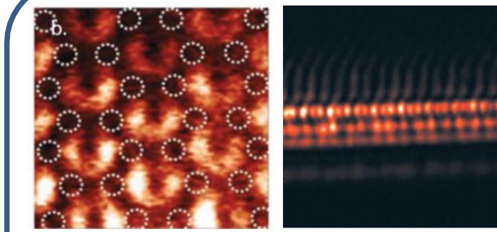
Lasers



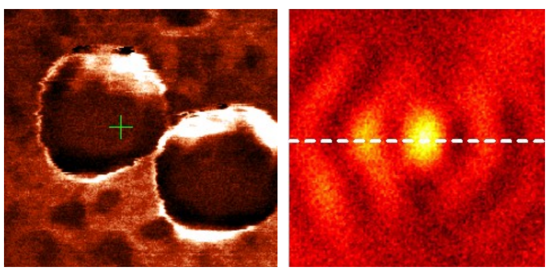
Quantum dots



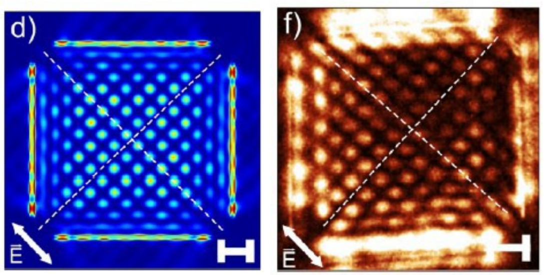
Polymers



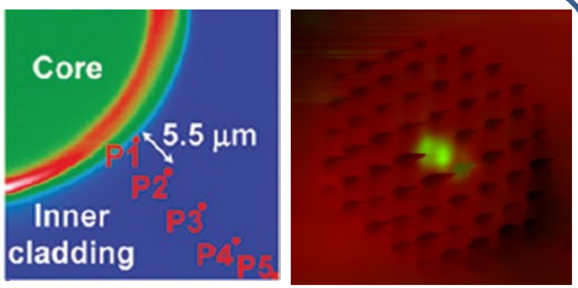
Photonic crystals



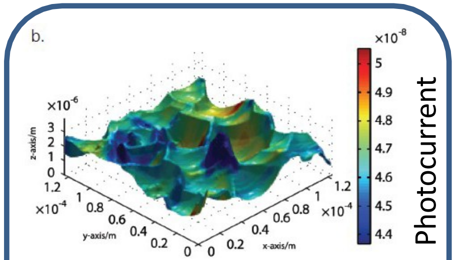
E-m field in plasmonic structures



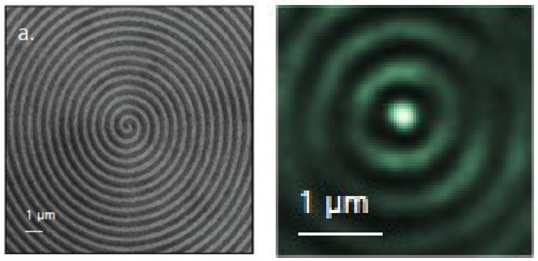
Surface plasmon polaritons



Optical fibers



Photovoltaics



Optical micro-devices

Physical and chemical characterization at the nanoscale: experimental approaches utilizing AFM probe

➢ Co-localized AFM-Raman

- Comprehensive simultaneous physical (AFM) and chemical (Raman) sample characterization.
- Spatial resolution: AFM - ~1 nm; Raman - ~200-400 nm.
- Various excitation and collection geometries.

Controlled environment: liquid, gases, temperature, electrochemistry, magnetic field

➢ Tip Enhanced Raman Scattering (TERS)

- Signal enhancement for weakly scattering samples.
- ~10 nm spatial resolution in Raman (chemical) imaging.
- Graphene and other carbon nanomaterials, polymers, thin molecular layers, semiconductor nanostructures, biological structures, DNA molecules etc.
- Advances in production of reproducible TERS probes (STM, tuning fork, AFM cantilevers).

➢ Aperture scanning near-field optical microscopy (SNOM)

- ~ λ/10 spatial resolution (~100 nm for NIR).
- Advances in cantilever SNOM manufacturing: contact & non-contact probes, improved signal collection efficiency.
- Plasmonics and nanophotonics structures, metamaterials, lasers, optical fibers, photovoltaics, QDs, etc.

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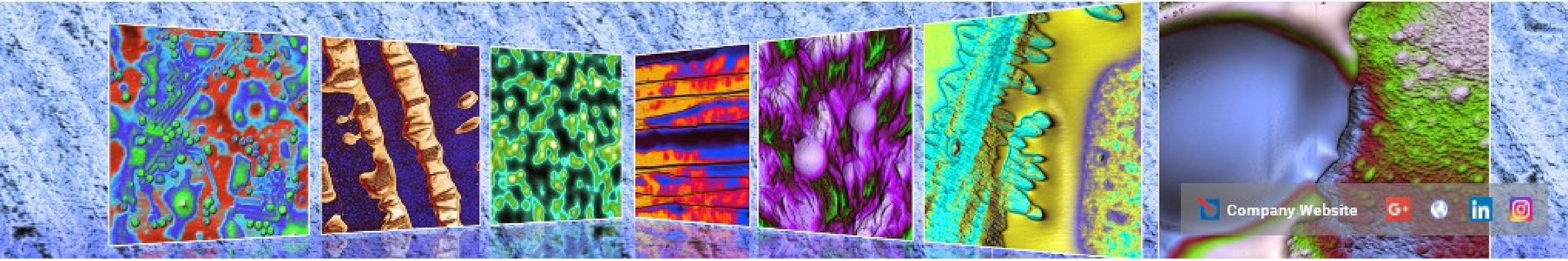
Thank you for your attention!

www.ntmdt-si.com



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