ИССЛЕДОВАНИЕ УГЛЕРОДНЫХ МАТЕРИАЛОВ МЕТОДАМИ СКАНИРУЮЩЕЙ ЗОНДОВОЙ МИКРОСКОПИИ И СПЕКТРОСКОПИИ ВЫСОКОГО ПРОСТРАНСТВЕННОГО РАЗРЕШЕНИЯ

09 Августа 2019

В.А. Быков

Группа компаний НТ-МДТ Спектрум Инструментс, Москва

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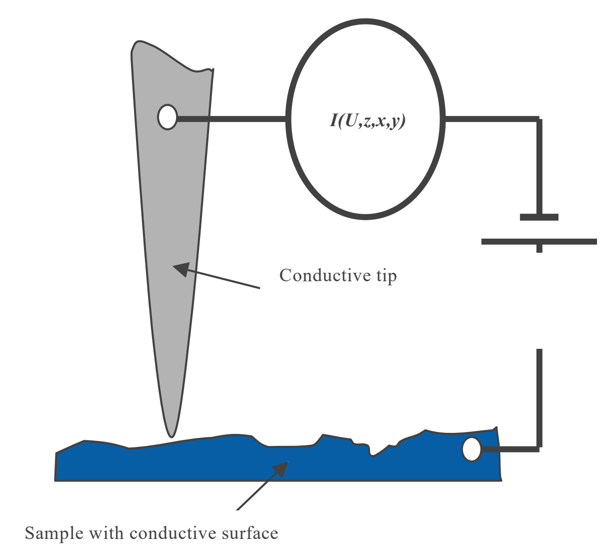
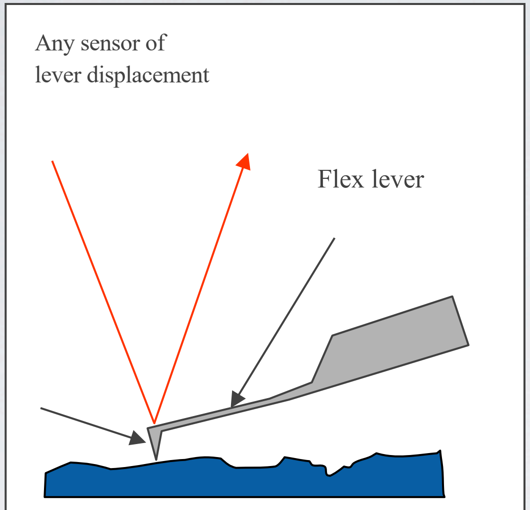
НАНОтехнологическое общество России
Общероссийская общественная организация

NT-MDT Spectrum Instruments

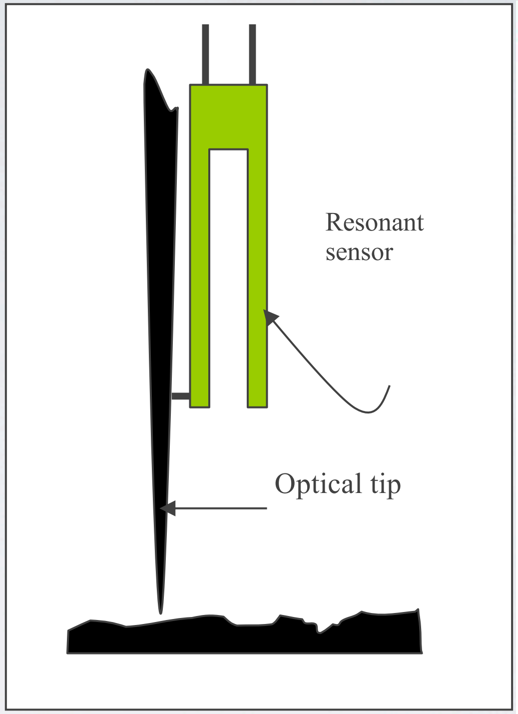
Scanning Probe Microscopy (SPM)



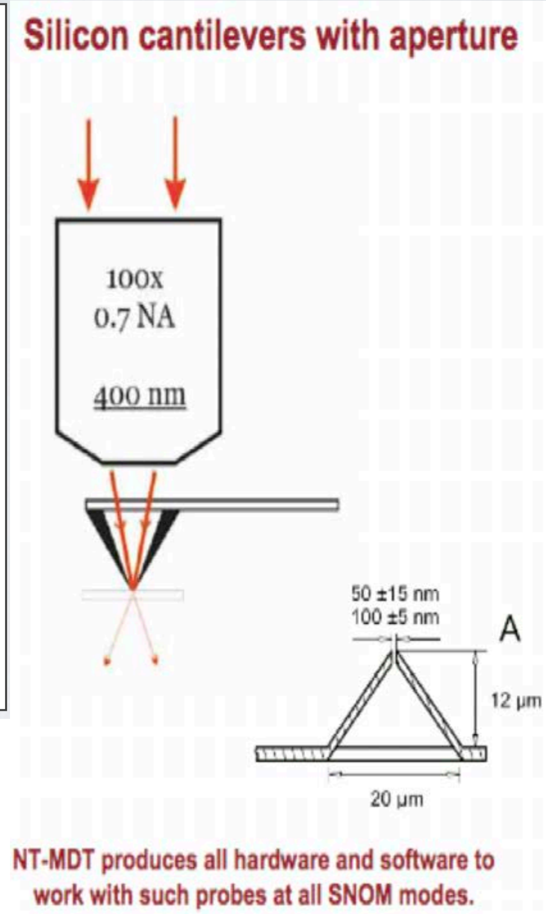
Scanning Tunneling Microscopy
Conductive samples

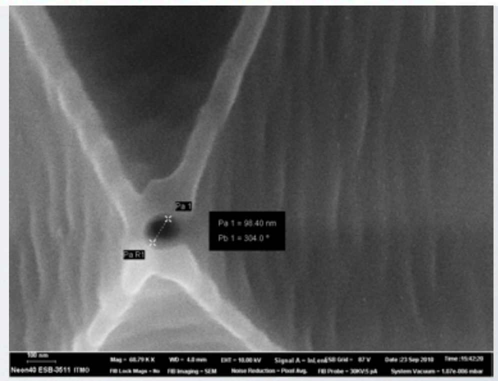


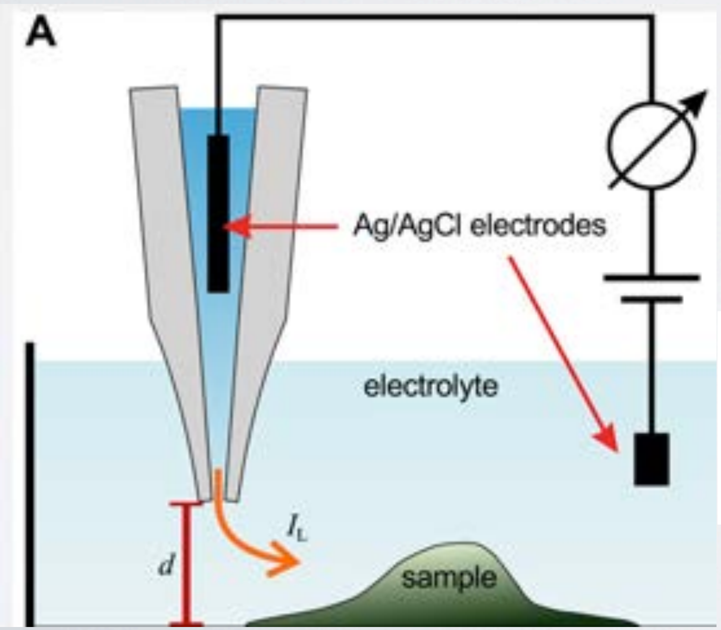
Atomic Force Microscopy
Any solid surfaces



Aperture
Scanning Near-Field Microscopy
Optical properties



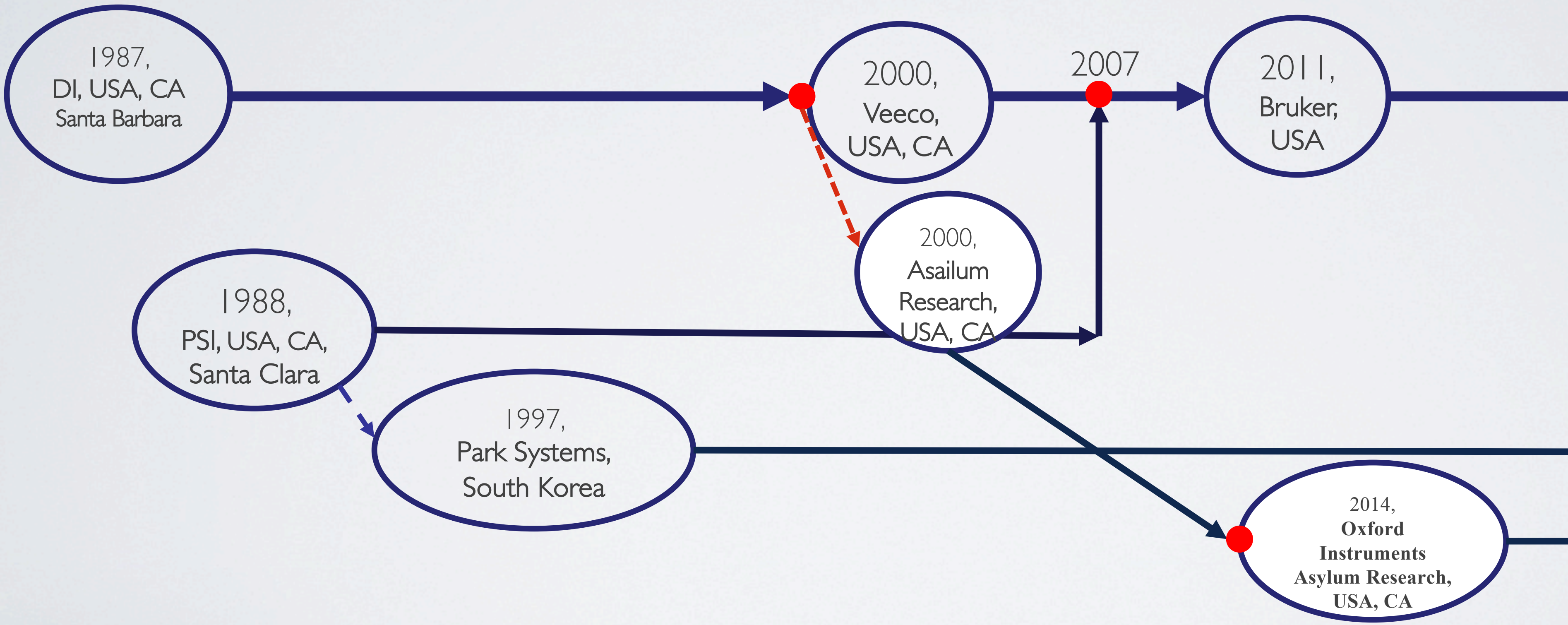




Scanning Electrochemical Capillary Microscopy,
I – 10^{-9}-10^{-15}

1966 - 1981 – Изобретение СТМ, Рассел Янг (1966), Герд Бинниг, Герберд Рорер (1979), Эрнст Руска (ЭМ)
Нобелевская премия за изобретение туннельной и электронной микроскопии 1986)
1986 – Изобретение АСМ (Герд Биниг, Кристофер Гербер, Кельвин Куэйт)

In 1987, while on sabbatical, Vergil Elings co-founded Digital Instruments (DI), which bec
the world's leader in the design and manufacture of Scanning Probe Microscopes (SPMs



Global Atomic Force Microscopes (AFM) Market Insights, Forecast from 2018 to 2025

Chapter Eight Manufacturers Profiles

8.1 Bruker Corporation

8.2 JPK Instruments

8.3 NT-MDT SI

8.4 Keysight Technologies

8.5 Park Systems

8.6 Witec

8.7 Asylum Research(Oxford Instruments)

8.8 Nanonics Imaging

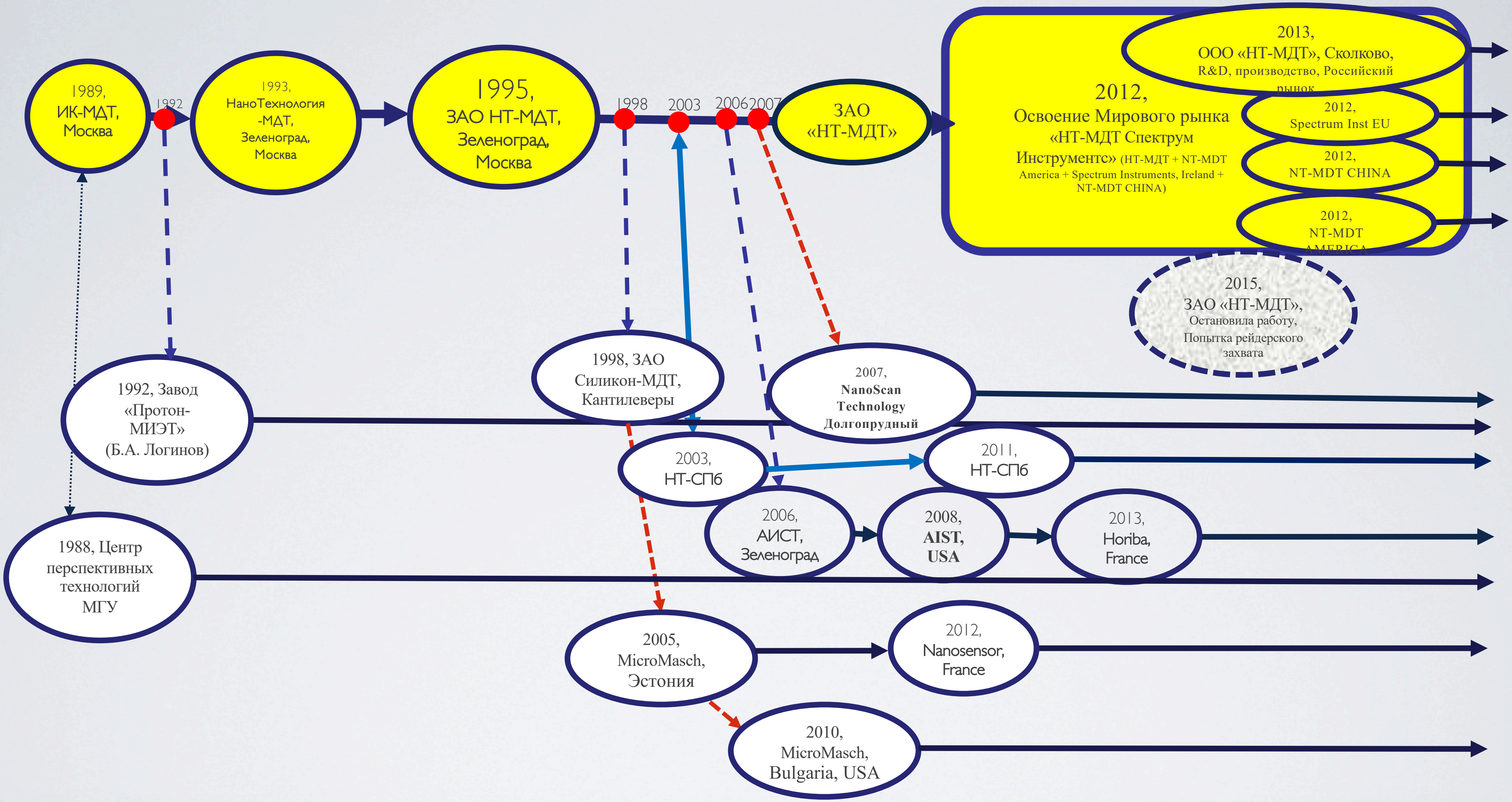
8.9 Nanosurf

8.10 Hitachi High-Technologies

8.11 Anasys Instruments

8.12 RHK Technology

8.13 A.P.E. Research



1989, ИК-МДТ, Москва
1992
1993, НаноТехнология -МДТ, Зеленоград, Москва
1995, ЗАО НТ-МДТ, Зеленоград, Москва
1998
2003
2006
2007
ЗАО «НТ-МДТ»
2012, Освоение Мирового рынка «НТ-МДТ Спектрум Инструментс» (НТ-МДТ + NT-MDT America + Spectrum Instruments, Ireland + NT-MDT CHINA)
2013, ООО «НТ-МДТ», Сколково, R&D, производство, Российский
2012, Spectrum Inst EU
2012, NT-MDT CHINA
2012, NT-MDT
2015, ЗАО «НТ-МДТ», Остановила работу, Попытка рейдерского захвата
1992, Завод «Протон-МИЭТ» (Б.А. Логинов)
1998, ЗАО Силикон-МДТ, Кантилеверы
2007, NanoScan Technology Долгопрудный
2003, НТ-СПб
2011, НТ-СПб
2006, АИСТ, Зеленоград
2008, AIST, USA
2013, Horiba, France
1988, Центр перспективных технологий МГУ
2005, MicroMasch, Эстония
2012, Nanosensor, France
2010, MicroMasch, Bulgaria, USA

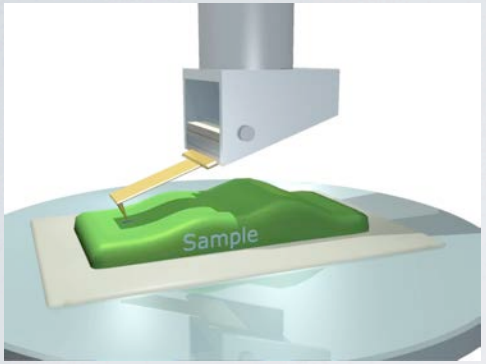
NT-MDT Spectrum Instruments

НТ-МДТ Спектрум Инструментс

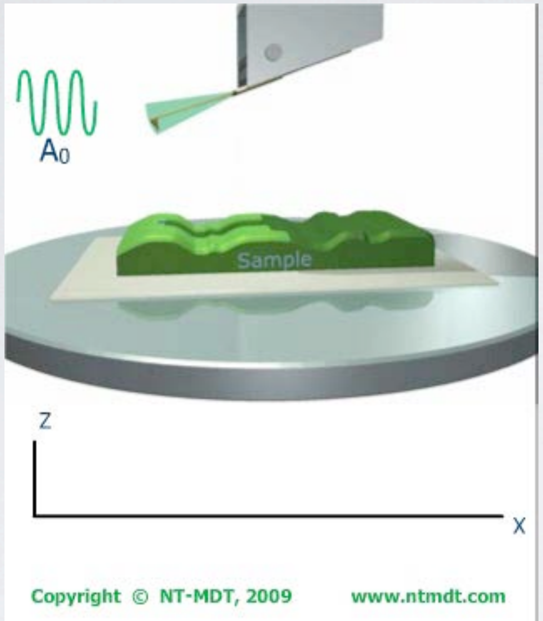
НАНОТЕХНОЛОГИЧЕСКОЕ ОБЩЕСТВО РОССИИ

Коллектив разработчиков – самый опытный на мировом рынке – опыт работы с 1989 года

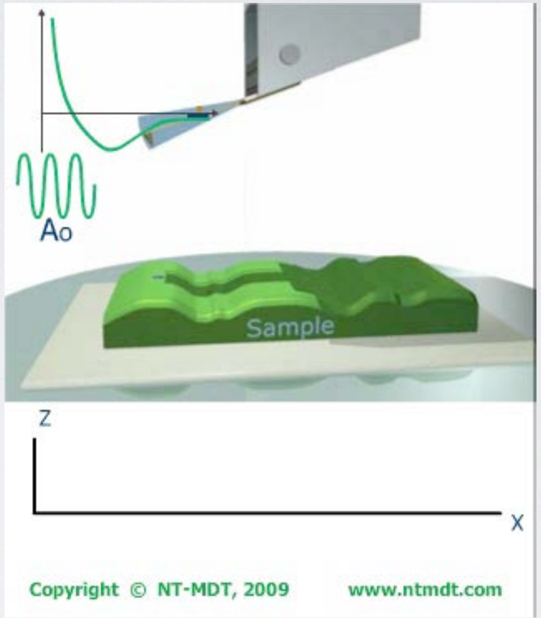
In modern SPM more than 40 different modes of studying the surface



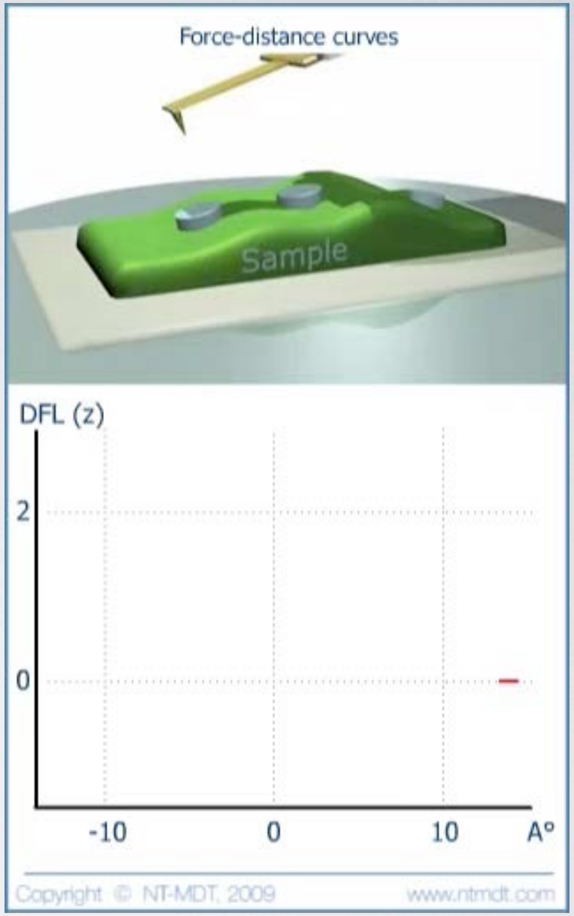
Contact AFM mode



Semicontact SPM –
Tapping mode



Noncontact SPM mode



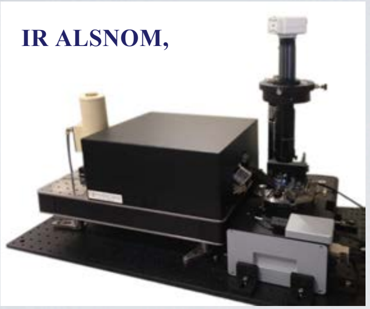
Scanning Force spectroscopy – Hybrid (PeakForce) mode

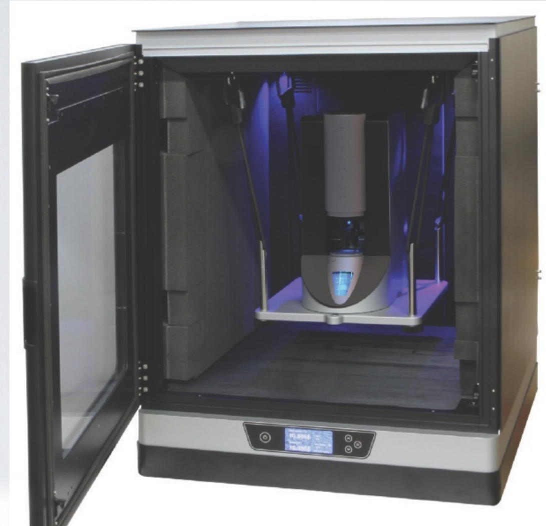
Research environments: Air, controlled atmosphere, liquids, electrolytes, vacuum from 10^{-3} to 10^{-11} torr

СЗМ – комплексный анализ поверхностных структур

- Туннельная микроскопия и спектроскопия;
- Профиль поверхностных структур и его зависимость от давления прижима;
- Неоднородность силы трения в системе зонд – поверхность;
- Неоднородность адгезионных сил;
- Распределение поверхностного потенциала (Кельвин-мода);
- Распределение электрической емкости в системе кантилевер –поверхность;
- Распределение теплопроводности;
- Распределение модуля Юнга;
- Диагностика пределов упругой деформации;
- Распределение магнитных сил;
- Распределение пьезоэлектрических характеристик поверхностных структур;
- Распределение оптических свойств поверхности в видимой (спектроскопия комбинационного рассеяния с пространственным разрешением до 10 нм) и ИК области спектра с разрешением значительно превышающим дифракционные ограничения (ближнепольная беаппертурная оптическая микроскопия);
- Безапертурная ИК и терагерцовая спектроскопия с пространственным разрешением до 10 нм – качественный анализ поверхности;
- Возможность модификации поверхности с созданием и исследованием свойств наноструктур

NT-MDT Spectrum Instruments Product Line

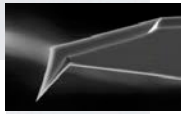


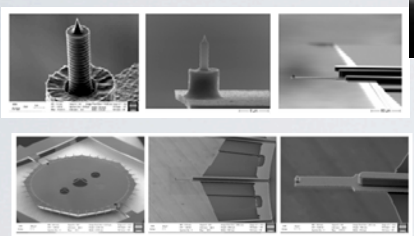


ТИТАНИУМ 2016

ИНТЕГРА-СПЕКТРА-4Р

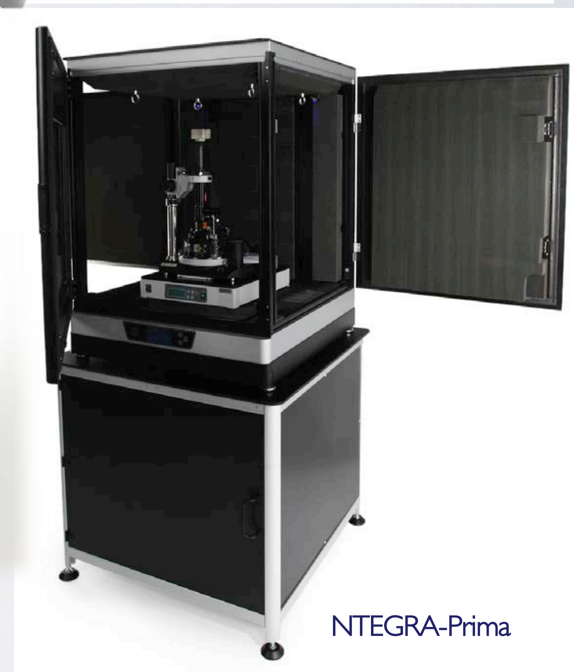
polySi-Technology, R_c- 3-5 nm





Новые типы кантилеверов (2015 -2016 г.г.)

SOLVER-Pipe -2017



NTEGRA-Prima

NT-MDT Spectrum Instruments

NT-MDT Spectrum Instruments

Образовательный проект СТАРТ

15-03-1930 – 01-03-2019

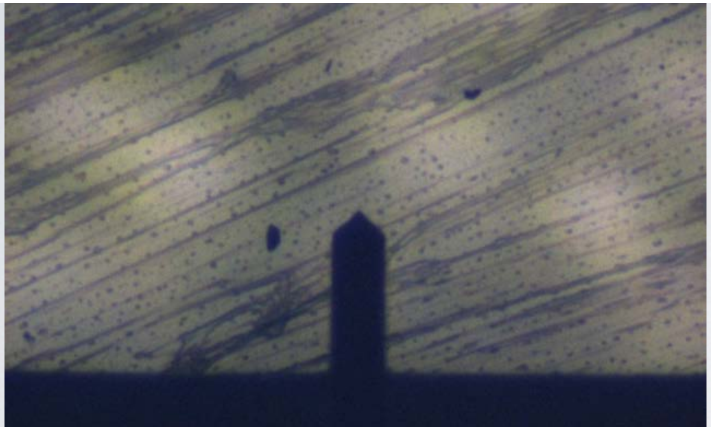
Инициатором проекта по использованию сканирующих зондовых микроскопов в школах, колледжах, высших учебных заведениях был лауреат Нобелевской премии по физике Жорес Иванович Алферов. Идея оказалась жизнеспособной и популярной.

Разработки приборов начались с 2002 года. Последовательно было выпущено три поколения приборов этого типа. Уже вторая версия приборов – НАНОЭДЬЮКАРОР-II вошла в сотню лучших мировых разработок.

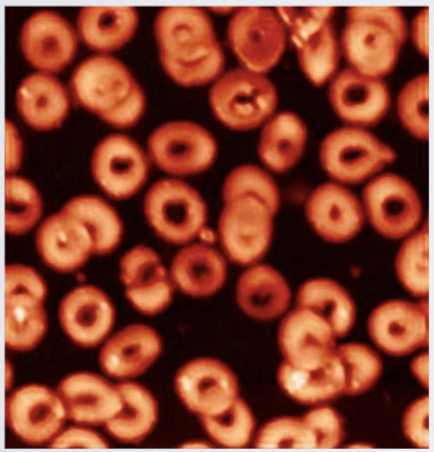
Учебно-исследовательский лабораторный комплекс НАНОЭДЮКАТОР
установлен в более чем 80 ВУЗах, и 320 школах в России и за рубежом.

В настоящее время создан 3-й вариант этих приборов с мощным интеллектуальным наполнением на базе алгоритмов искусственного интеллекта, позволяющий сосредоточить внимание учащихся не на методике и приборе, а на предмете исследования исследования – биологических препаратах клеток, вирусов, молекул. На свойствах исследуемых материалов.

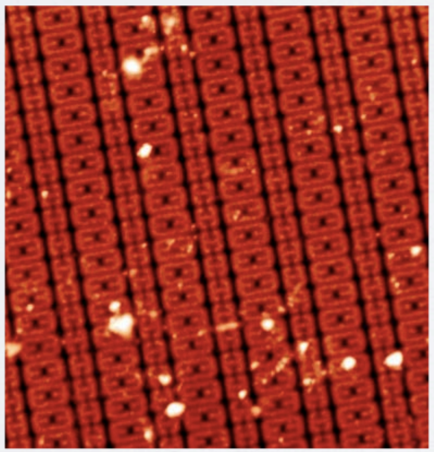
Солвер-НАНО – новая генерация НАНОЭДЬЮКАТОРА -Бюджетный сканирующий зондовый микроскоп с развитыми опциями туннельной и атомно-силовой микроскопии



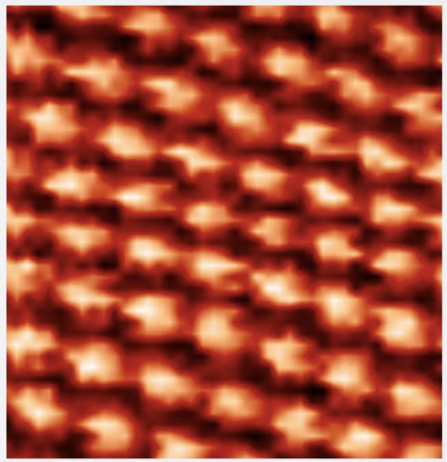
Оптика высокого разрешения (0,5 мкм).



Human erythrocytes, AFM
scan size 50×50 μm

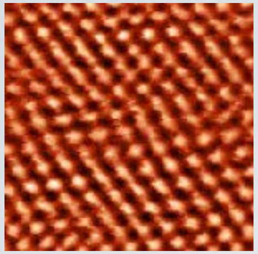


IC, AFM
scan size 30×30 μm

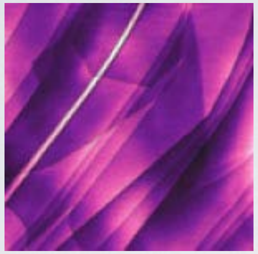


HOPG, atomic resolution, STM
scan size 2×2 nm

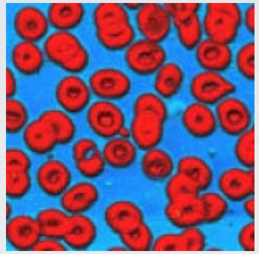
NT-MDT
Spectrum Instruments



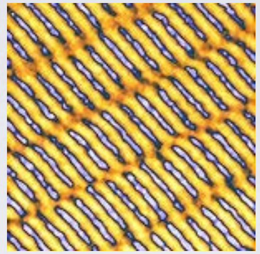
Атомная решетка ВОПГ.
Размер скана 4×4 нм.
Контактная латеральная АСМ



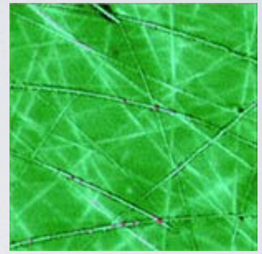
Атомные слои на графите.
Размер скана 1.8×1.8 мкм.
АМ АСМ



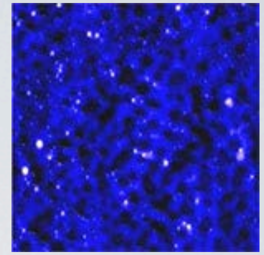
Клетки крови.
Размер скана 50×50 мкм.
АМ АСМ



Магнитные домены НЖМД.
Размер скана 30×30 мкм.
АМ МСМ

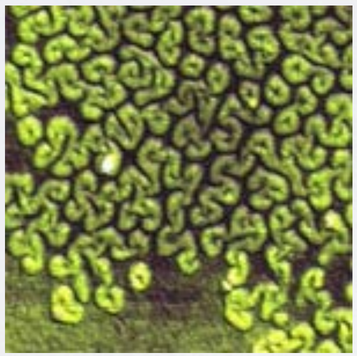


Серебряные проволоки.
Размер скана 4×4 мкм.
АМ АСМ

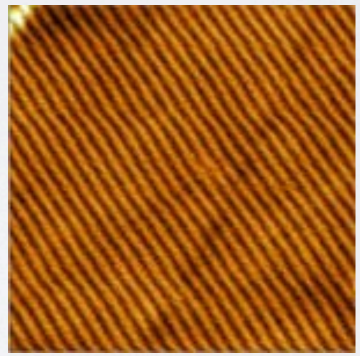


Смесь полистирен-полиэтилена.
Размер скана 20×20 мкм.
HybriD метод АСМ

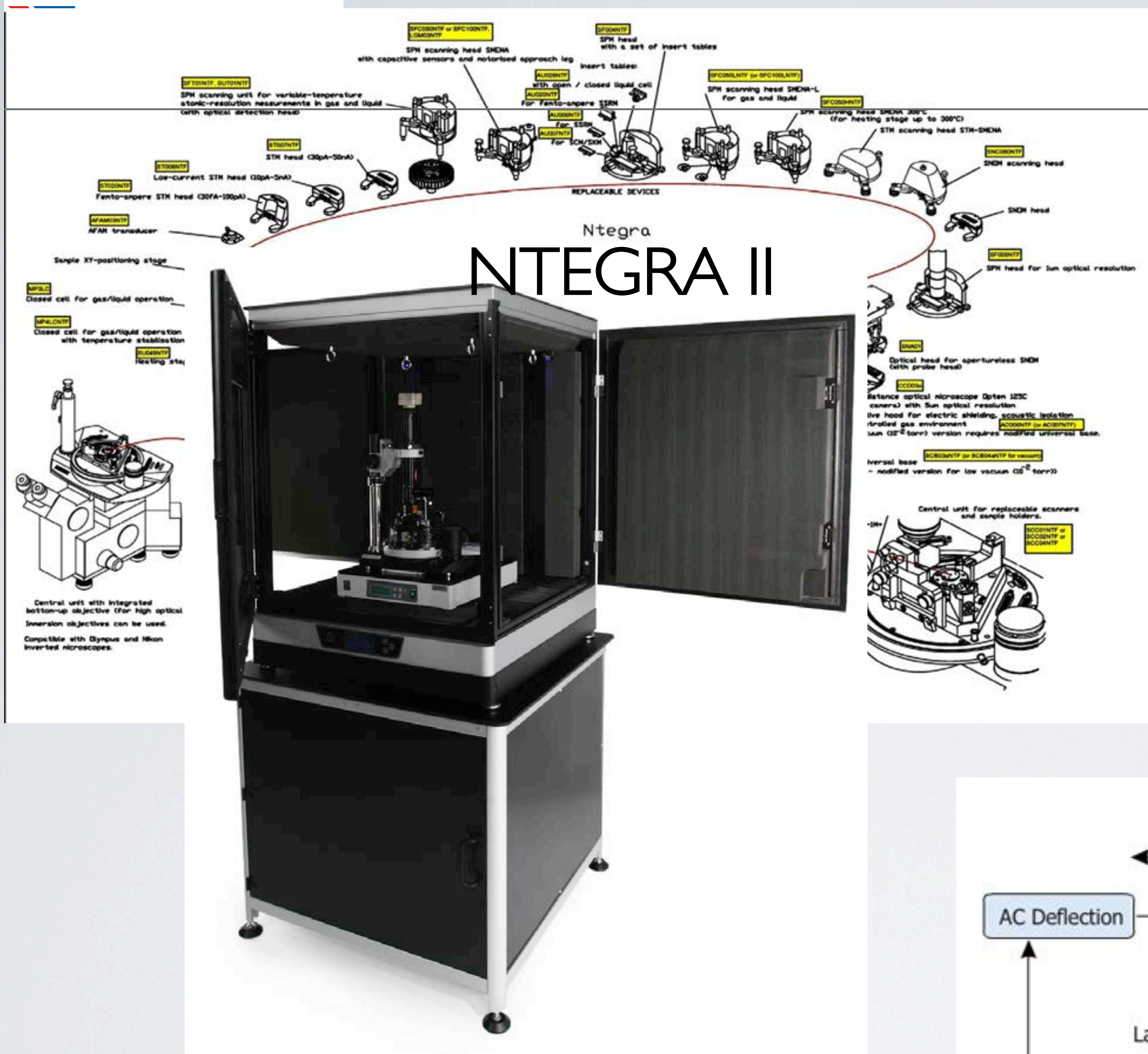
Получено на приборах СОЛВЕР-НАНО



Флуороалканы.
Размер скана 500×500 нм.
АМ АСМ

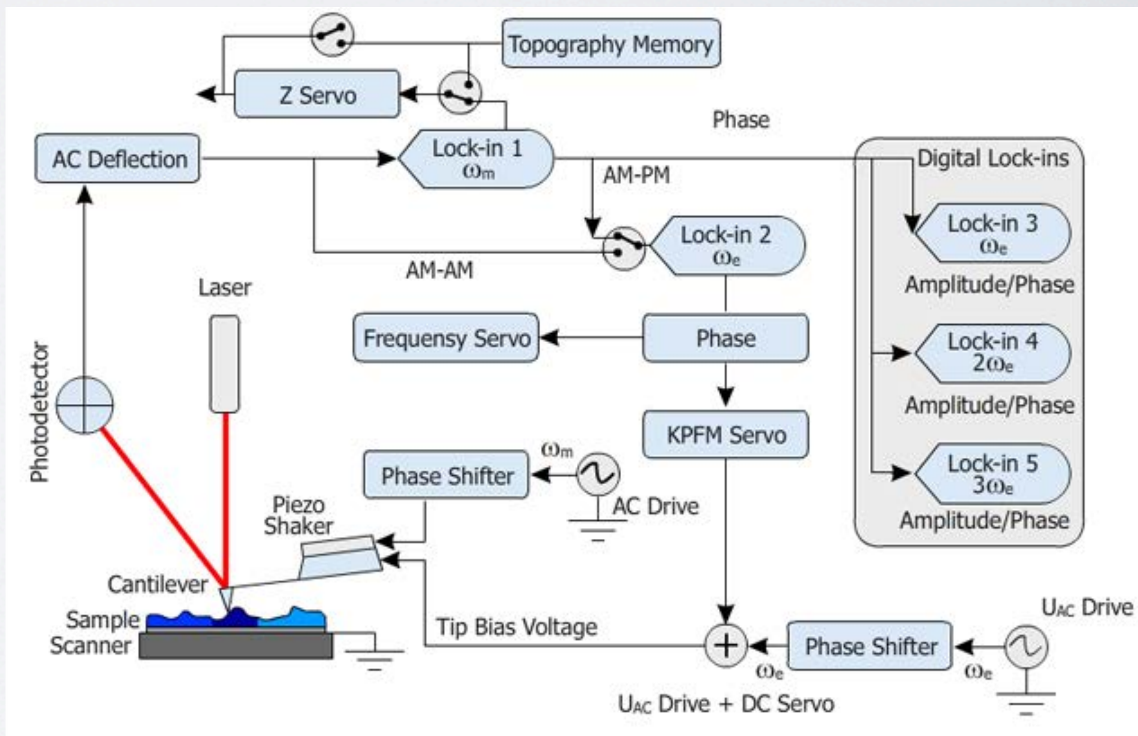


С60Н122 на ВОПГ.
Размер скана 250×250 нм.
АМ АСМ



PX ULTRA CONTROLLER

- Частотный диапазон до 5MHz
- 5 предусилителей
- ADC скорость отработки – 500kHz
- ADC разрешение – 18bit
- Шум фазы до – 0,01^0



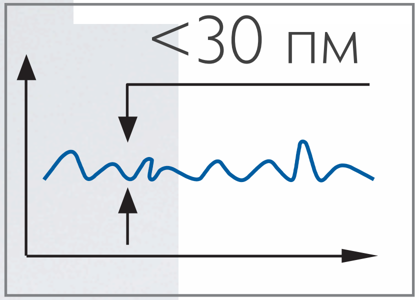
VEGA – АСМ для больших образцов.

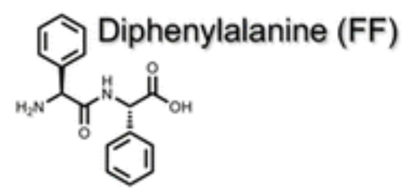
5x5 nm, HOPG

8×8 мкм

diphenylalanine peptide nanotubes

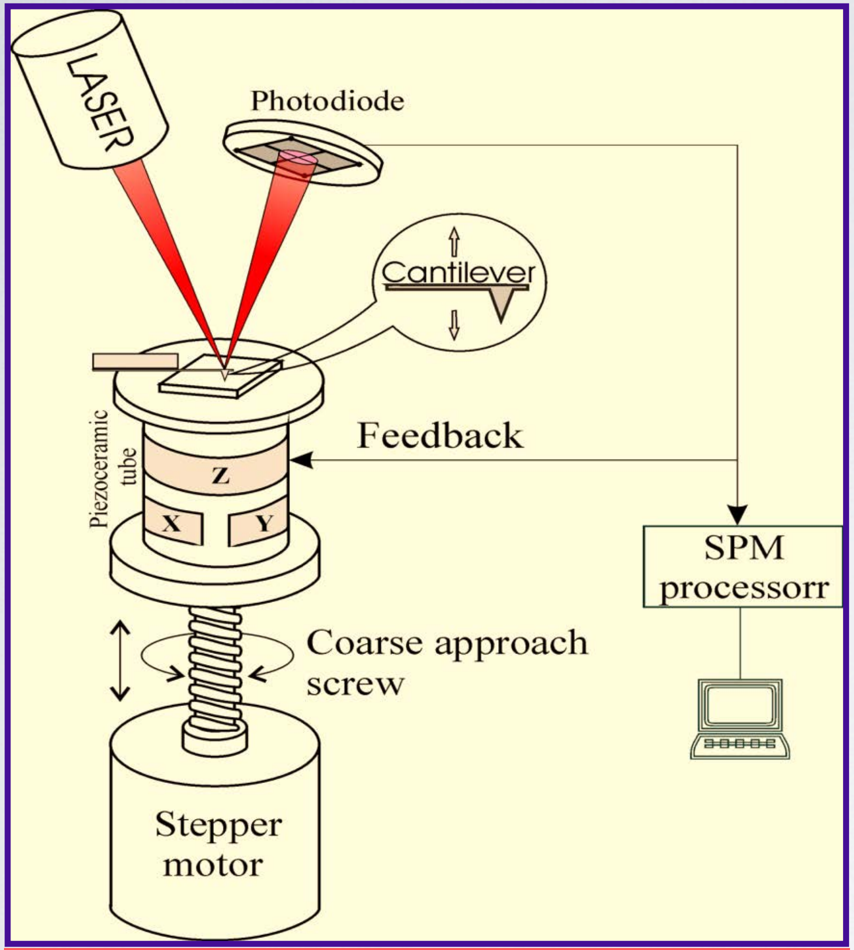
Пептидные нанотрубки дифенилаланина, 8×8 мкм. Распределение диэлектрической проницаемости



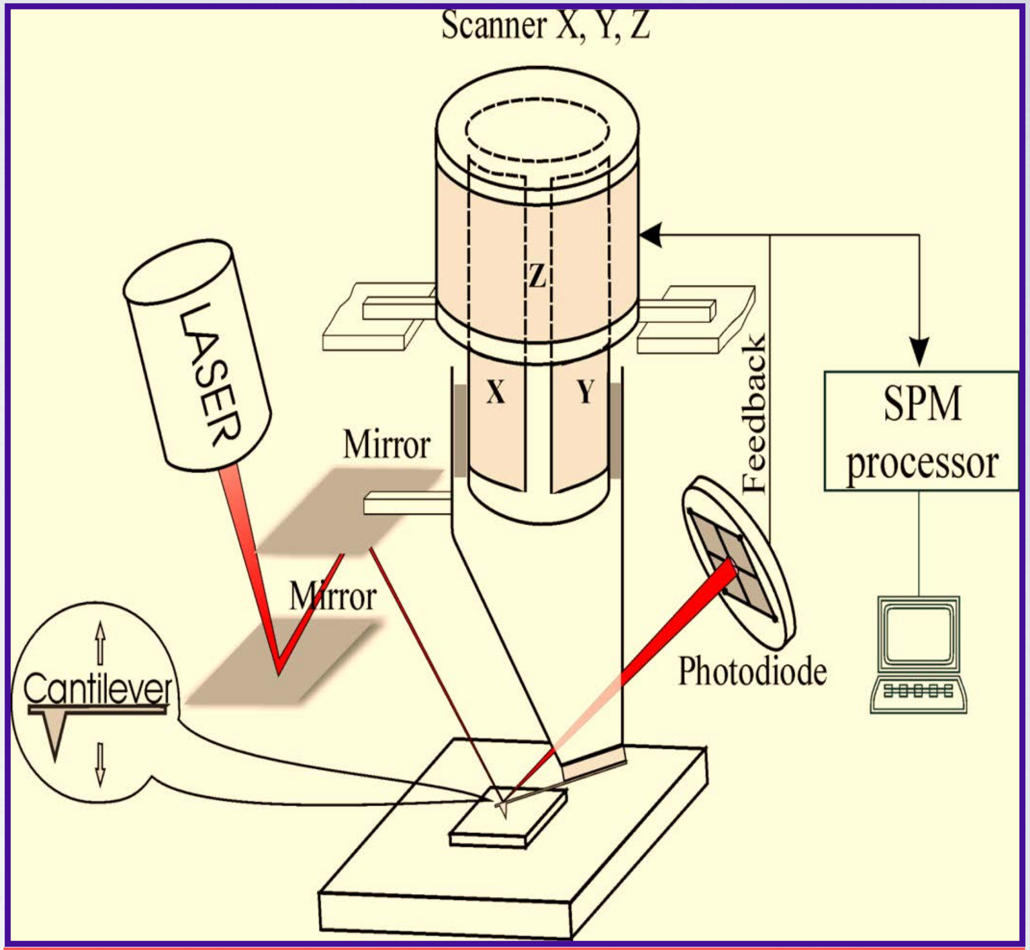


Специально разработанная оптическая схема обладает **самым низкого значения уровня спектральной плотности шума (25 фм/√Гц)** датчика оптической системы регистрации

ATOMIC FORCE MICROSCOPY



Scanning by sample



Scanning by probe

Piezoceramic elements for sub nanometer displacements, but CREEP and HISTERESIS!!!

www.ntmdt-si.com

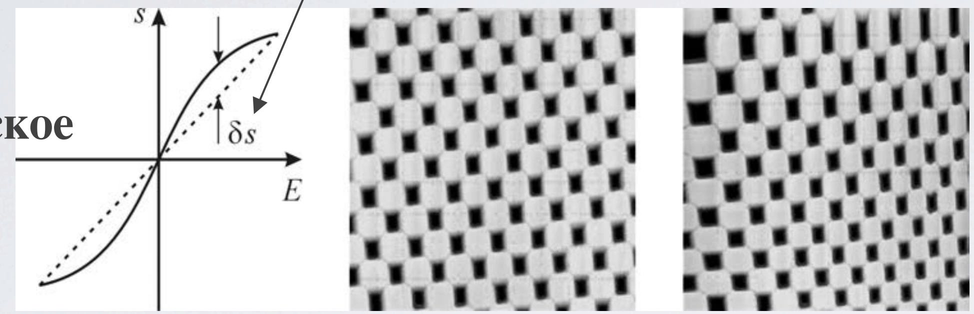
Собственная нелинейность сканера

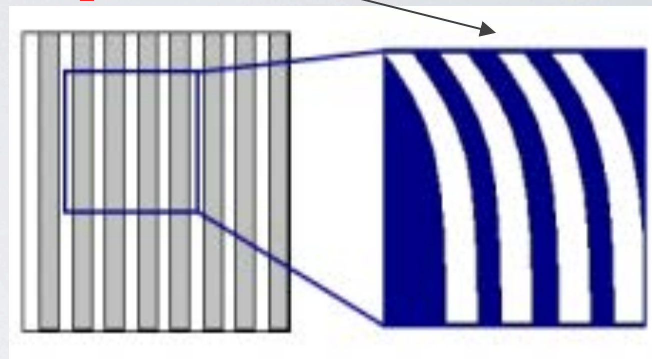
искажения

Крип

Относительное удлинение

Электрическое поле

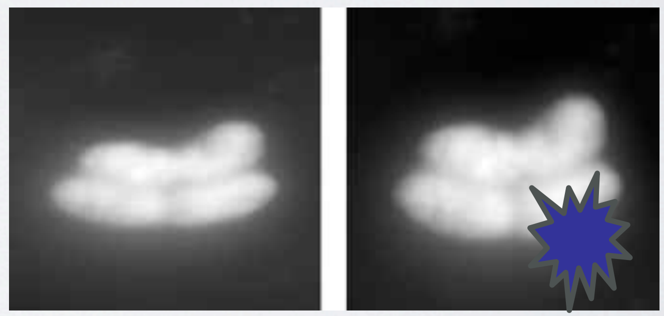




В плоскости *XY* крип проявляется при перемещении или масштабировании области сканирования.

В плоскости *XY* собственная нелинейность проявляется в неравномерности шага сканирования. В *Z* направлении собственная нелинейность будет приводить к погрешностям при измерении высоты микрорельефа поверхности.

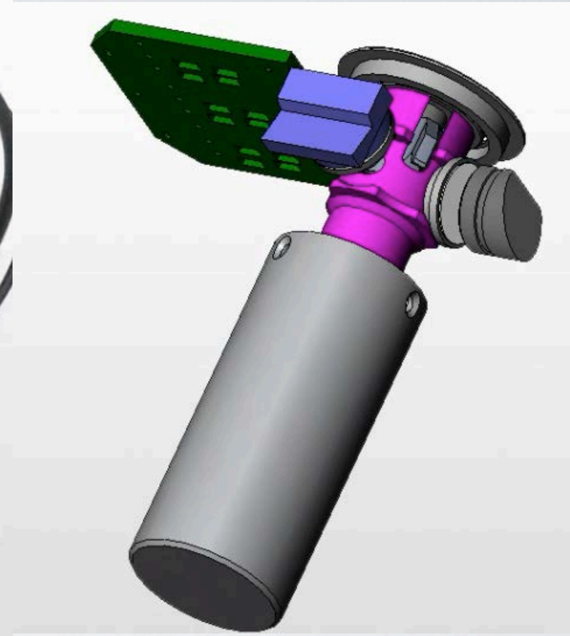
Термический дрейф компонентов АСМ



http://afmhelp.com/

Искажение АСМ-изображения бактерии из-за дрейфа

DECISION – 3D High accuracy capacitance sensors !!!



		Сканирование образцом	Сканирование зондом
Нелинейность, XY (с датчиками обратной связи)		≤0.1%	≤0.15%
Уровень шума, Z (СКВ в полосе 1000 Гц)	С датчиками	0.04 нм (типично), 0.06 нм	0.06 нм (типично), 0.07 нм
	Без датчиков	0.03 нм	0.05 нм

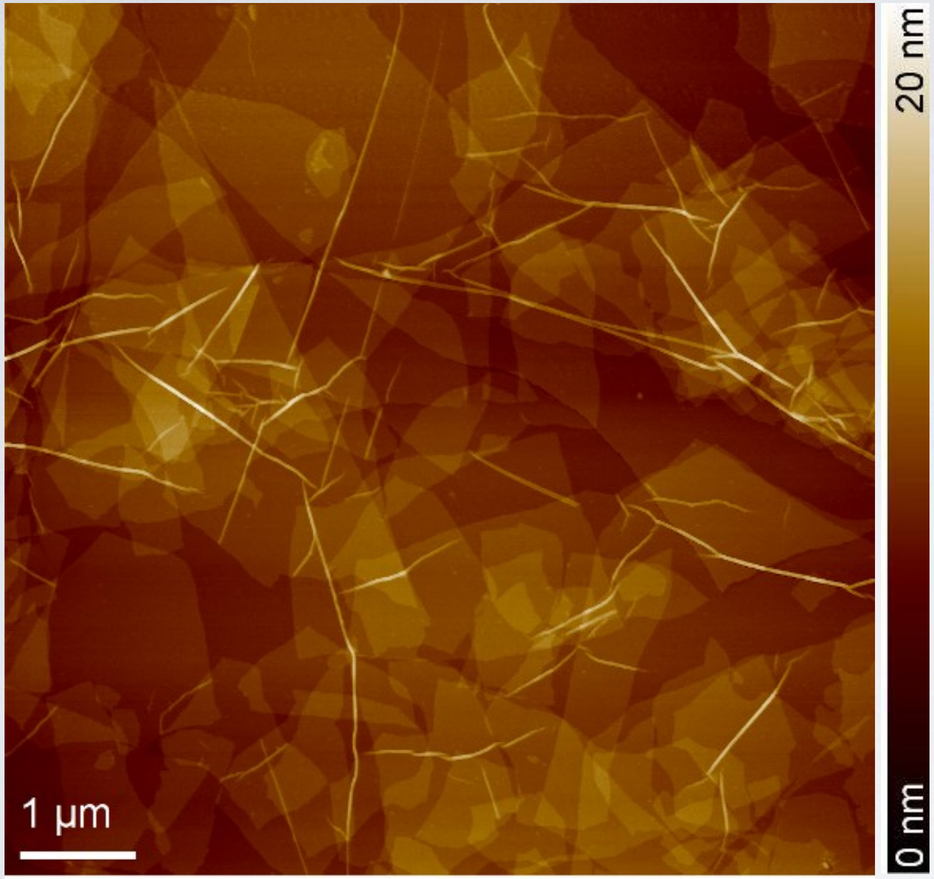
NT-MDT

Closed-loop control as used for nanolithography, scan size 1.9x1.9 μm

Closed-loop operation off

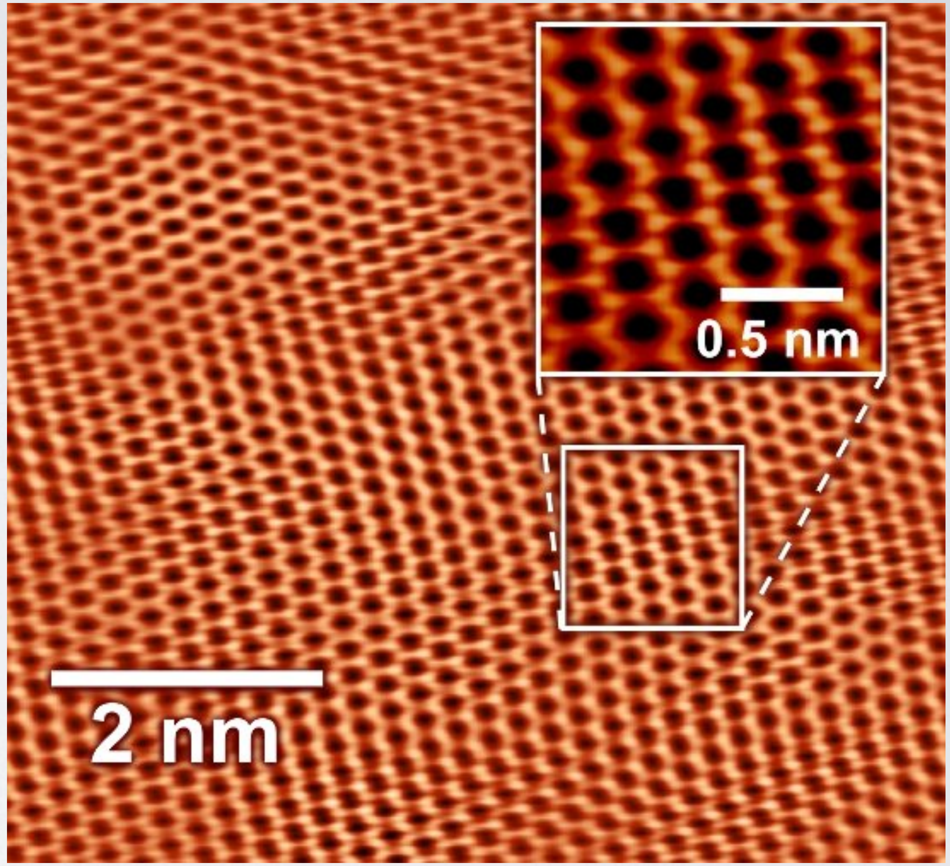
Closed-loop operation on

High resolution AFM and STM of graphite structures



The high-resolution AFM image showing an assembly of single-layer, functionalized Graphene sheets.

Some of the sheets are many square micrometers large. The thickness of each sheet is less than 1 nm.

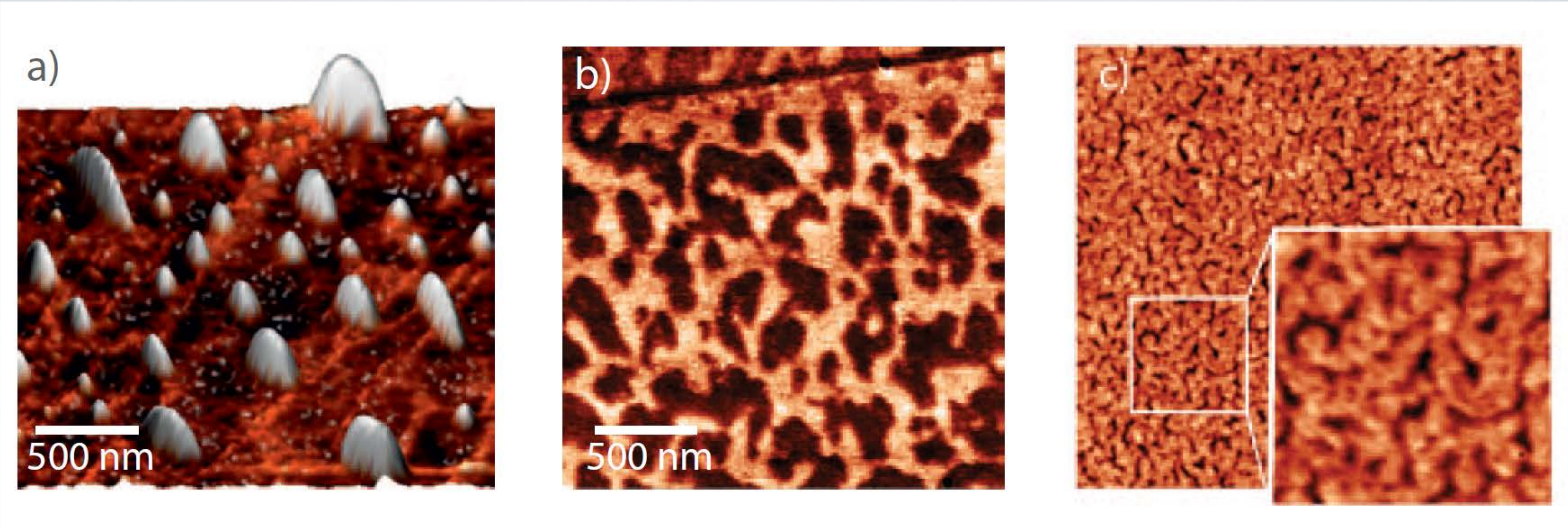


Atomic resolution STM image of graphite (HOPG)

Image courtesy:
Dr. Hannes Schniepp (The College of William & Mary, USA)

Graphene in different atmospheric conditions

AFM topography



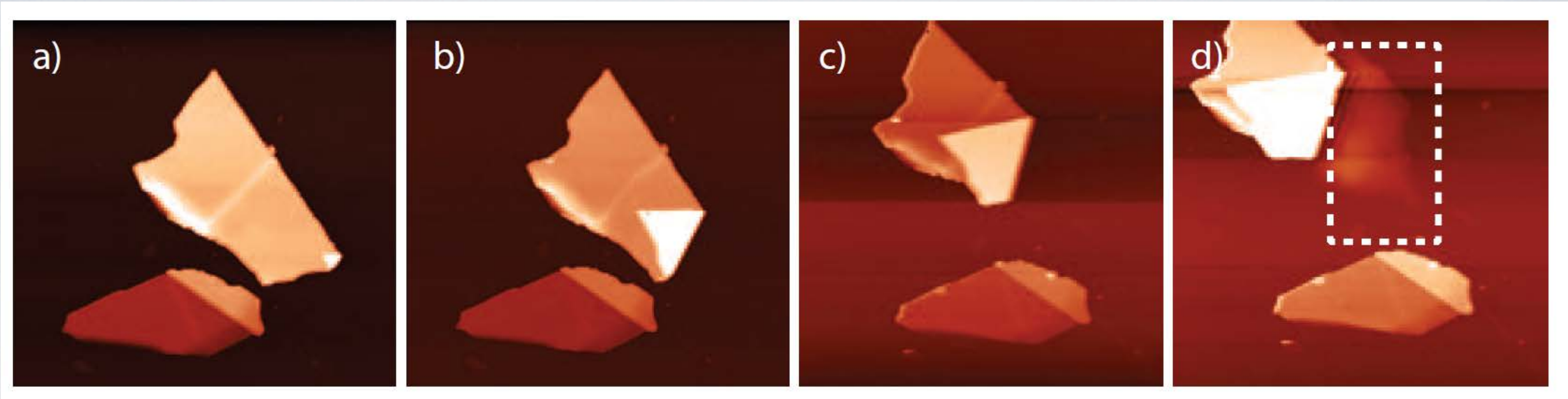
In ambient conditions

After heating above 100 ºC

In toluene vapour

D.W. Horsell, P.J. Hale and A.K. Savchenko, Microscopy and Analysis 25(1), 15 (2011),

Nanomanipulation of graphene flake by AFM



Successive steps in multilayer graphene folding

Graphene (multilayer) folded in successive steps (image 3, scans a-d) by an AFM cantilever. The graphene is attached to a silica / silicon substrate. The degenerately doped silicon is separated from the graphene by 300 nm silica. Between each fold, 10 V is applied between the silicon and the tip held at the centre of the graphene crystal. After folding, a 'ghost' of the graphene is left behind (see white highlighted region in scan (d). This is from charge built up in the silica from the applied voltage: charge from the tip is dispersed across the conductive graphene crystal then charges impurities in the silica. Even in ambient conditions, this effect lasts for several hours.

D.W. Horsell, P.J. Hale and A.K. Savchenko, Microscopy and Analysis 25(1), 15 (2011),

Basics of the Hybrid Mode

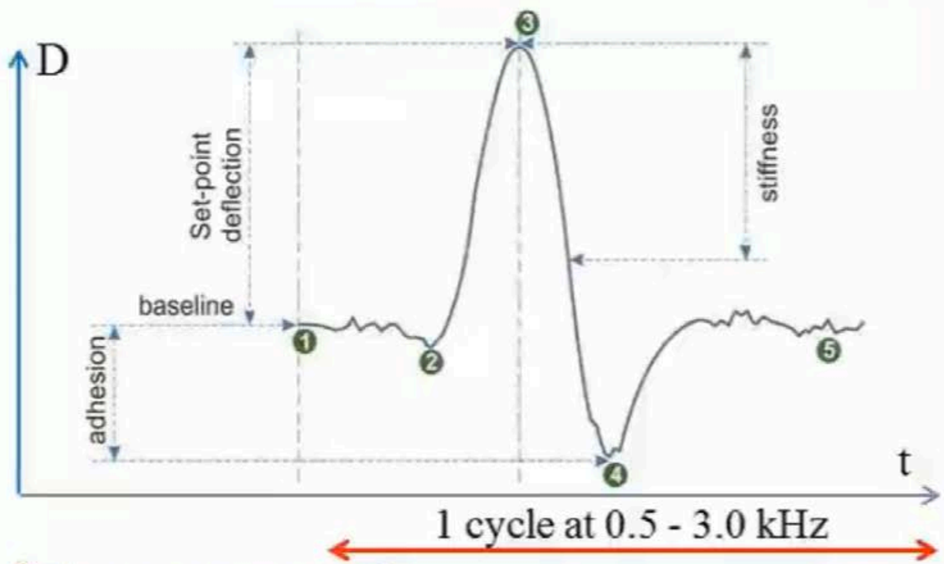
Predecessors

H. Becker, et al "Stylus profiler featuring an oscillating probe" US Patent 2728222, 1955.

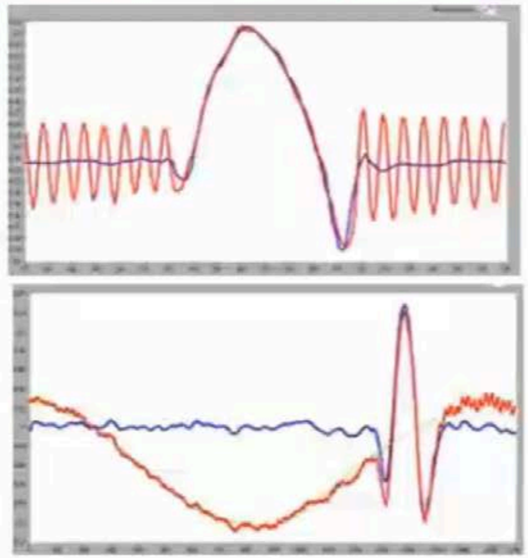
V. Elings, & J. Gurley "Jumping probe microscope" US Patent 5,229,606, 1993.

Pulsed Force (Witec), Jumping Mode (NanoTech), Peak Force (Bruker), Anasys

Temporal Deflection Plot – The Bank of the Local Properties!

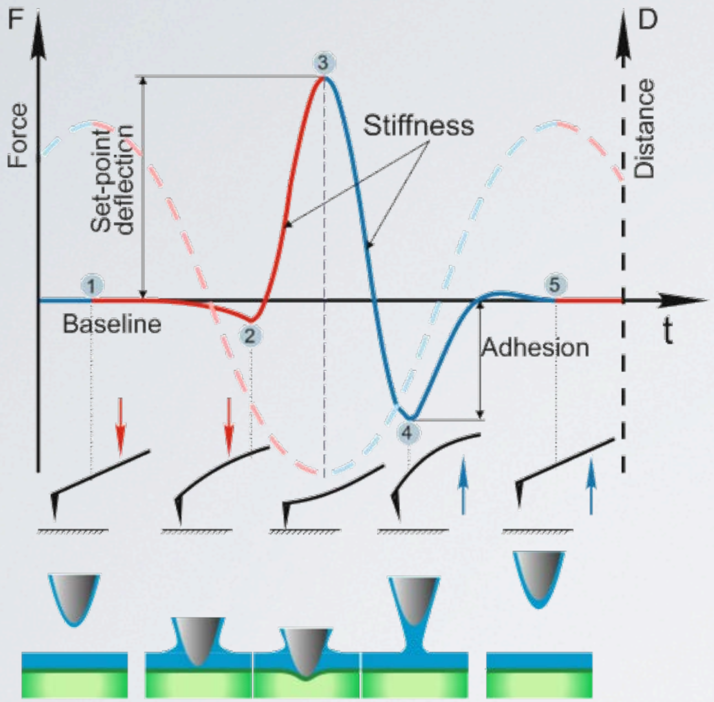


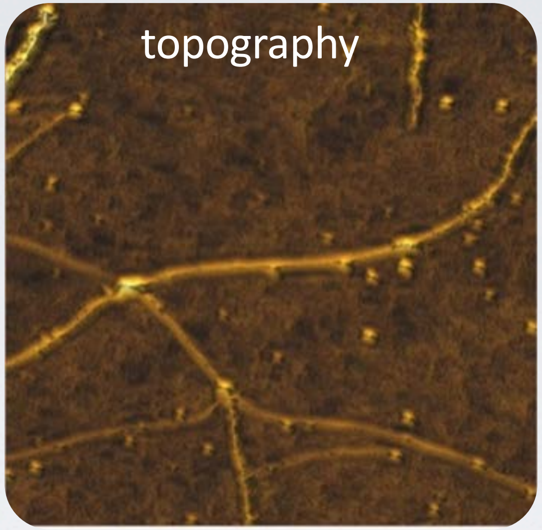
Real-time Wavelet Filtering

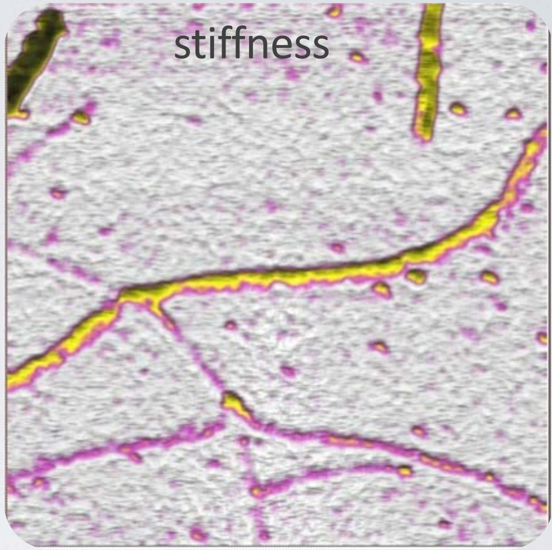


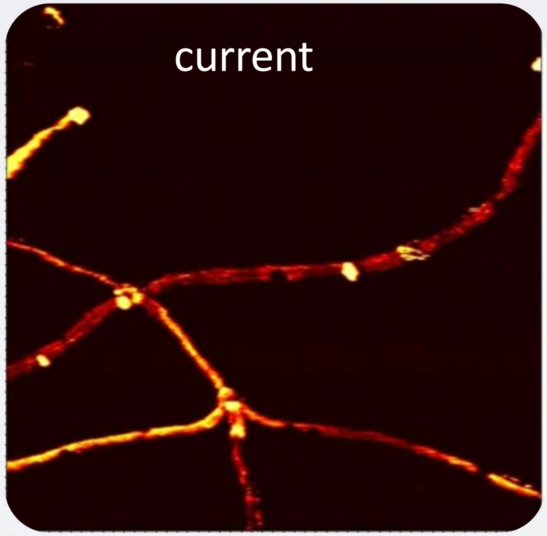
HybriD Mode: loose CNT conductivity

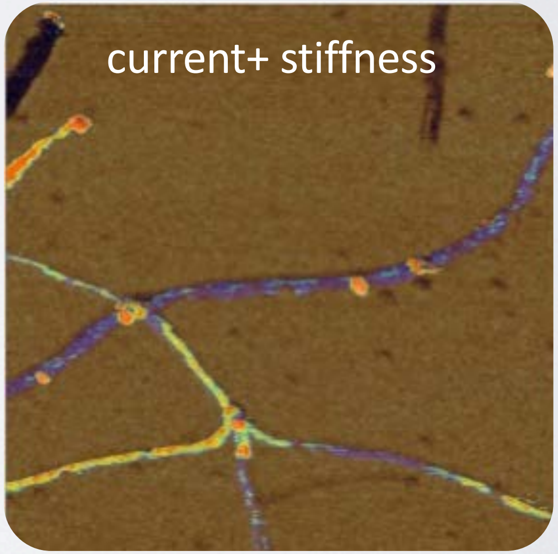
HybriD Mode





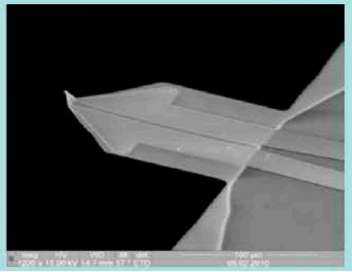
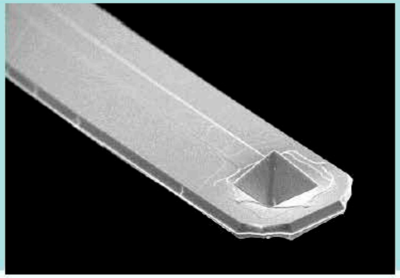


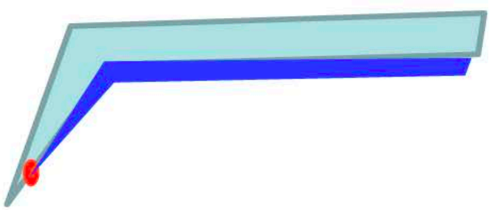


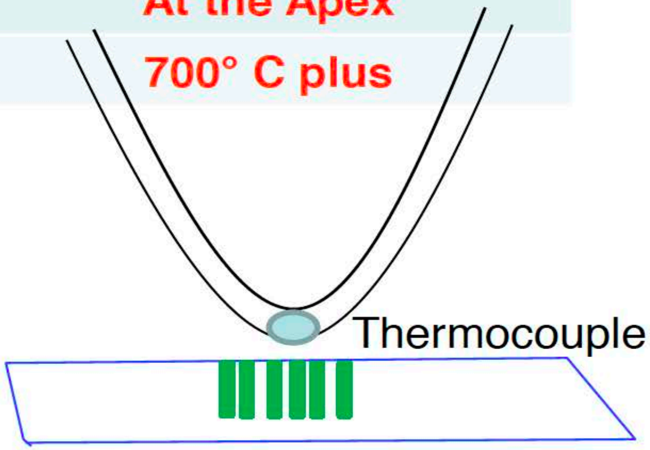


1x1um
Complex study of "loose" carbon nanotubes on SIO_2

Cantilevers for thermoconductivity measurements

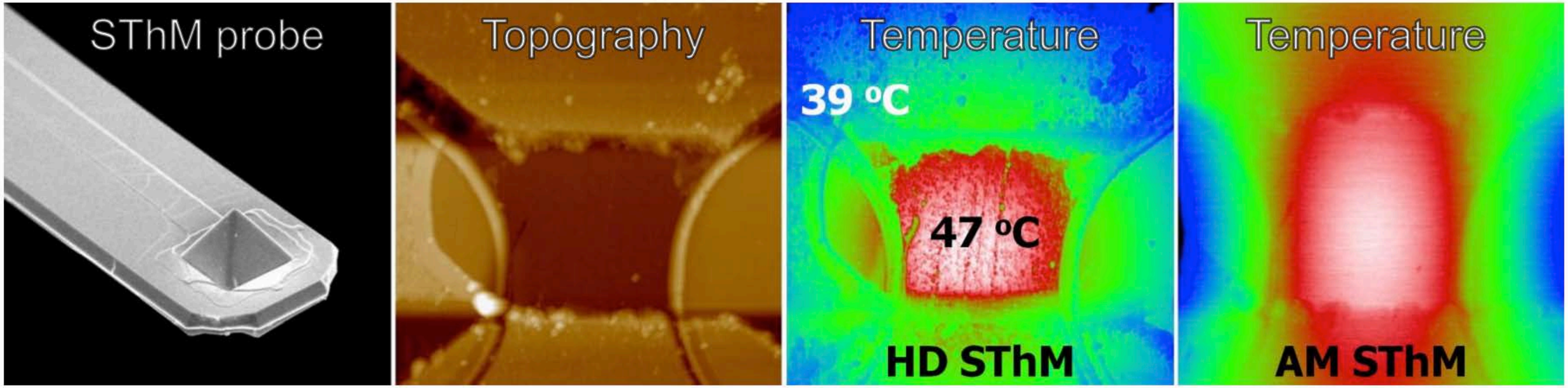
SThM Probes		
	Conventional Technology	**APPNANO**
Tip ROC (nm)	100 nm	**> 50nm**
Lateral Thermal Resolution	100 nm	**up to 20nm**
Thermal Sensor	Thermistor	**Thermocouple**
Location	Near the Apex	**At the Apex**
Maximum Temperature	160° C	**700° C plus**



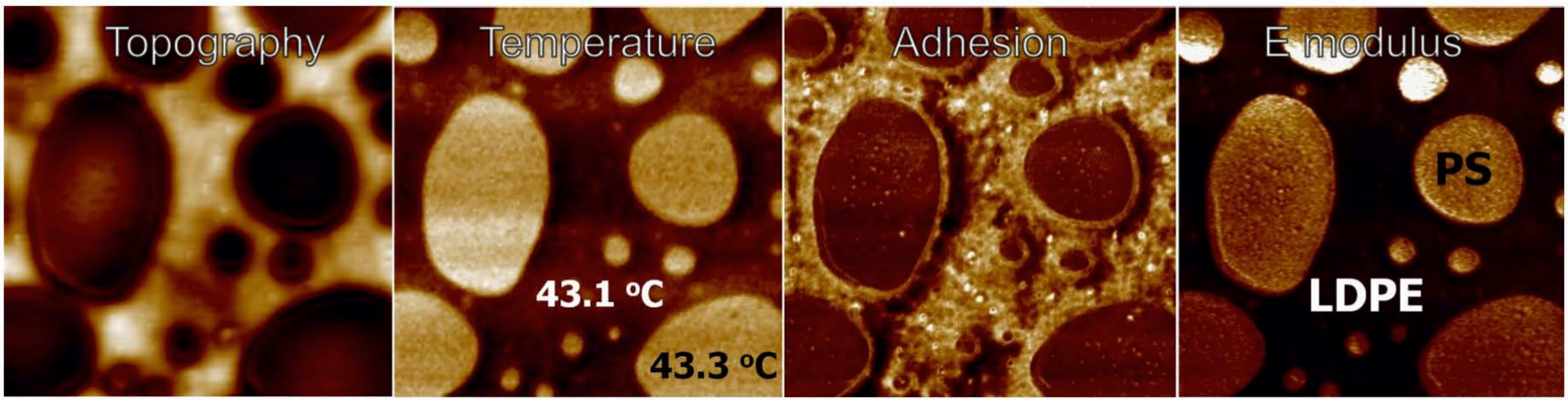


HybriD Scanning Thermal Microscopy

HD Scanning Thermal Microscopy (HD SThM) allows studying local thermal properties – temperature and thermal conductivity – simultaneously with QNM measurements.

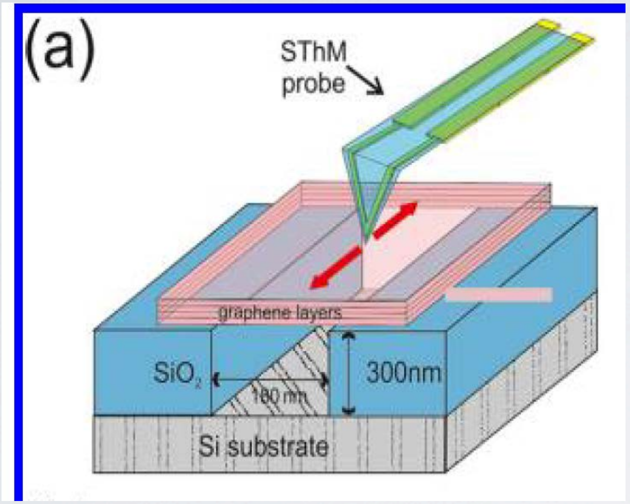


SEM image of AppNano VertiSense™ thermocouple probe and comparison of HD SThM and AM SThM techniques. Scan size: 17×17 μm.

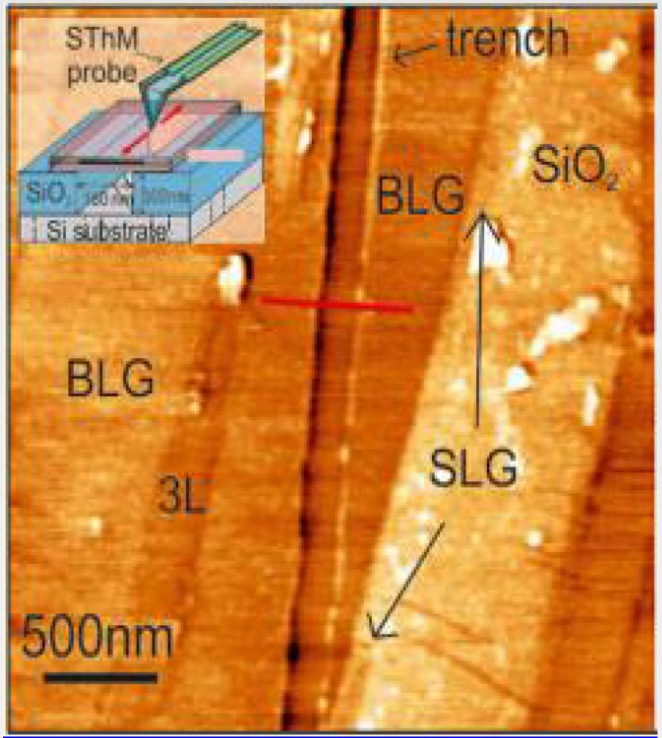


HD SThM study of PS-LDPE. Scan size: 10×10 μm.

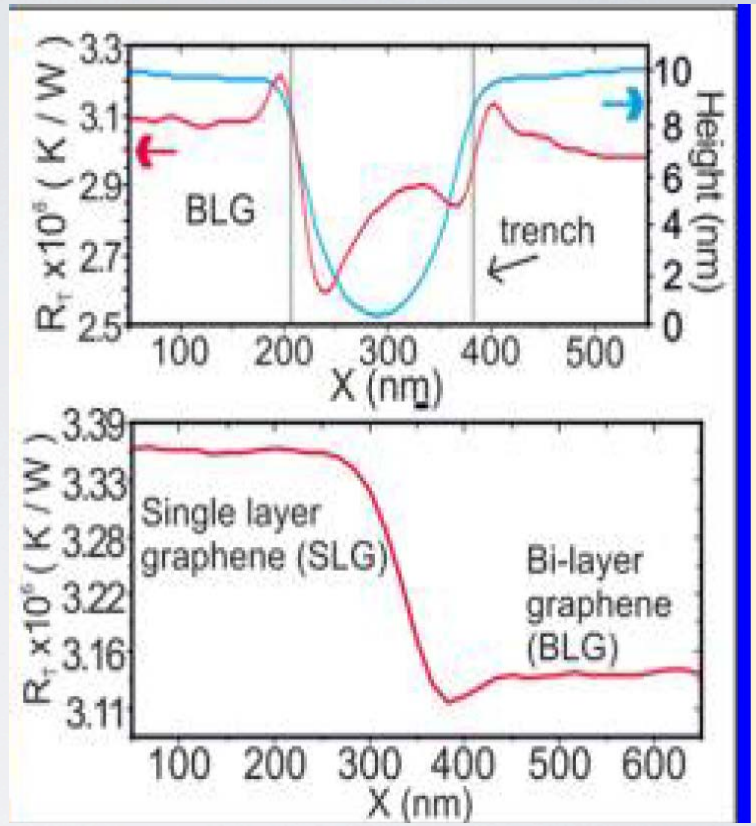
Thermal conductivity measurements of supported and suspended graphene single- and multilayers



Special SThM tip works al local heater and temperature sensor



Thermal conductivity map (sensor tip temperature)



Thermal resistance profiles: supported and suspended bilayer graphene, supported bi- and single layer graphene.

Direct Nanoscale Imaging of Ballistic and Diffusive Thermal Transport in Graphene Nanostructures

Manuel E. Pumarol,[†] Mark C. Rosamond,[‡] Peter Tovee,[†] Michael C. Petty,[‡] Dagou A. Zeze,[‡] Vladimir Falko,[†] and Oleg V. Kolosov[†,*]

[†]Physics Department, Lancaster University, Lancaster, LA1 4YB, United Kingdom
[‡]School of Engineering and Computing Sciences, Durham University, Durham DH1 3LE, United Kingdom

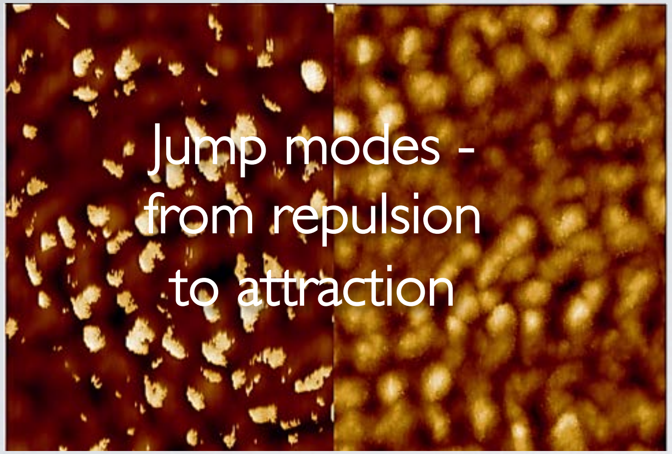
Nano Lett. 2012, 12, 2906−2911

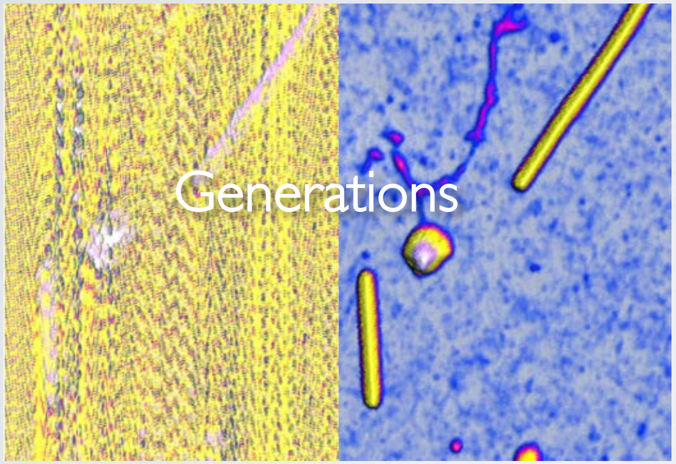
But to use it correctly to have perfect results it need you need to optimize at least 4 parameters:

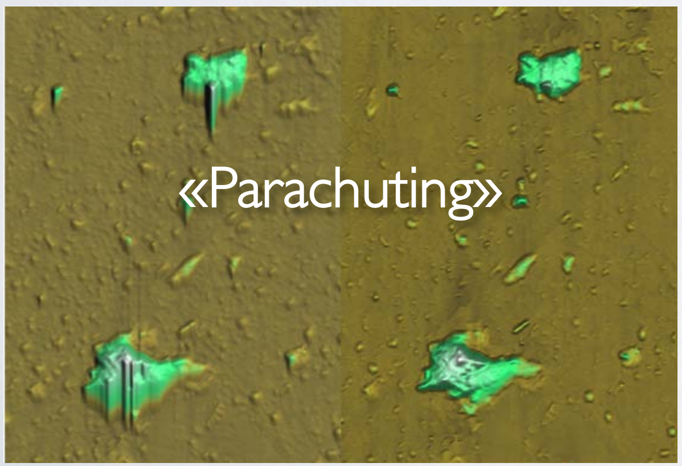
- **Amplitude of probe oscillation (A_0);**
- **Feedback set point (SP);**
- **Integral feedback coefficient (k_i)**
- **Speed of scanning (V_x) ;**

And 2 additional parameters:

- LP – Low Pass filter band;
- k_p – proportional feedback gain







www.ntmdt-si.com

ScanTronic™ –

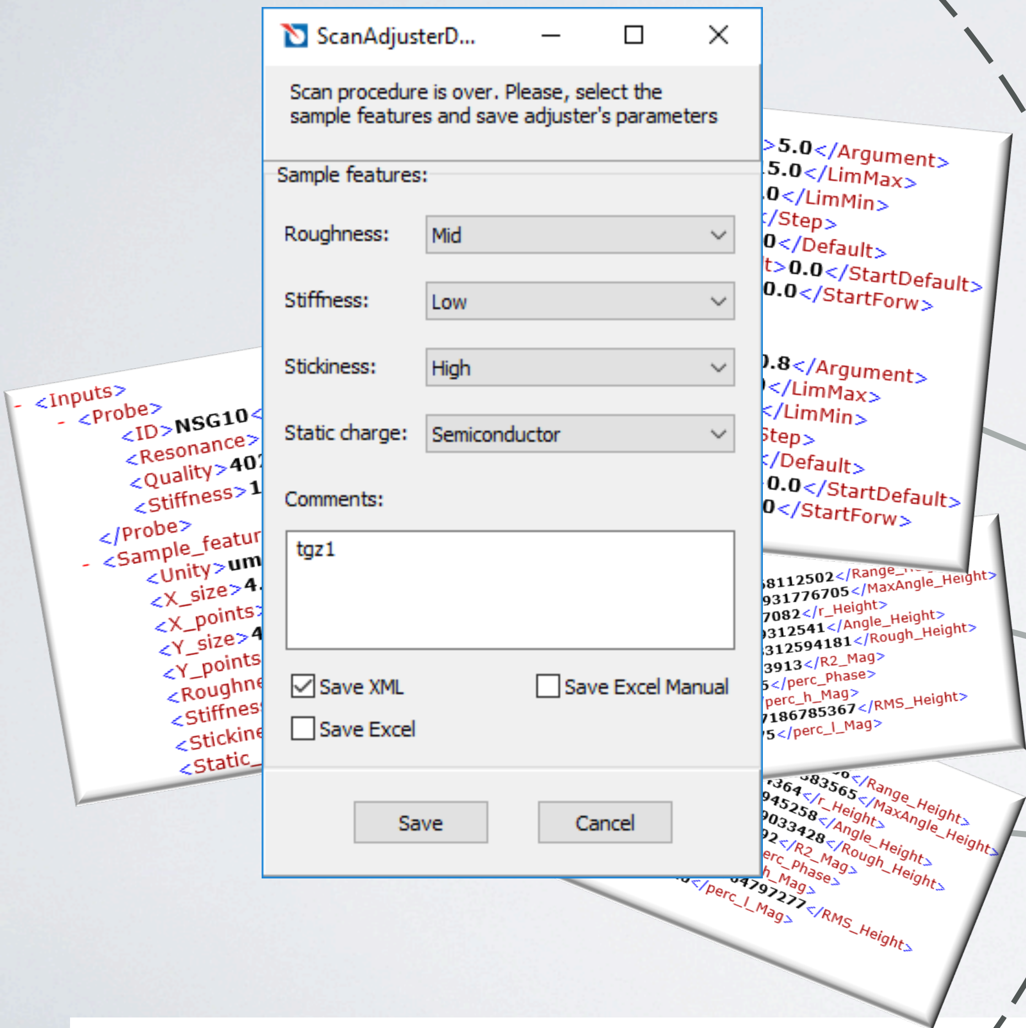
Artificial Intelligence to AFM

Straightforward for beginners

Helpful for experts

Selection of initial parameters for optimization

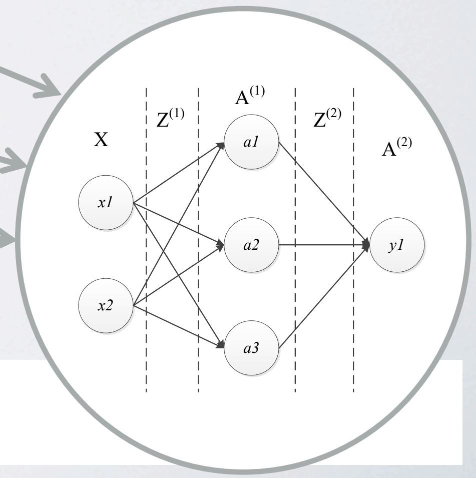
Initial Information



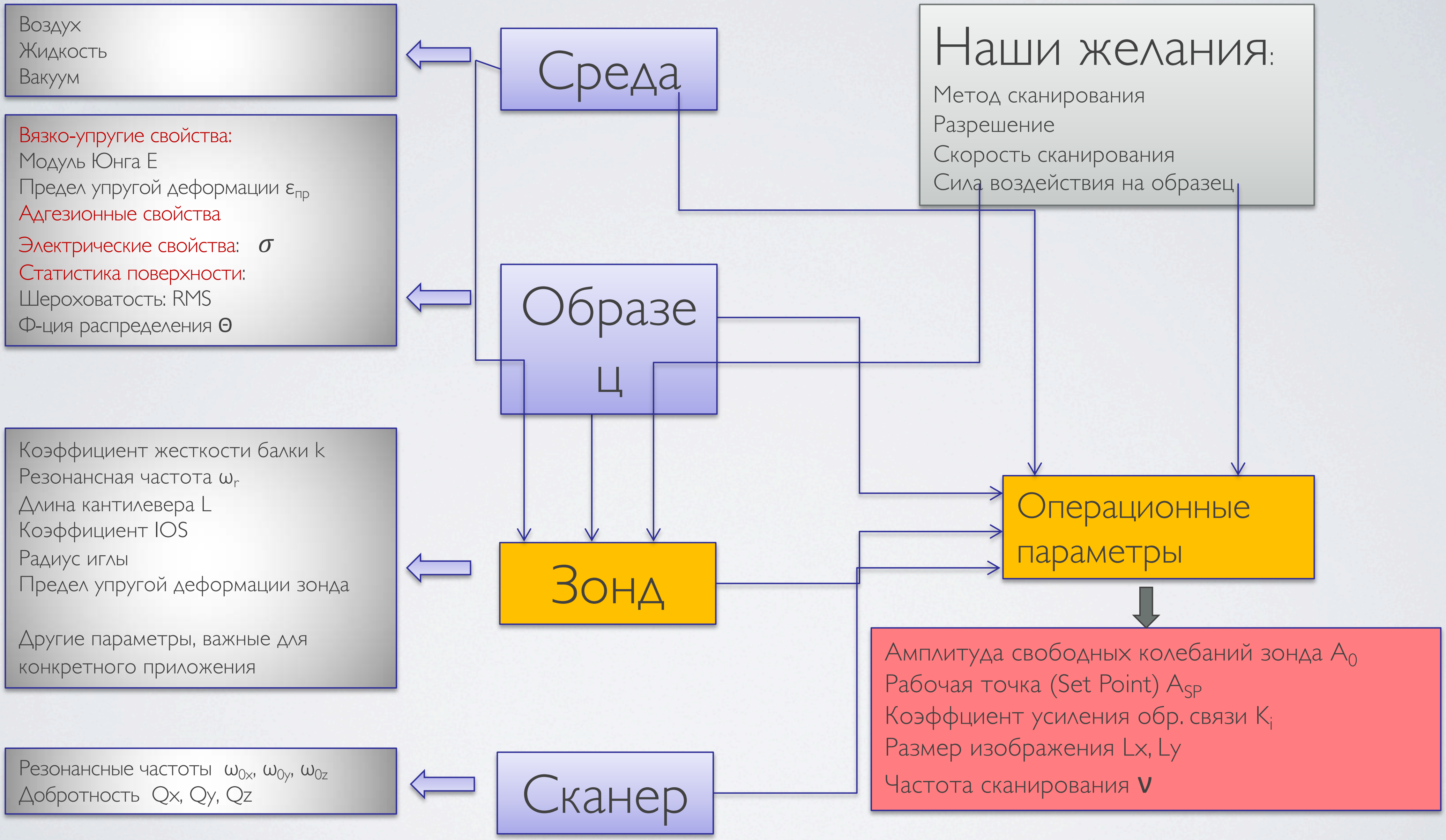
Training

Training Based on the backpropagation method using the BFGS algorithm (Broyden-Fletcher-Goldfarb-Shanno)

The search for the minimum of the objective function is performed, which makes it possible to adjust the optimal synapse weights way

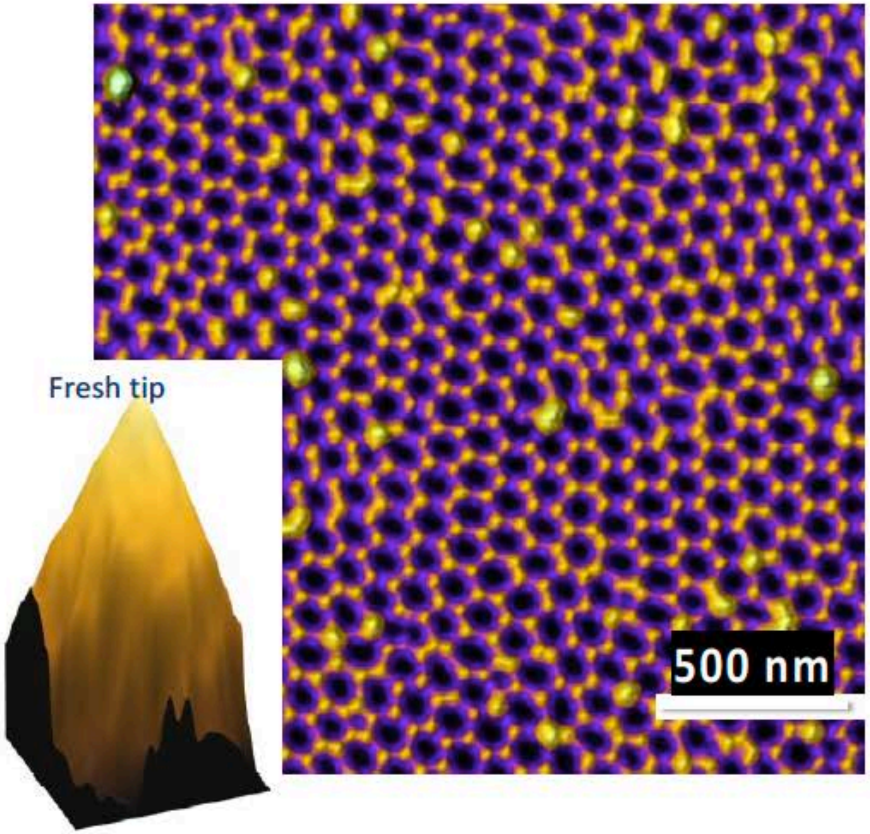


Факторы и параметры, влияющие на выбор зонда и параметров сканирования

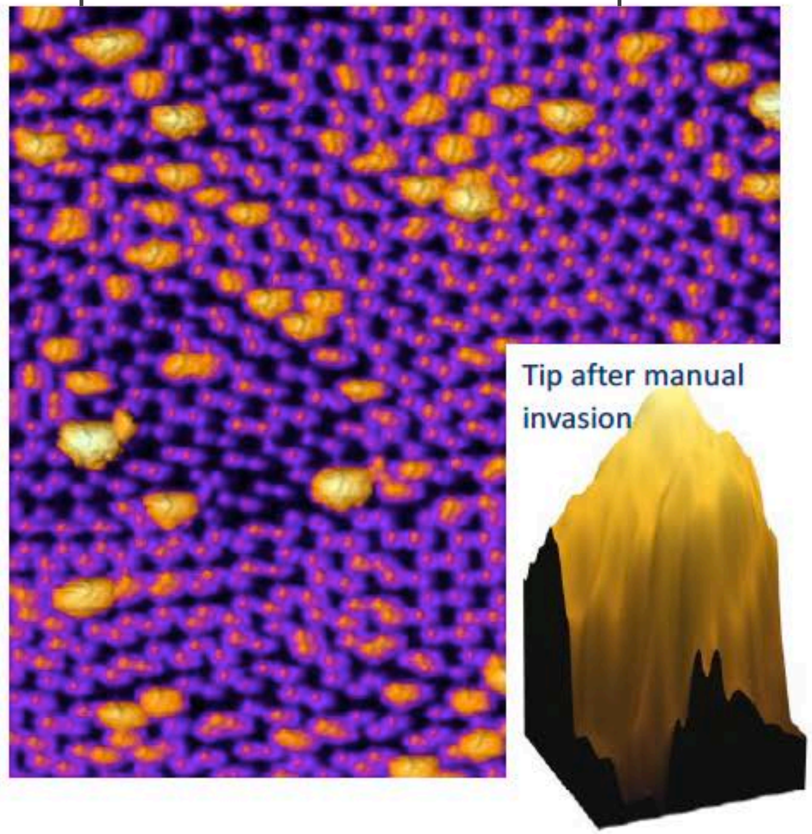


Scan Tronic: Examples of application

AI – ScanTronic!!!

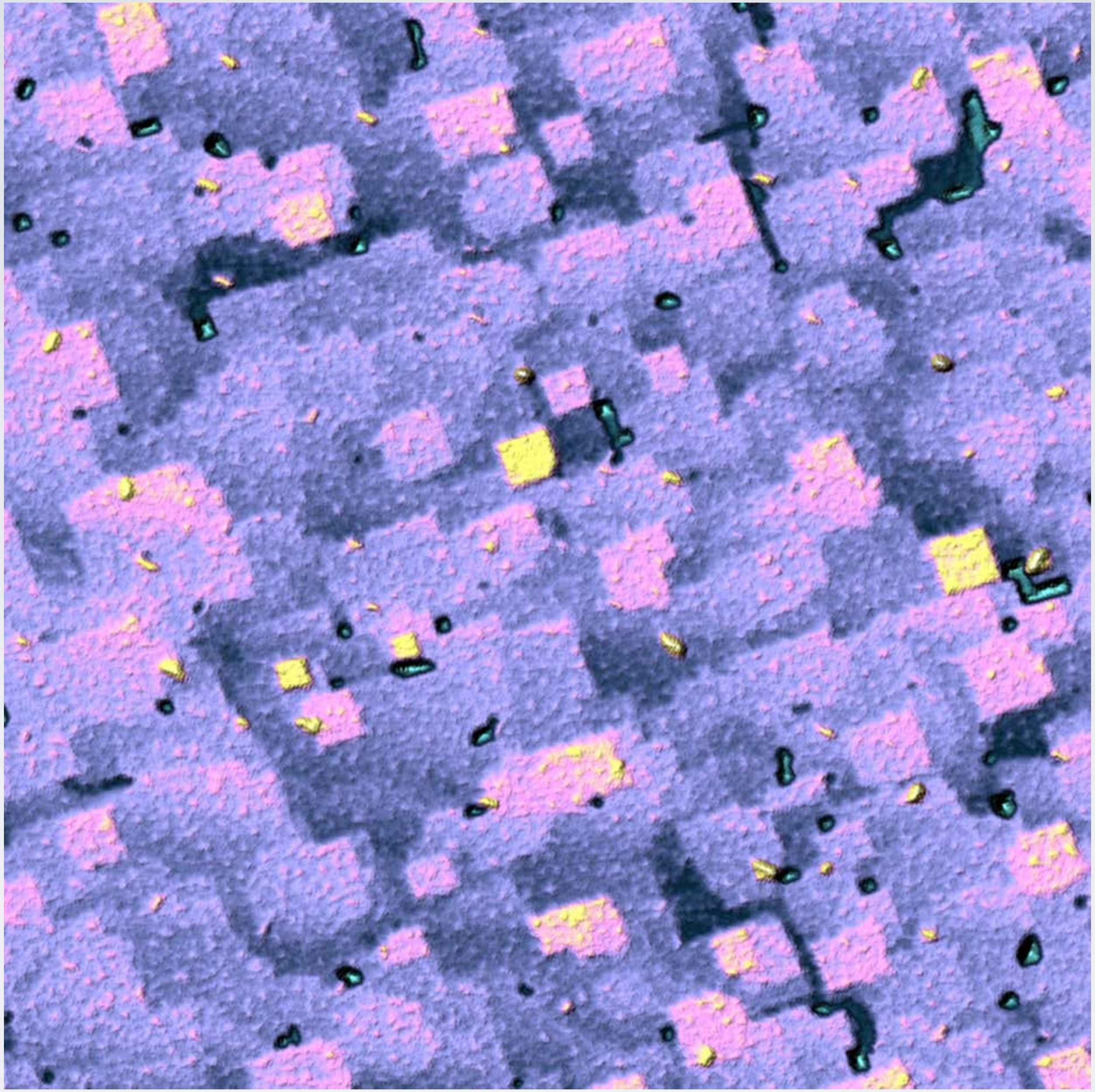


Experienced AFM specialist

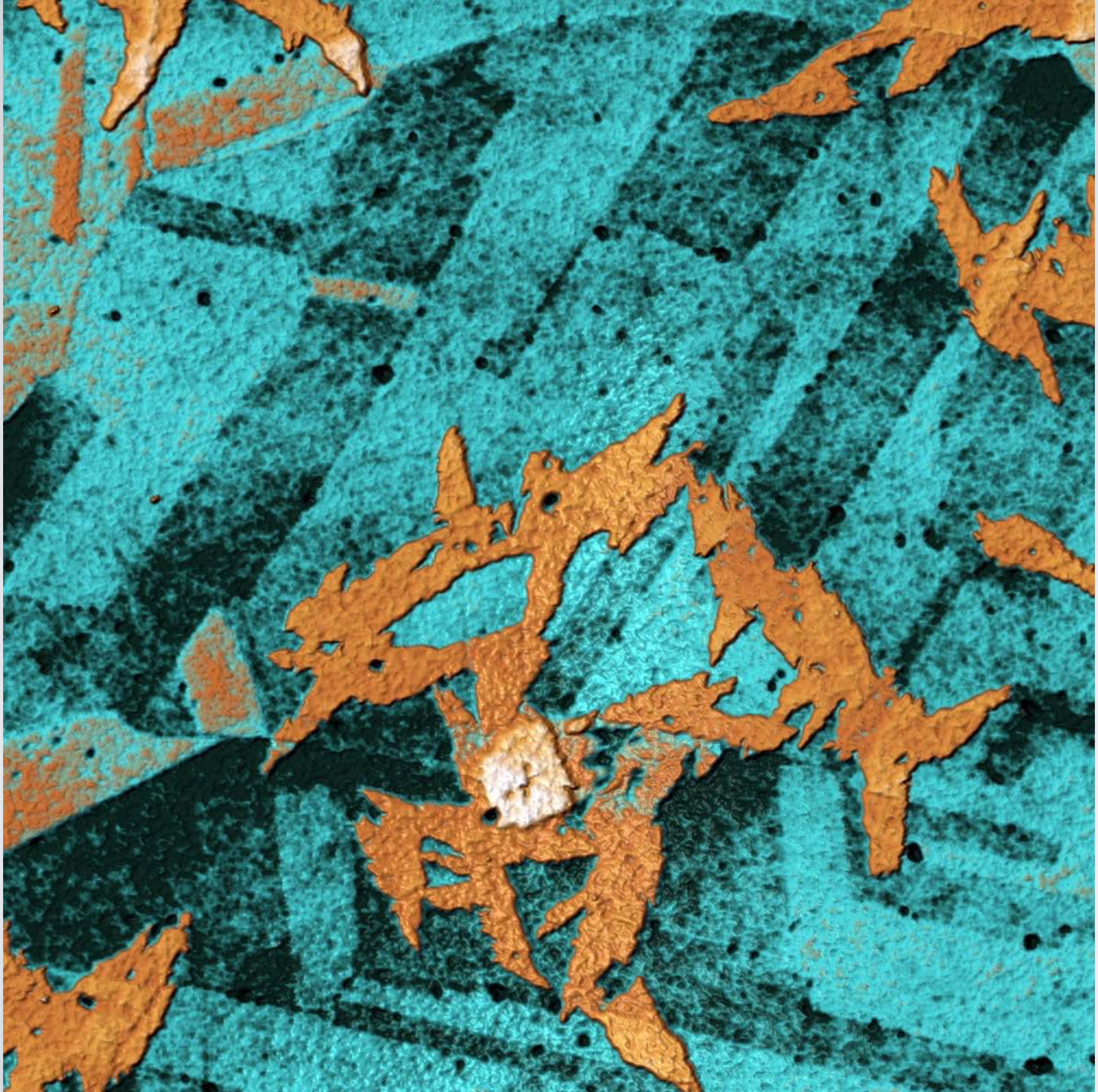


Al_2O_3 - "Grater" sample for tips.
Left – topography, ScanTronic used, right – manual attempt to adjust scanning parameters

AI – ScanTronic!!!



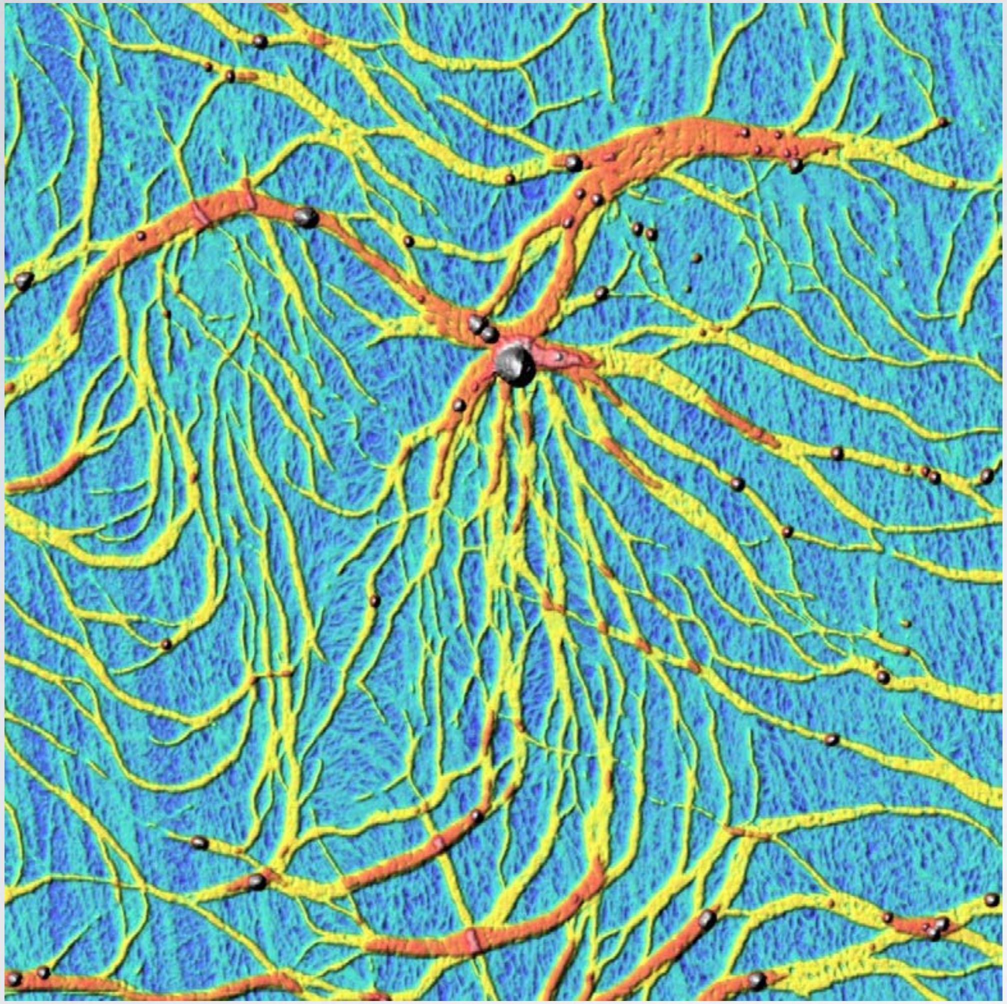
Si_3N_4, 2x2 mkm



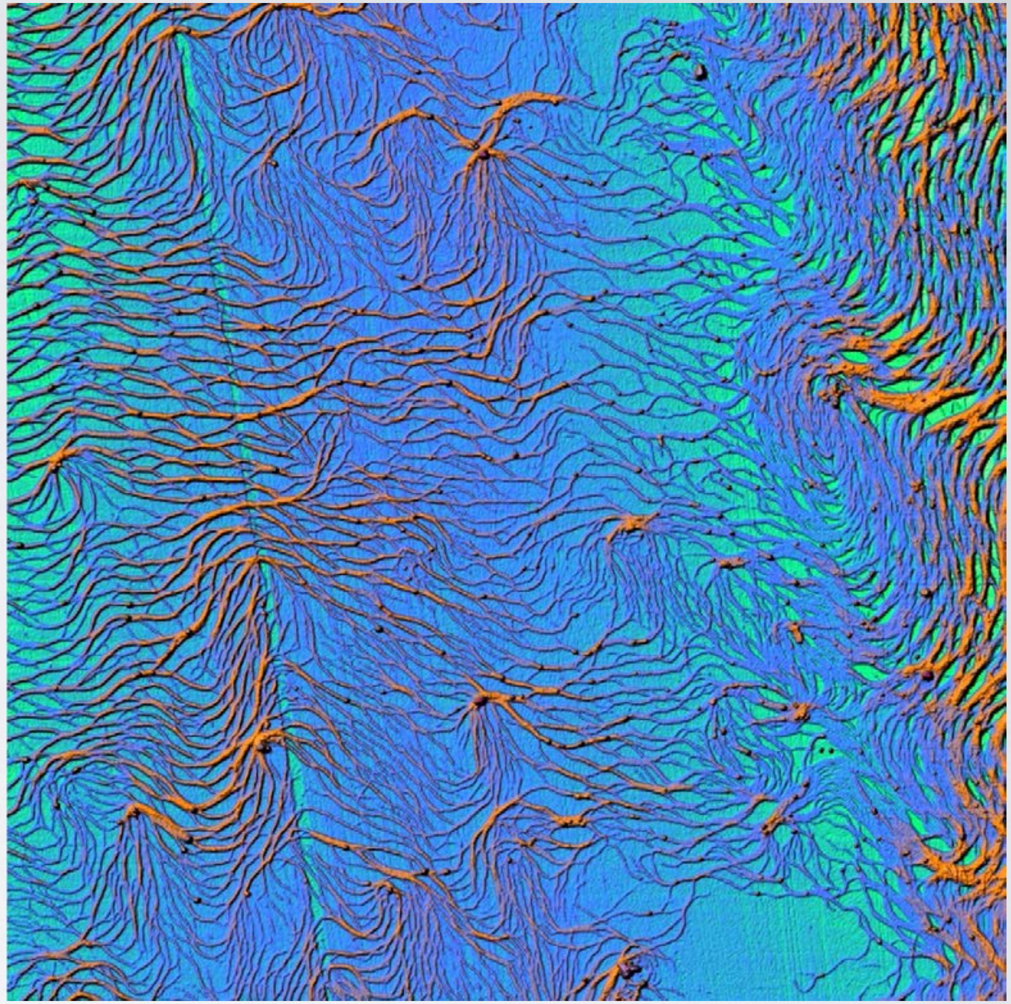
AI – ScanTronic!!

Cu/CuO,
5x5 mkm
Topography in fashion in semi-contact mode in ScanTronic mode

AI – ScanTronic!!!



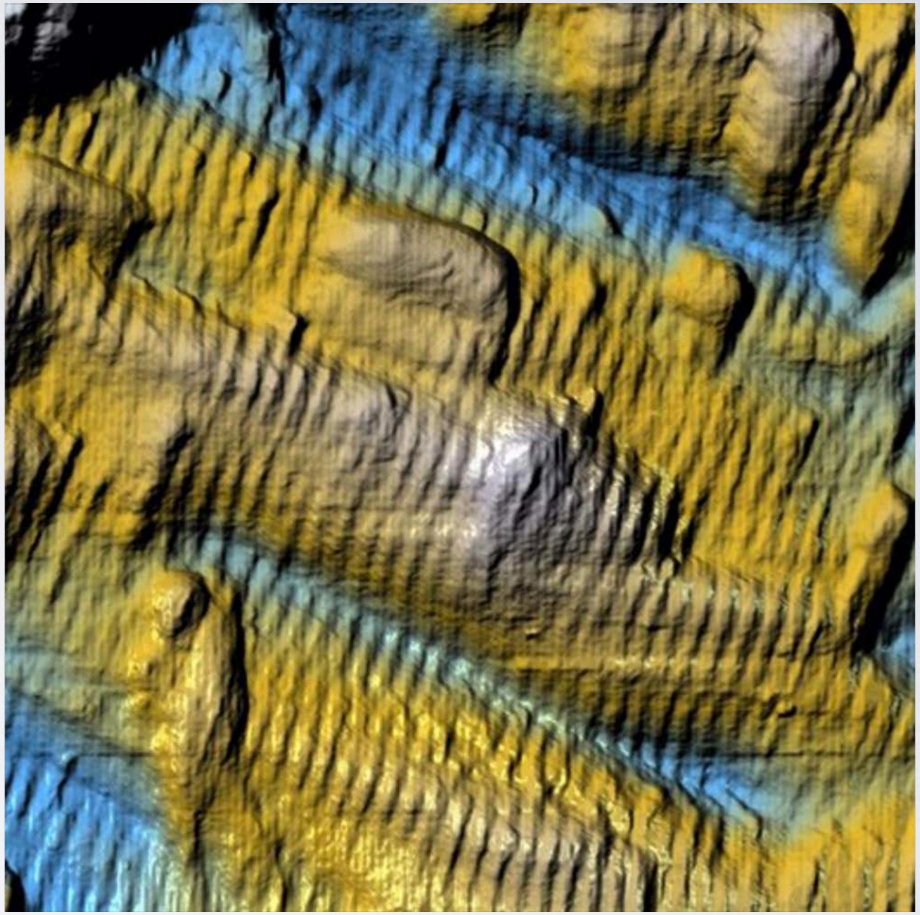
4x4 mkm



15x15 mkm

Cubic red dye on mica,
Topography in fashion in semi-contact mode in ScanTronic mode

5x5x1,7 um



2x2x0,3 um

Collagen is the main building material for connective tissues. On these images you can see the bunch of rabbit collagen fibers. On right image we can clearly see the periodic structure of these nano-ropes. Period size is ~50 nm. Image was done in liquid conditions by means of HybriD Mode. Image by Craig Wall, NT-MDT America

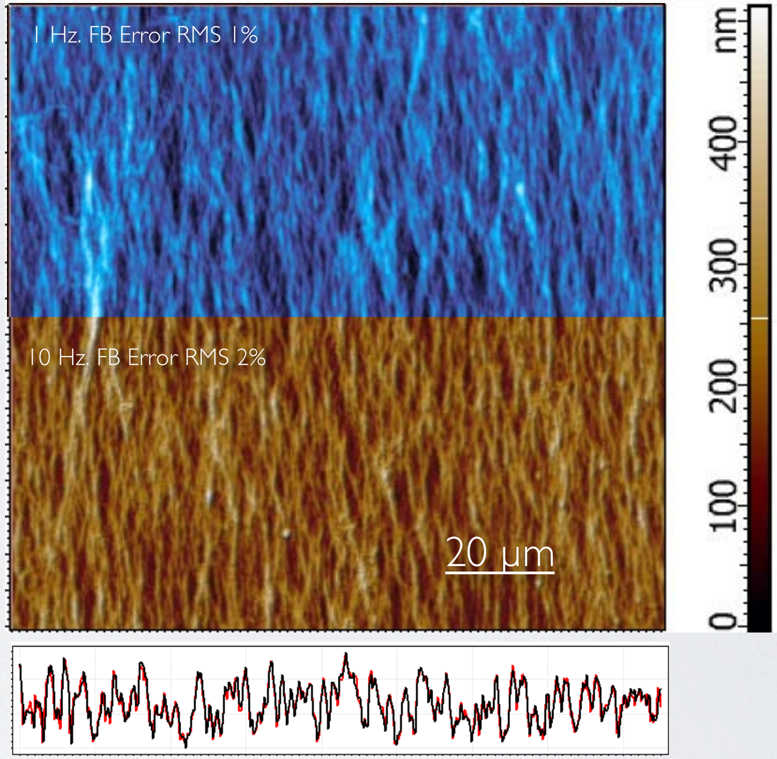
Fast Scan

2018

Fastest Scaner.

Max Scan Size XY/Z, µm: 90×90×4 ±10%

Line speed: 2 mm/sec



AFM image of collagen fibers.
1024x1024
Scan size 90 * 90 * 0,5µm

NT-MDT Spectrum Instruments

NTEGRA Spectra in Upright, Inverted and Side illumination configuration

Light input from side (with scanning mirror)

Top optics (LED illuminator & camera)

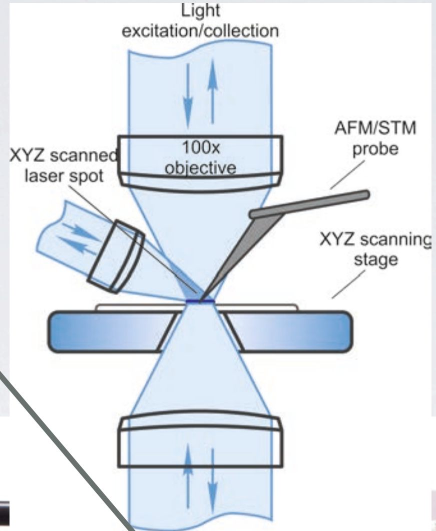
Light input from top (with scanning mirror)

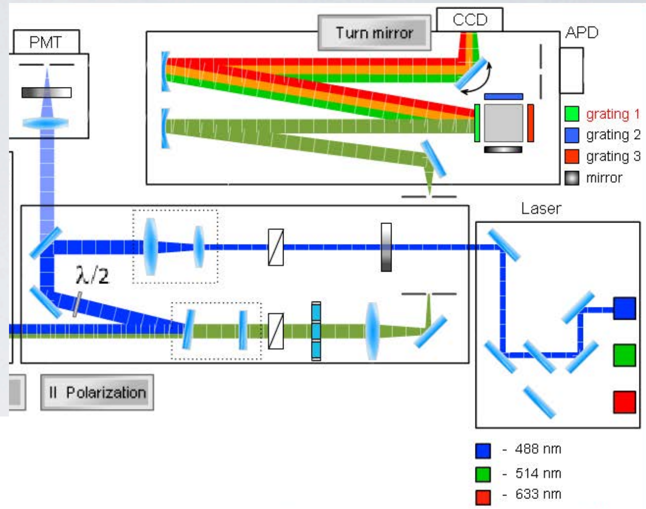
Optical AFM (AFM probe + 100x objective on the top)

XYZ sample stage (bottom illumination objective inside)

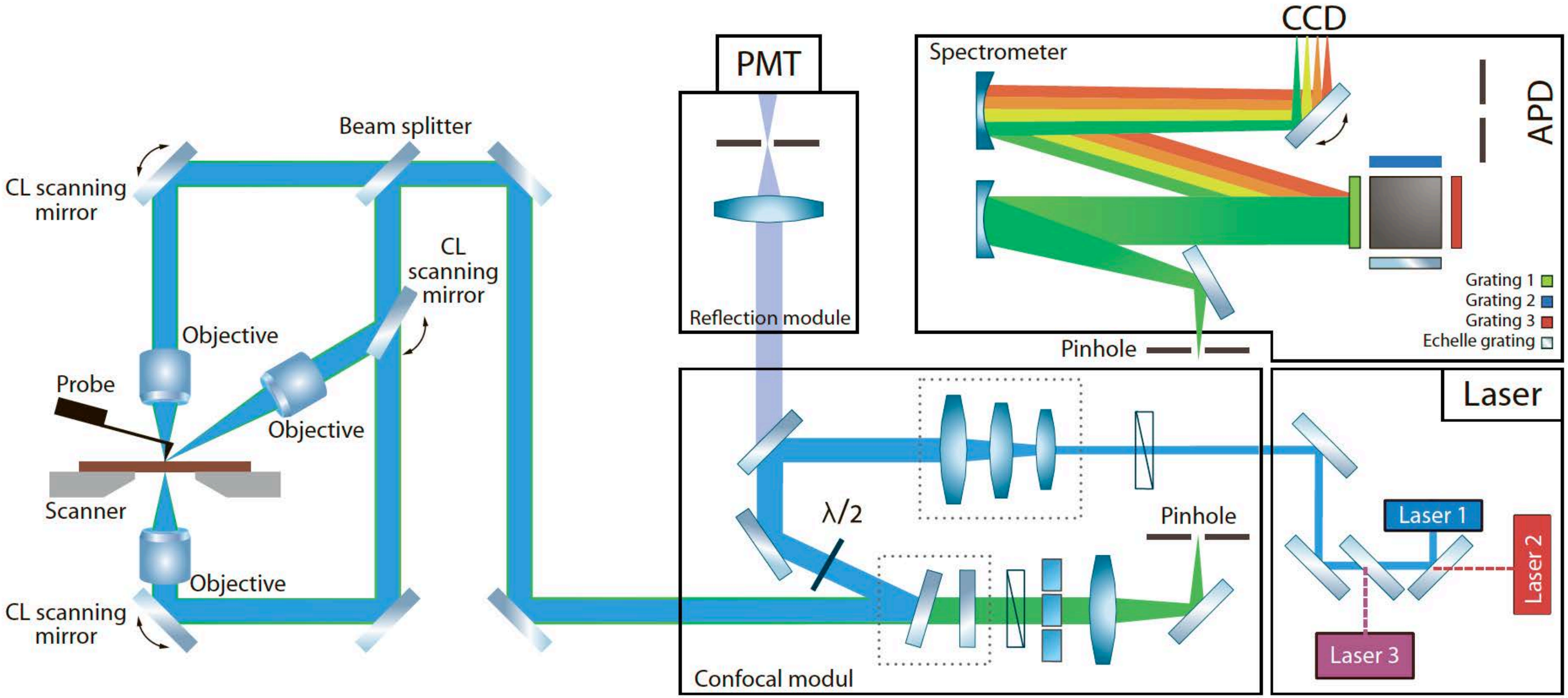
Light input from bottom (with scanning mirror)

Bottom optics (LED illuminator & camera)





Принцип работы

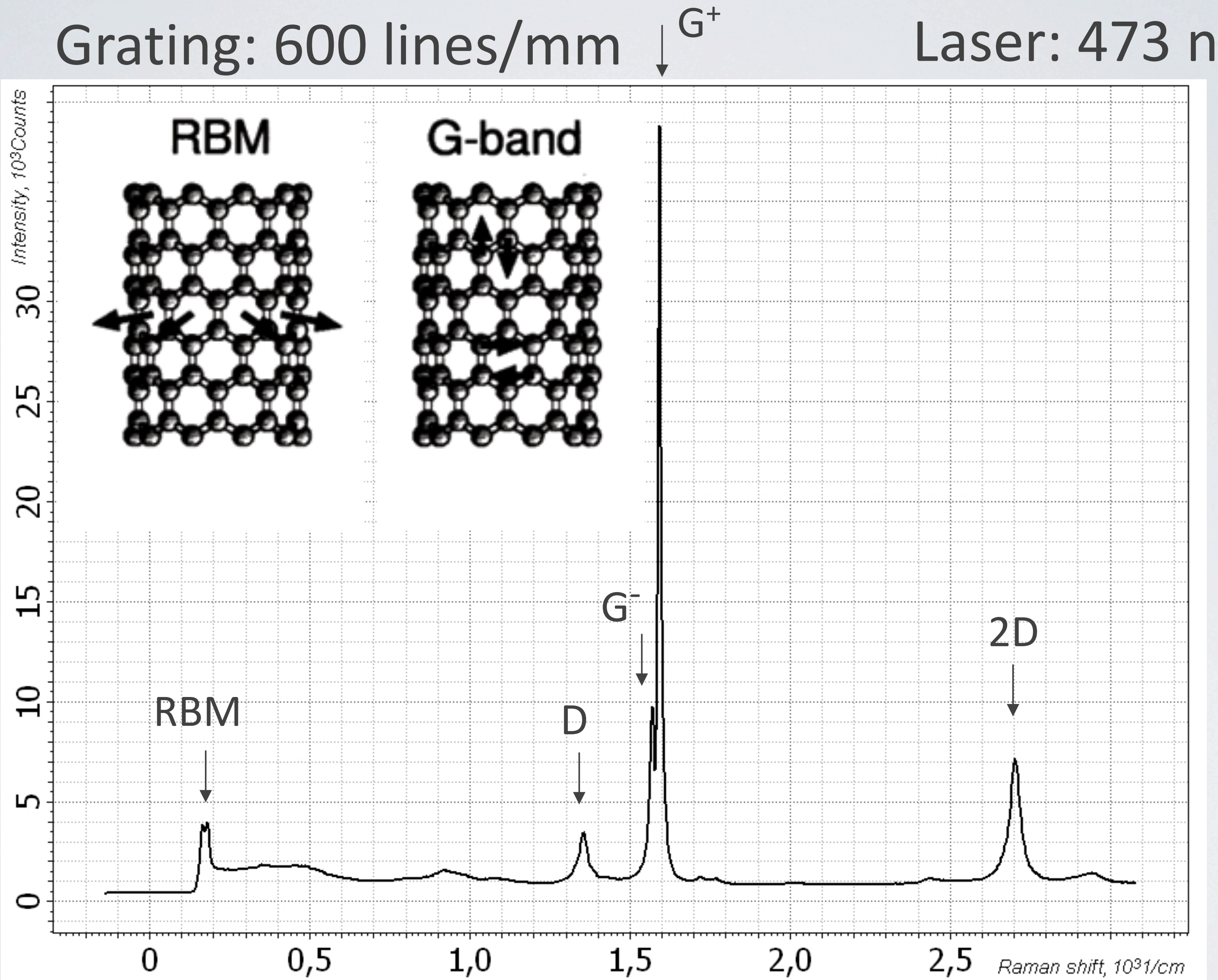


- True confocal design. Motorized confocal pinhole.
- Diffraction limited resolution guaranteed (e.g. 200 nm for blue laser, immersion optics)
- Extremely high optical throughput (~70-80 % for spectrometer, ~40-50% sample-to-detector)
- Fully motorized laser change (up to 3 / 5 lasers). UV – VIS – IR 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

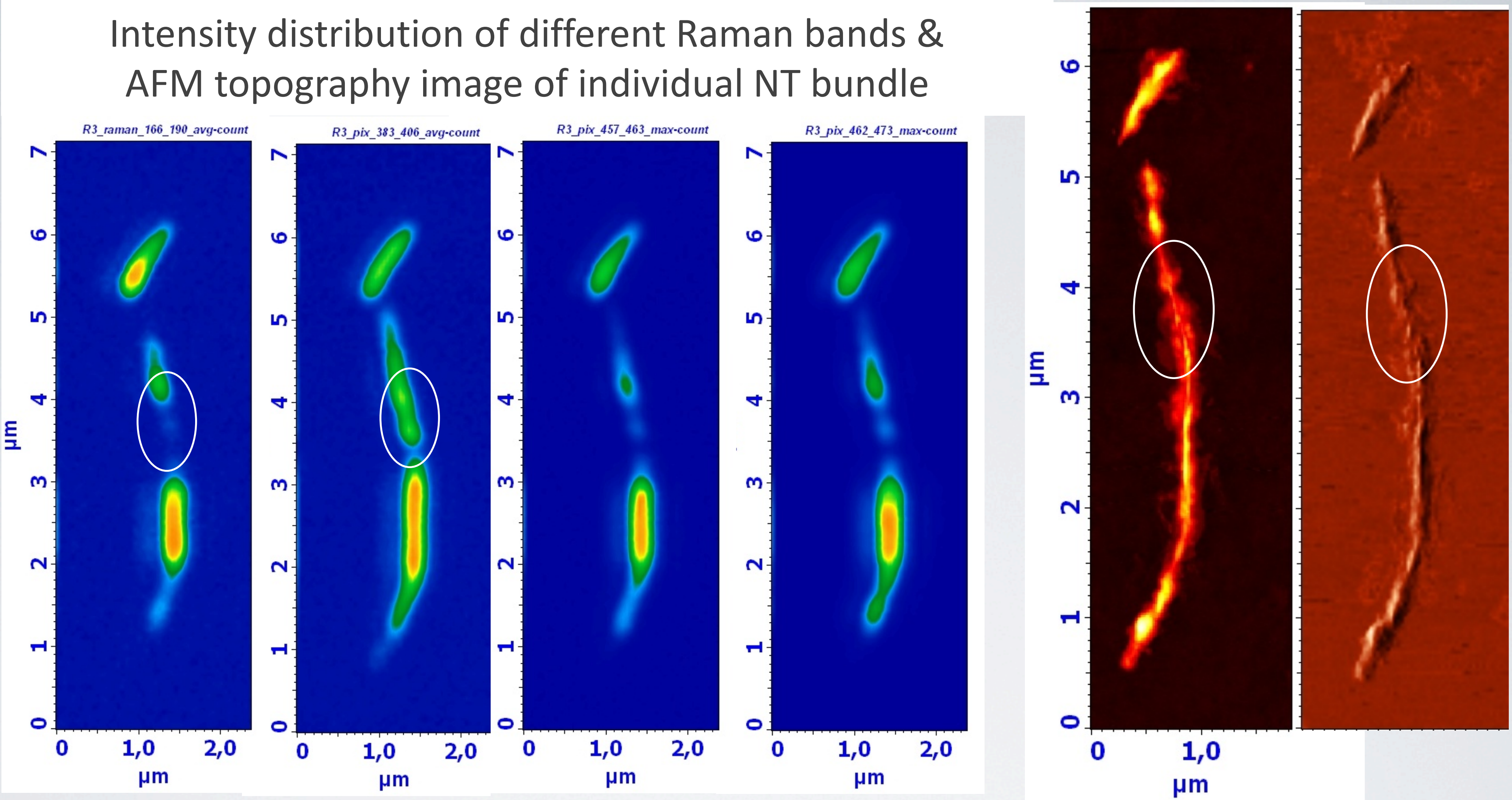
Sample: SWCNTs, Raman spectrum of nanotube bundle

Grating: 600 lines/mm

Laser: 473 nm



Intensity distribution of different Raman bands & AFM topography image of individual NT bundle

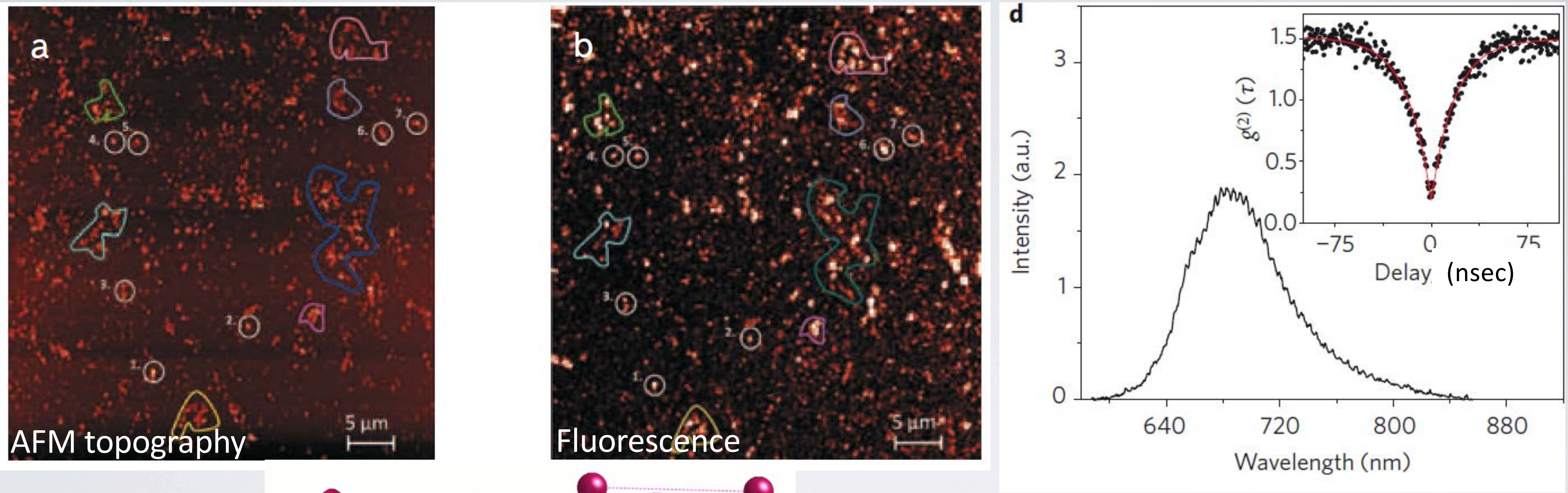


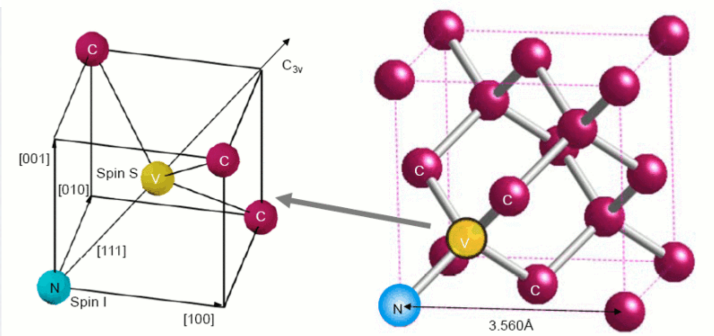
RBM-band *D-band* *G^- - band* *G^+ - band* *AFM height* *AFM phase*

Integration time: 100 ms / point. 50*150 points.

Total spectrum was acquired at each point of the scan. After measurement, different Raman bands are chosen and their intensity distribution is analyzed. <u>All the images (AFM + all Raman maps) can be obtained simultaneously, in a single experiment, without any moving of the sample or objective</u>

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 fluorescence 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)

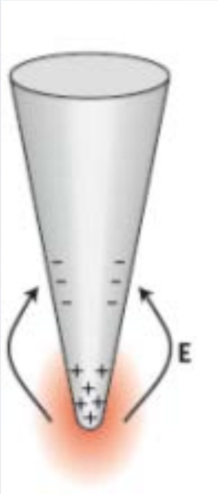
Image Credit: A/Prof. James Rabeau, Quantum Materials and Applications group, Department of Physics and Astronomy, Macquarie University (Sydney, Australia)

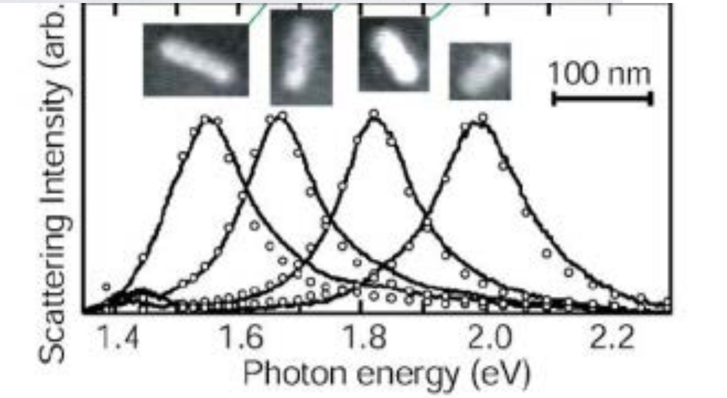
Wavelength dependence of TERS enhancement, graphene on SiO2

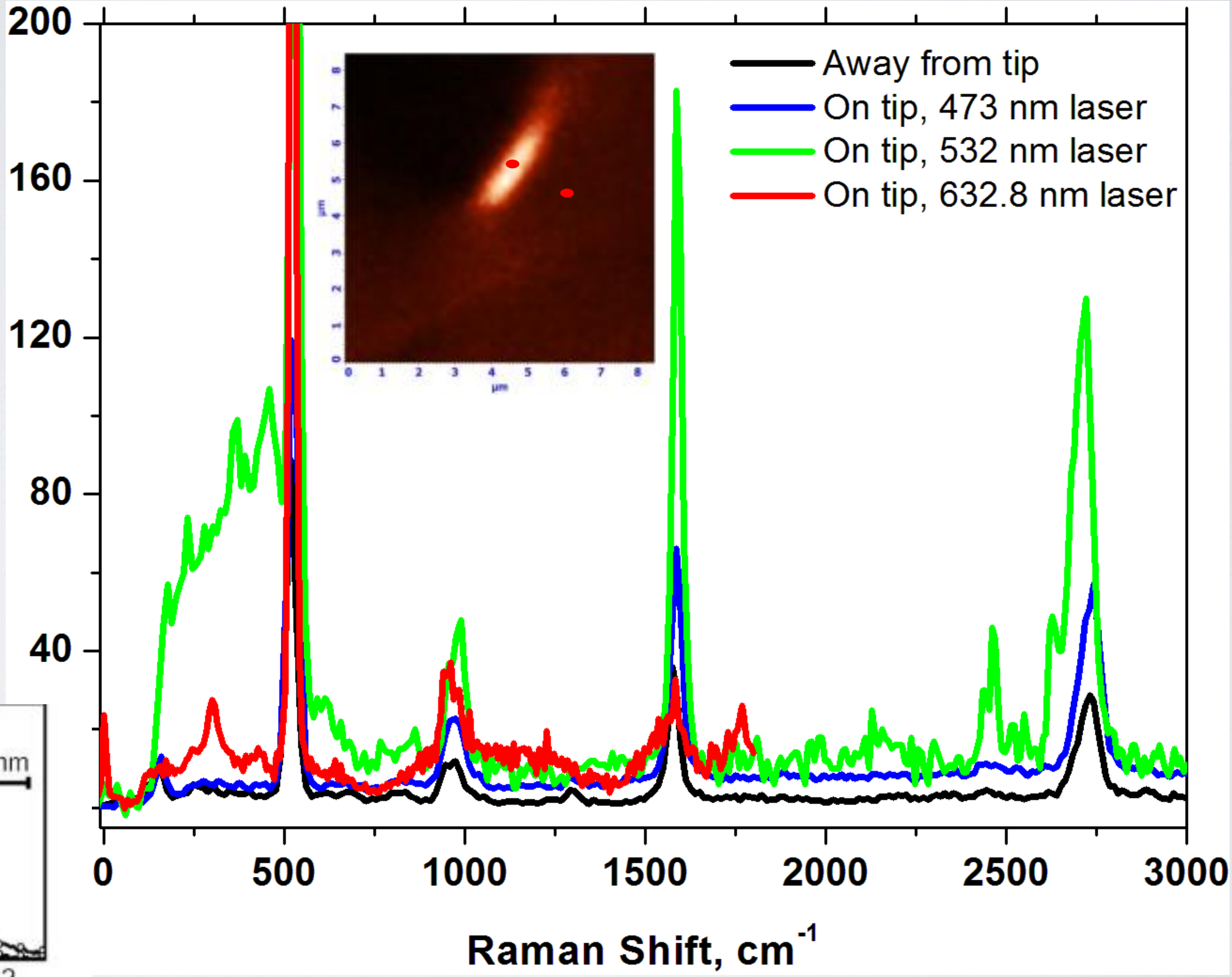
Laser:
633 nm, 532 nm, 473 nm

Tip: Au coated cantilever

Mode: Non-contact

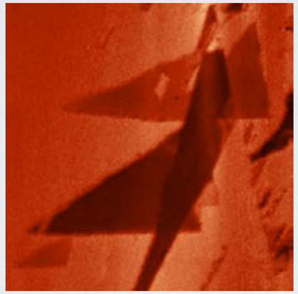






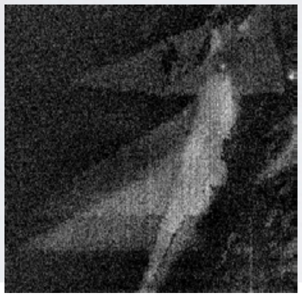
Graphene, AFM + Raman spectroscopy of Raman scattering
A single scan - a lot of data

Lateral Force Microscopy
(friction)

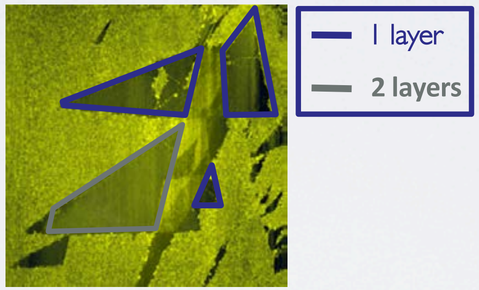


Electrostatic Force Microscopy
(charge distribution)

Force Modulation Microscopy
(elasticity)

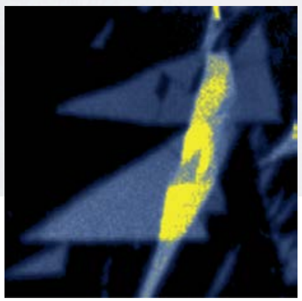


Capacitance Microscopy

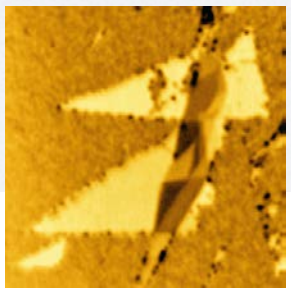


AFM Topography
Size: 30*30 µm

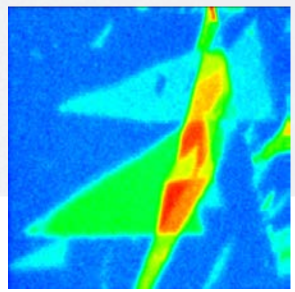
Scanning Kelvin Probe Microscopy
(surface potential)



Raman Map, 2D Band position



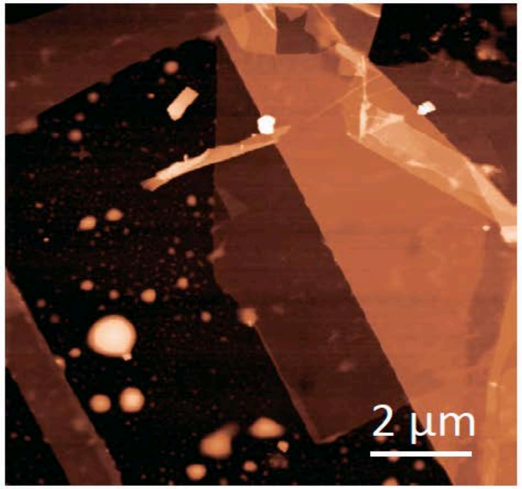
Confocal Rayleigh Microscopy



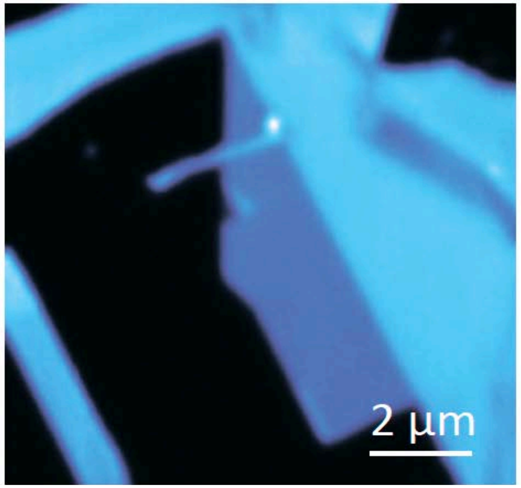
Raman Map, G-band Intensity

Graphene scales on Si/SiO_2

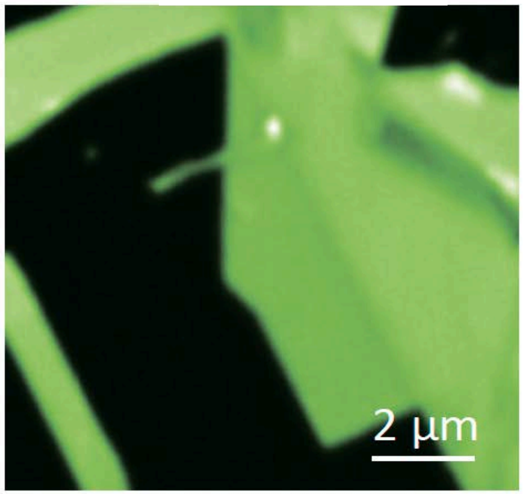
Чешуйки графена на Si/SiO_2



Topography

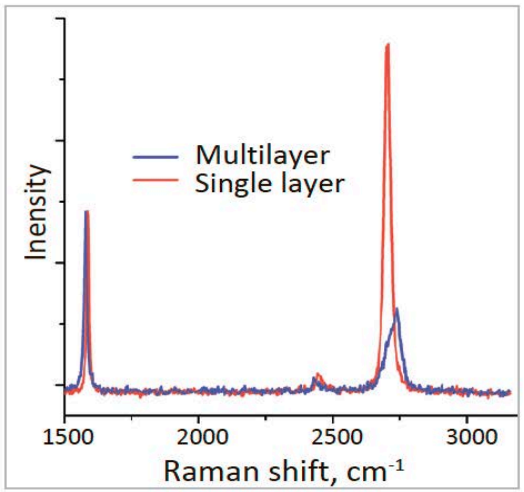


The intensity of the G-band

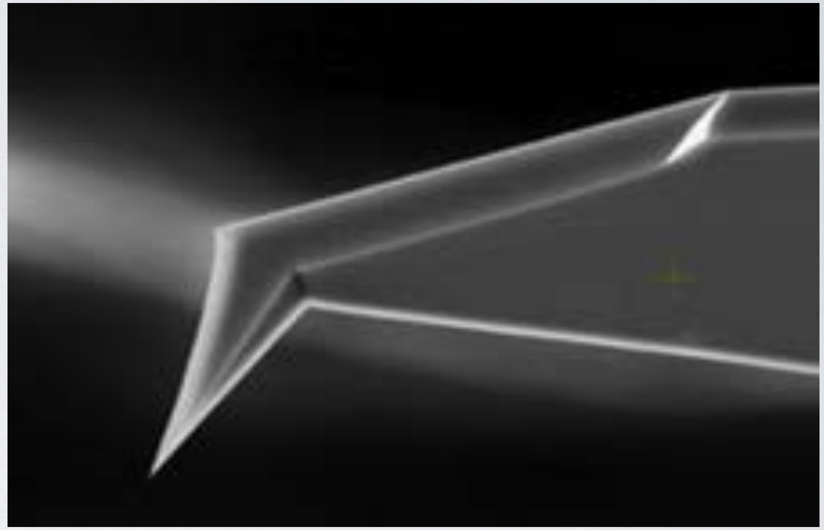


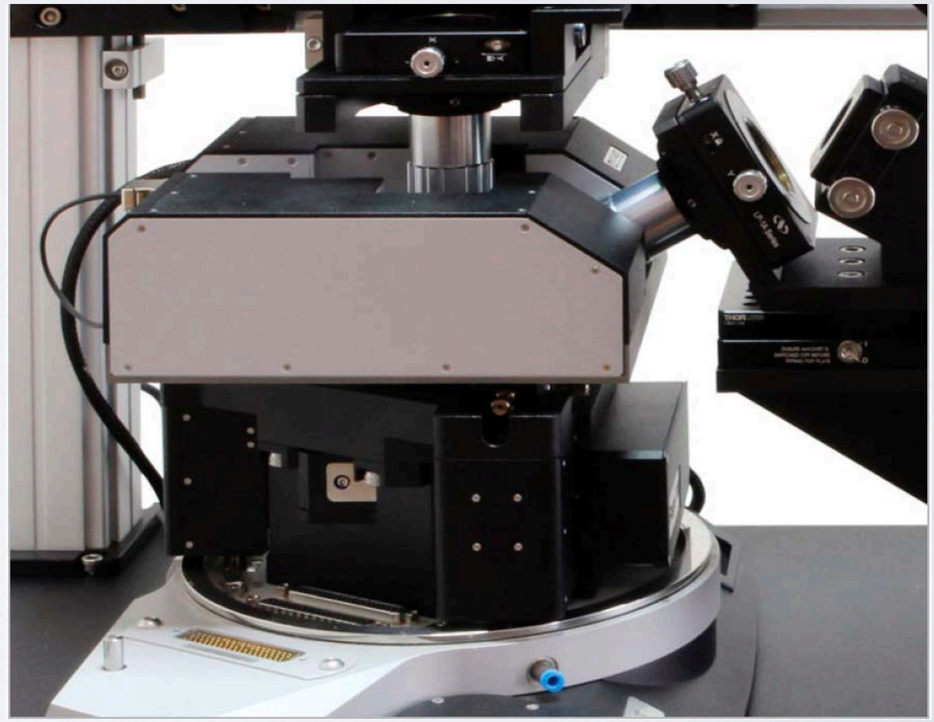
Инденсивность 2D полосы

The intensity of the 2D-band

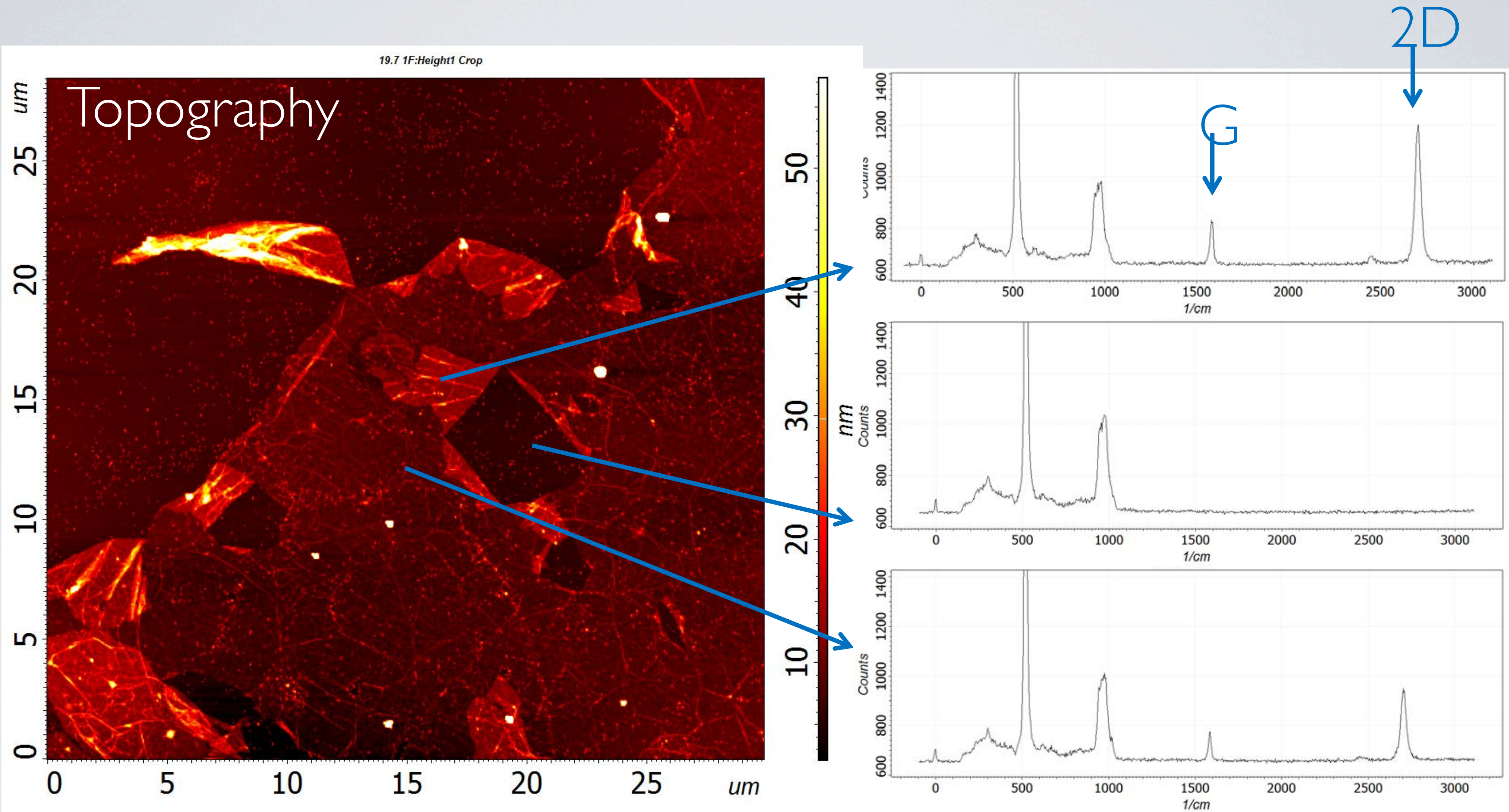


Рамановский спектр





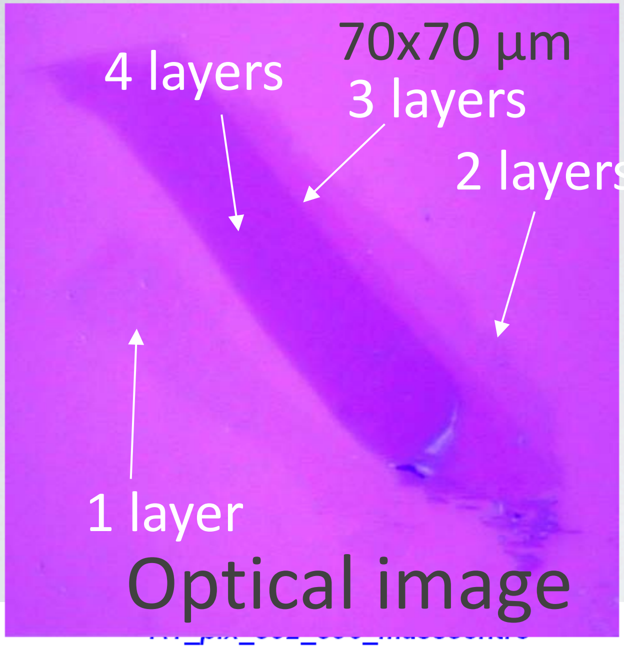
Graphene on SiO2/Si: AFM topography and single point Raman spectrum

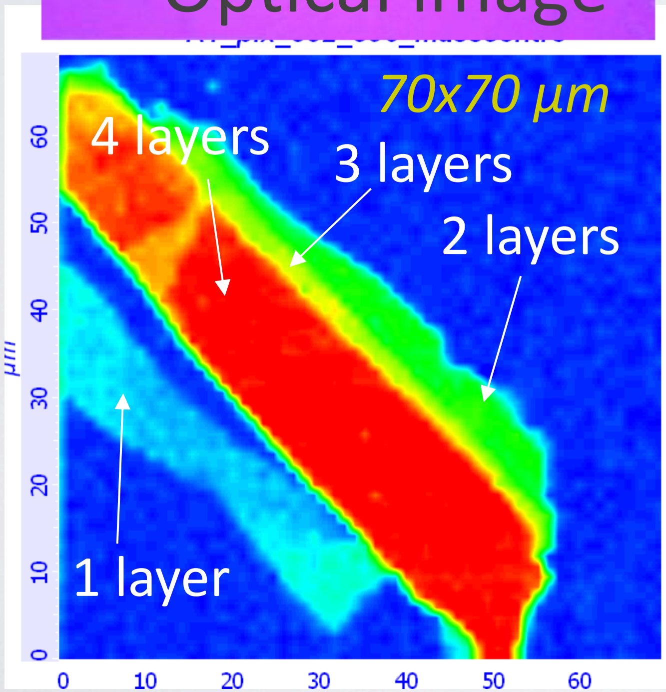


30x30 um AFM (topography) and Raman spectra.

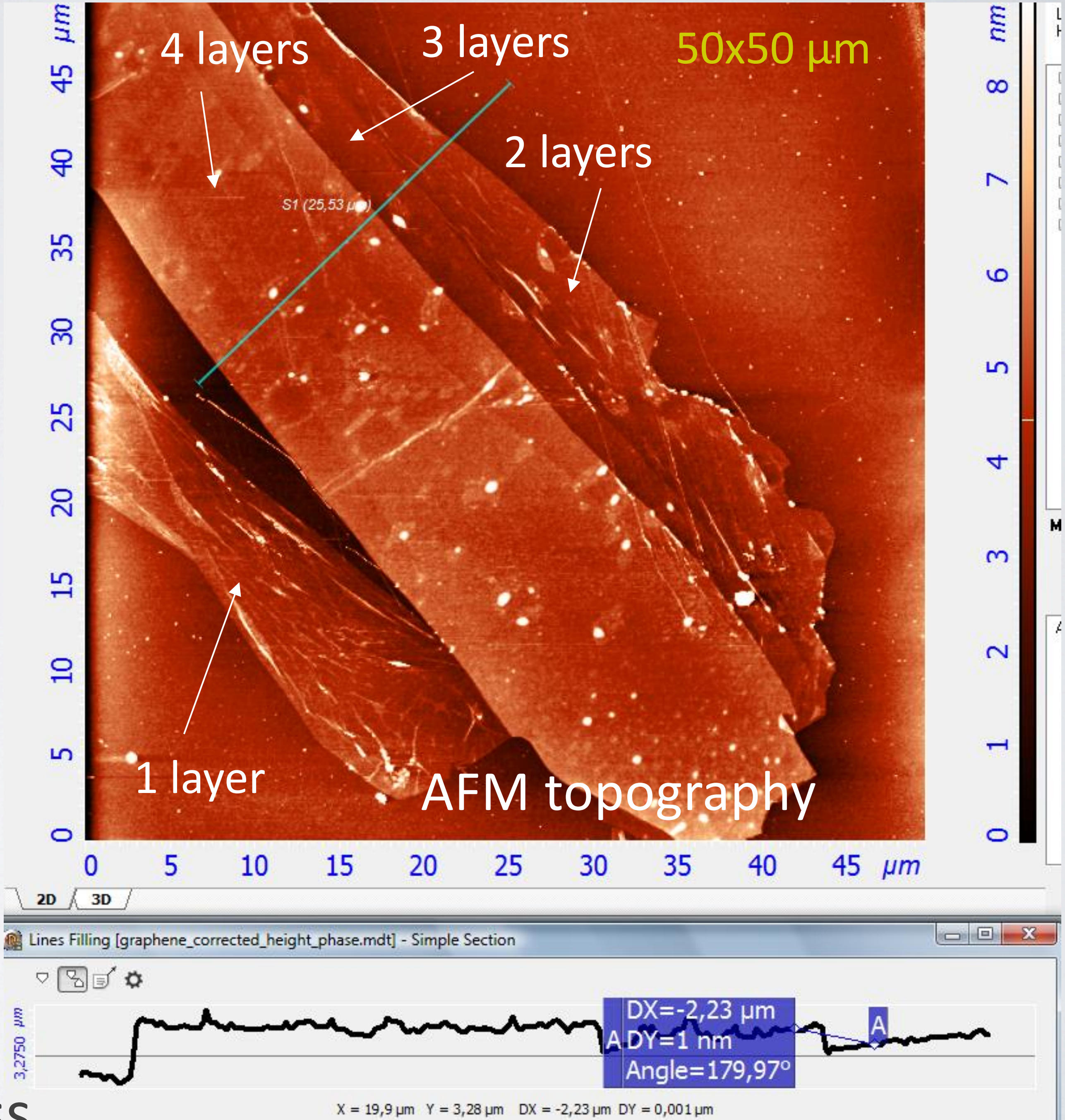
512x512 points. Laser power ~8 mW. 473 nm laser. 0.3s exposure time

Graphene flakes: AFM & Raman microscopy

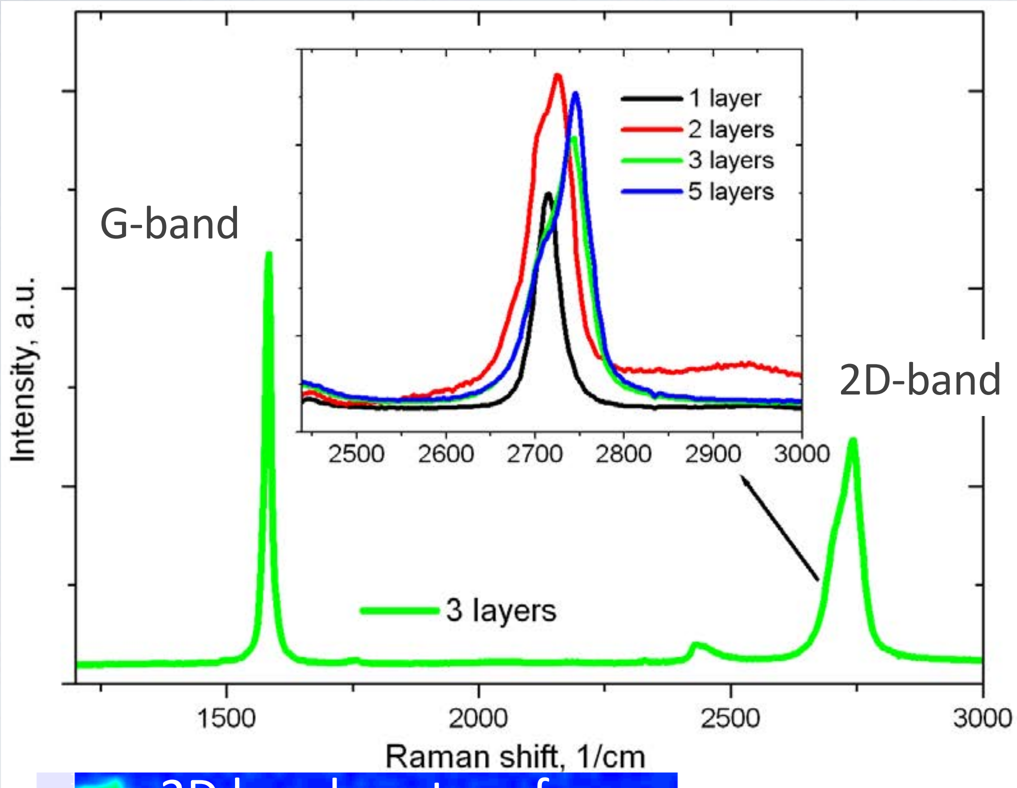


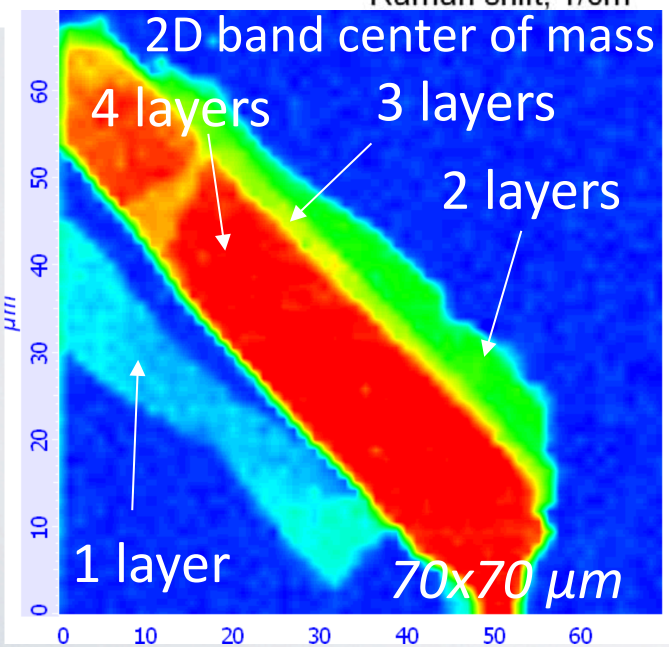


2D band center of mass

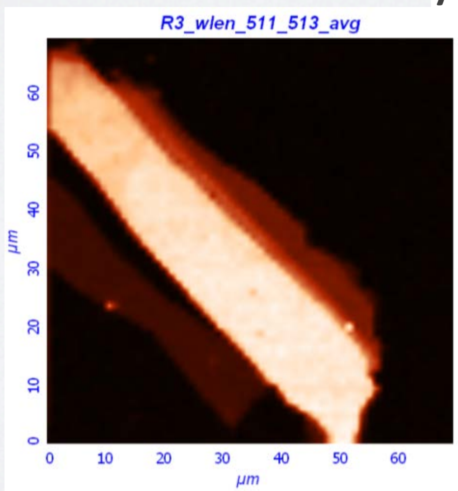


Raman spectroscopy of graphene flakes



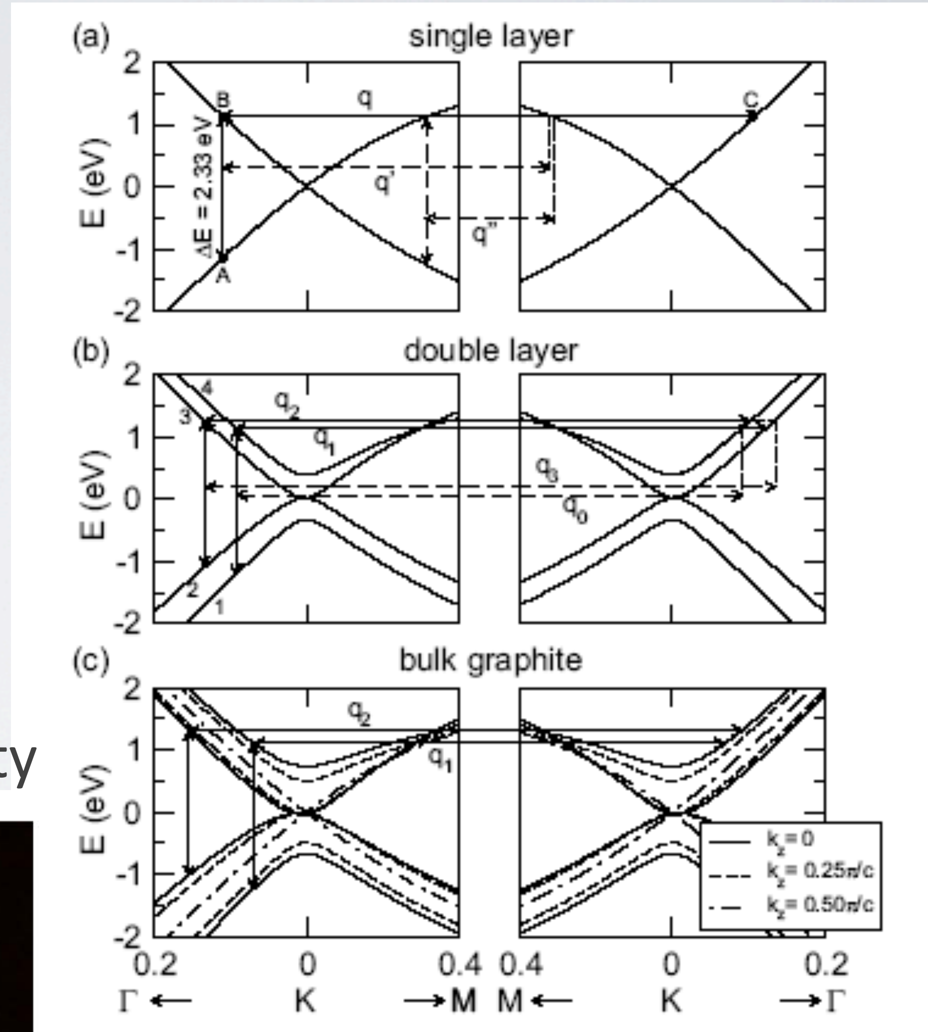


G-band intensity



NTEGRA Spectra

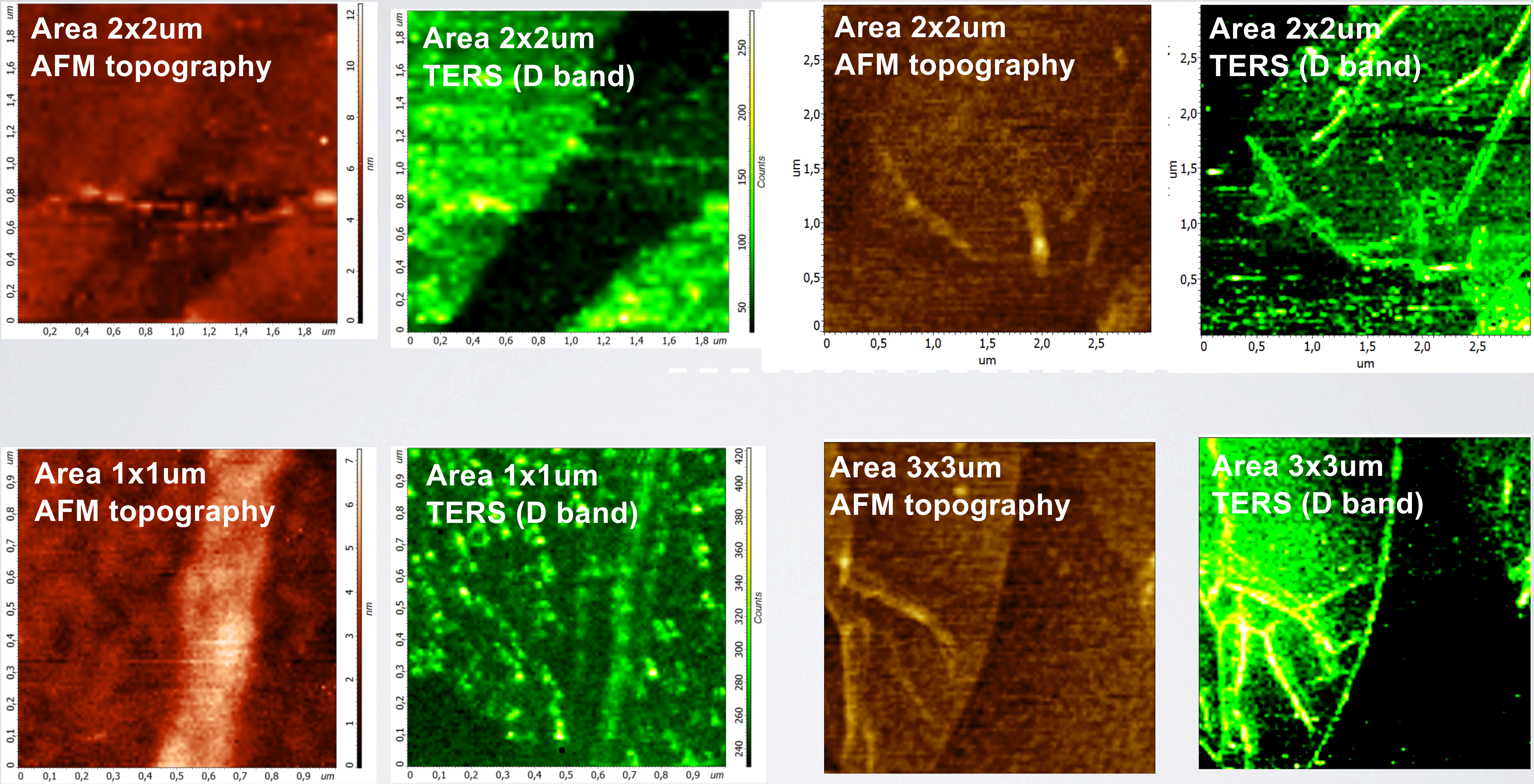
From: Davy Graph et al., 2006



Double resonant Raman scattering –
origin of 2D peak

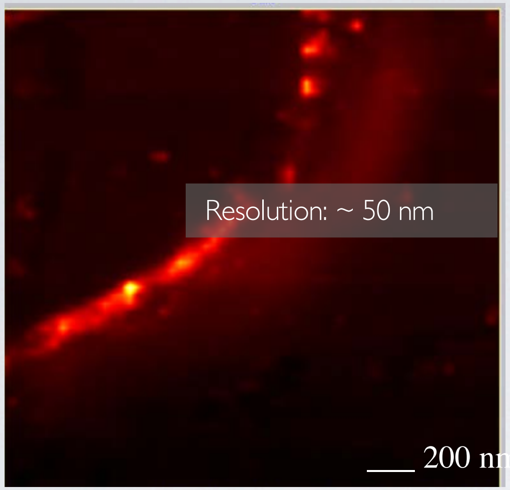
Data measured: P.Dorozhkin & E. Kuznetsov, NT-MDT

TERS on Graphene Oxide
AFM TERS cantilevers, HYBRID regime

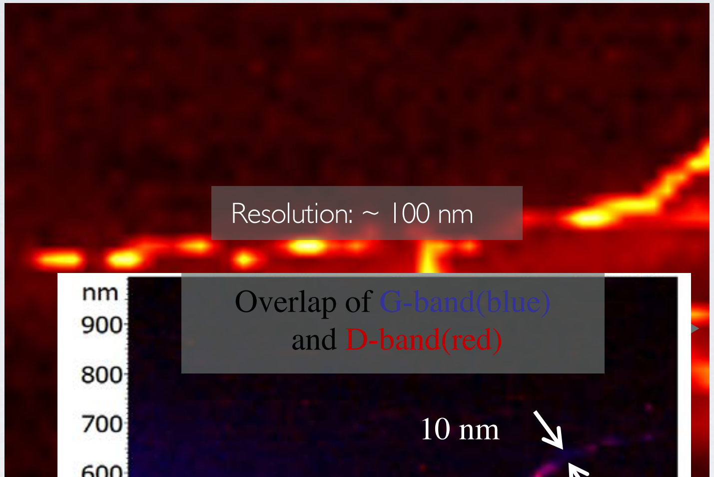


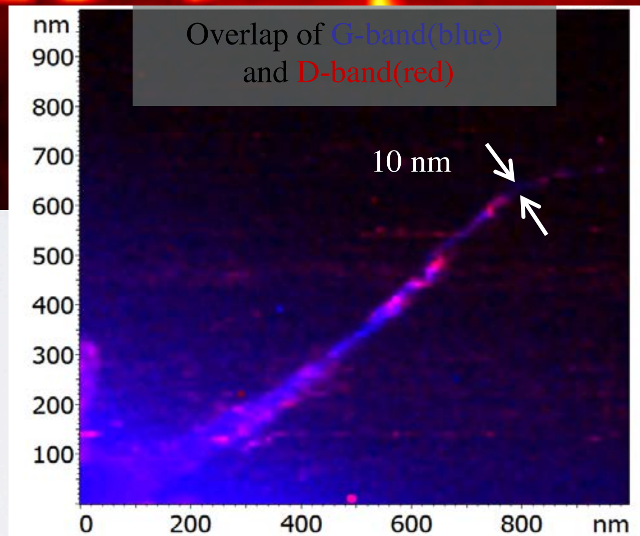
Typical resolution we obtain: ~ 10 – 40 nm.

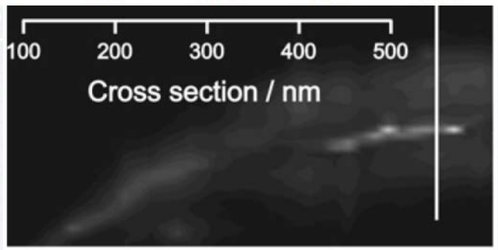
TERS of Carbone Nanotubes



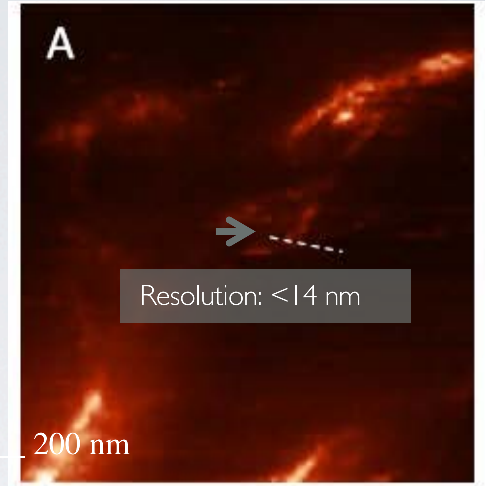
S.S. Kharintsev, G. Hoffmann, P.S. Dorozhkin, G. de With, and J. Loos, Nanotechnology 18 (2007), 315502





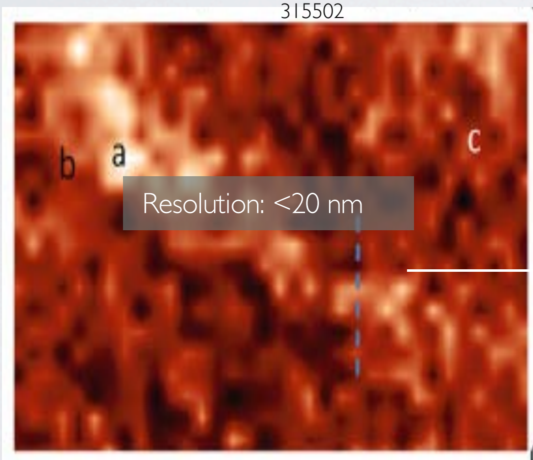


S. Kharintsev, G. Hoffmann, A. Fishman. & M. Salakhov J. Phys. D: Appl. Phys. 46 (2013) 145501



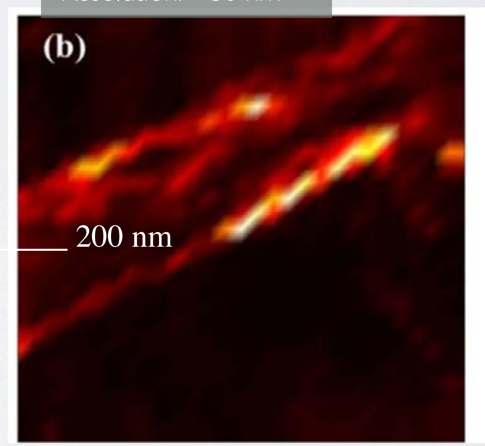
Chan K.L., Kazarian S.G., Nanotechnology 21, 445704 (2010)

Resolution: <14



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

Resolution: ~30 nm



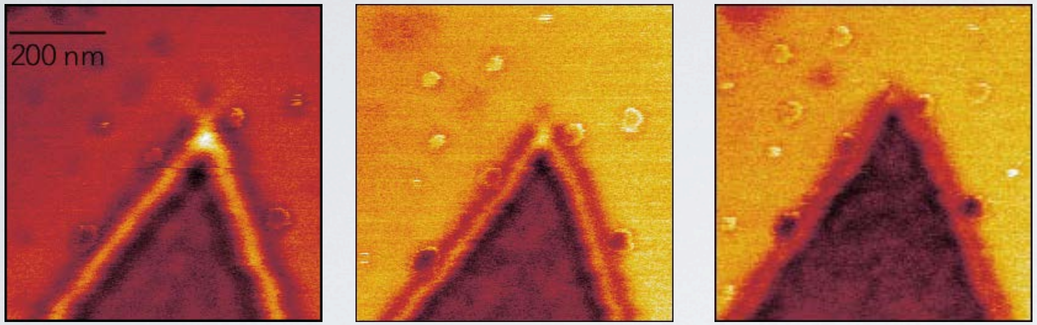
M. Zhang, J. Wang, Q. Tian, Optics Communications 315, 164 (2014)

NT-MDT Spectrum Instruments

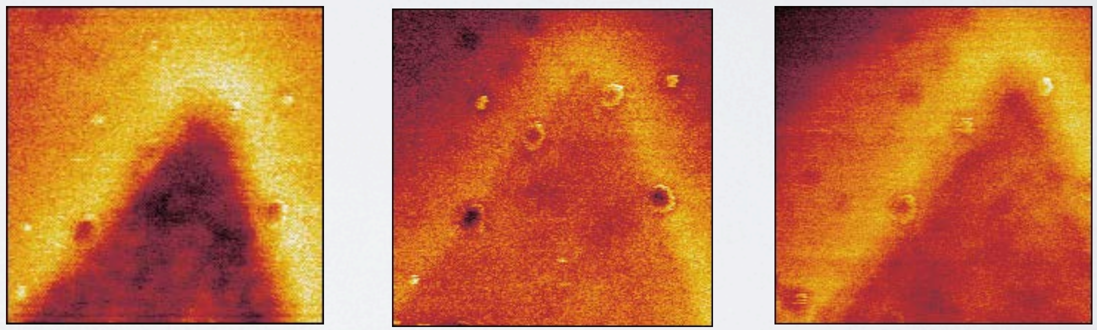
Gated Graphene on SiO_2

Real(Reflection) for λ= 10.6um

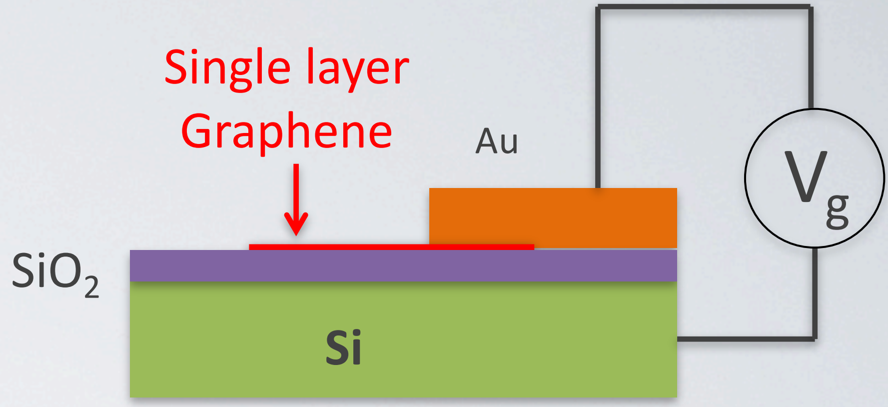
-60V -20V 0V



10V 30V 60V



Sample schematic



- 4 minutes per image
- 10nm resolution
- Tip launched plasmons clearly respond to V_g

Re(nR) Im(nR) Ampl. Phase

What about Amplitude and Phase?
The Nano Raman can do that too!

Sample provided by Xu Du (SBU), measured on nR/NTMDT, lab of Prof. Liu, (SBU)

nature nanotechnology
LETTERS
PUBLISHED ONLINE: 4 APRIL 2010 | DOI: 10.1038/NNANO.2010.44

Carbon nanotubes degraded by neutrophil myeloperoxidase induce less pulmonary inflammation

Valerian E. Kagan[1]*, Nagarjun V. Konduru[1], Weihong Feng[1], Brett L. Allen[2], Jennifer Conroy[3], Yuri Volkov[3], Irina I. Vlasova[1], Natalia A. Belikova[1], Naveena Yanamala[4], Alexander Kapralov[1], Yulia Y. Tyurina[1], Jingwen Shi[5], Elena R. Kisin[6], Ashley R. Murray[6], Jonathan Franks[7], Donna Stolz[7], Pingping Gou[2], Judith Klein-Seetharaman[4], Bengt Fadeel[5], Alexander Star[2] and Anna A. Shvedova[6]

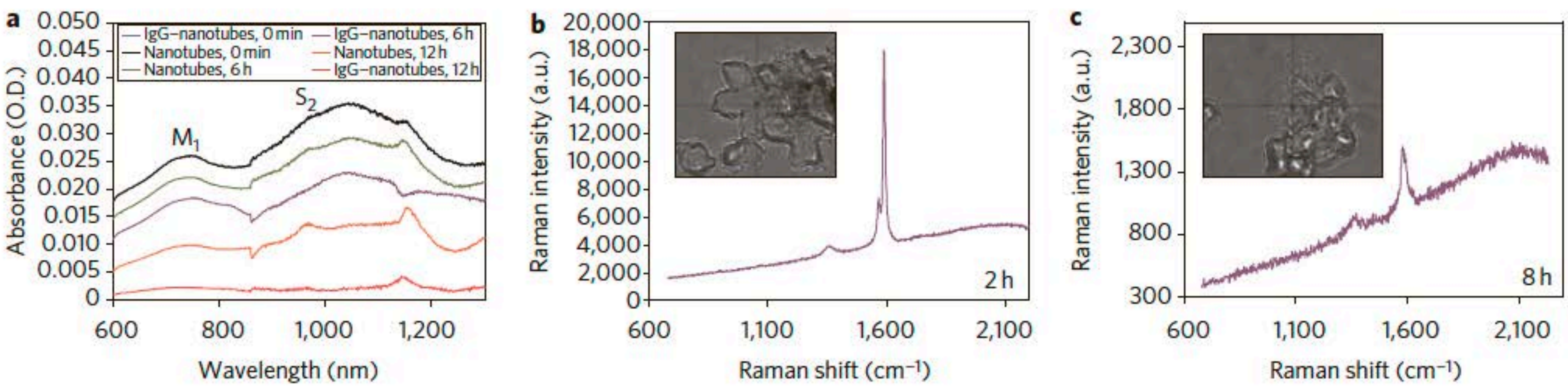
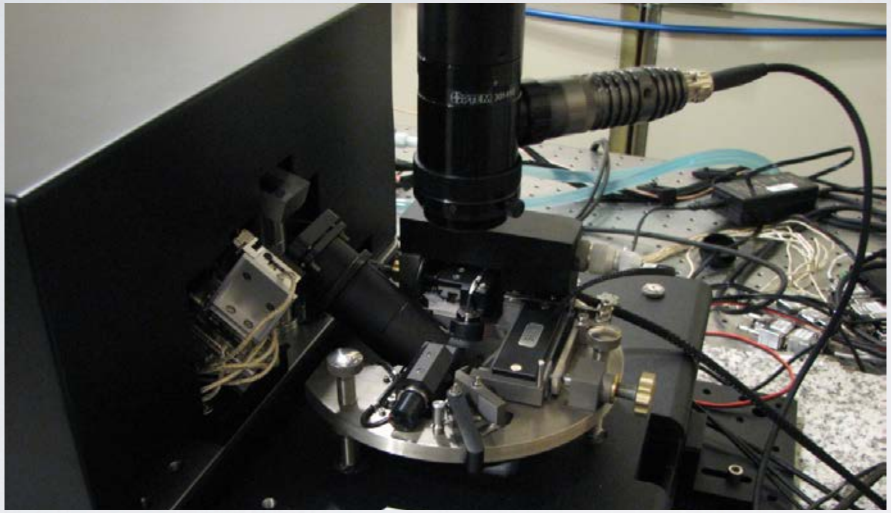
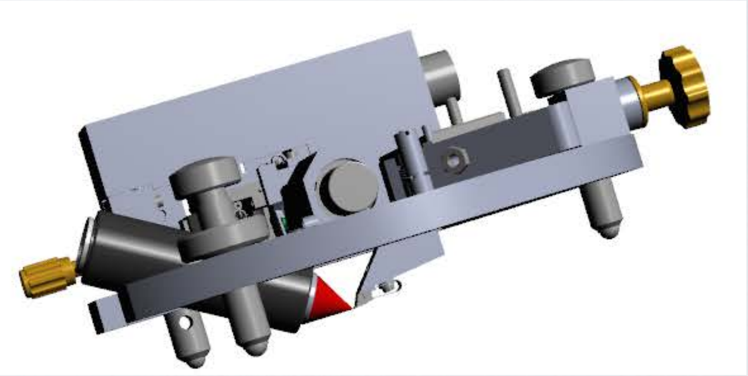
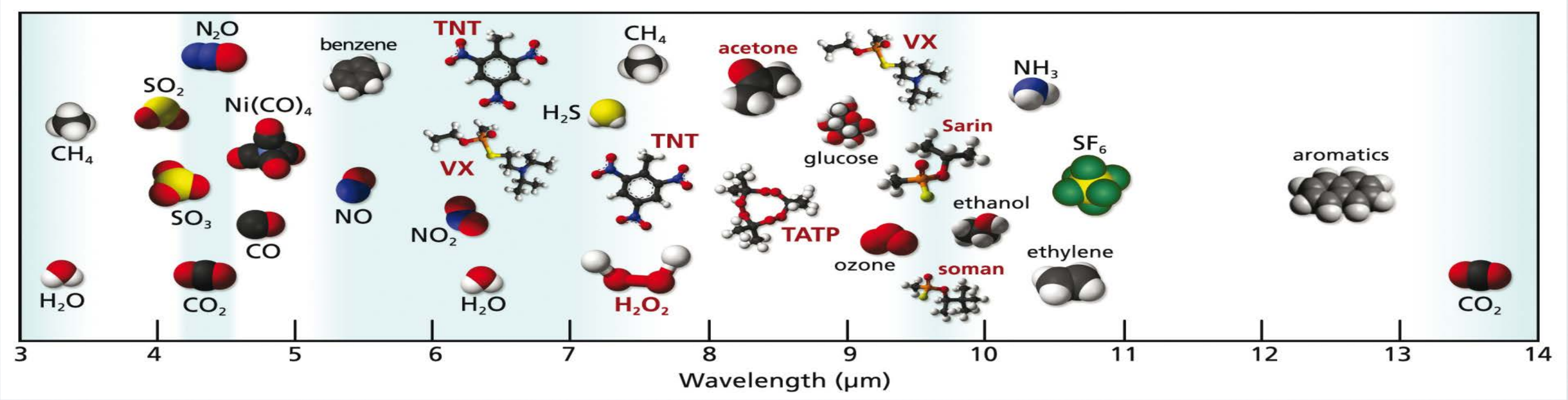


Figure 4 | Biodegradation of nanotubes in neutrophils evaluated by infrared and Raman spectroscopy. a, Vis–NIR spectra showing biodegradation of nanotubes and IgG–nanotubes by human neutrophils after 0, 6 and 12 h. O.D., optical density. **b**,**c**, Raman spectra (excitation, 473 nm) recorded from different areas of neutrophils containing IgG–nanotubes at 2 h (**b**) and 8 h (**c**). Inset shows bright-field image of the neutrophils with engulfed IgG–nanotubes. The Raman spectra (red lines) with their corresponding G- and D-bands recorded from different areas of neutrophils are indicated by the cross-wire on the bright-field images.

Aperture Less Nearfield Optical Microscope Head (s-SNOM Head) with IR lens

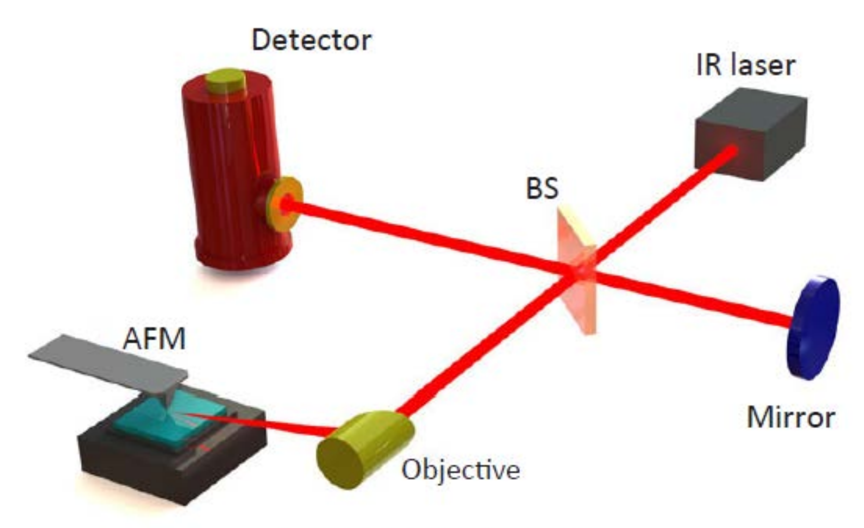






NT-MDT Spectrum Instruments

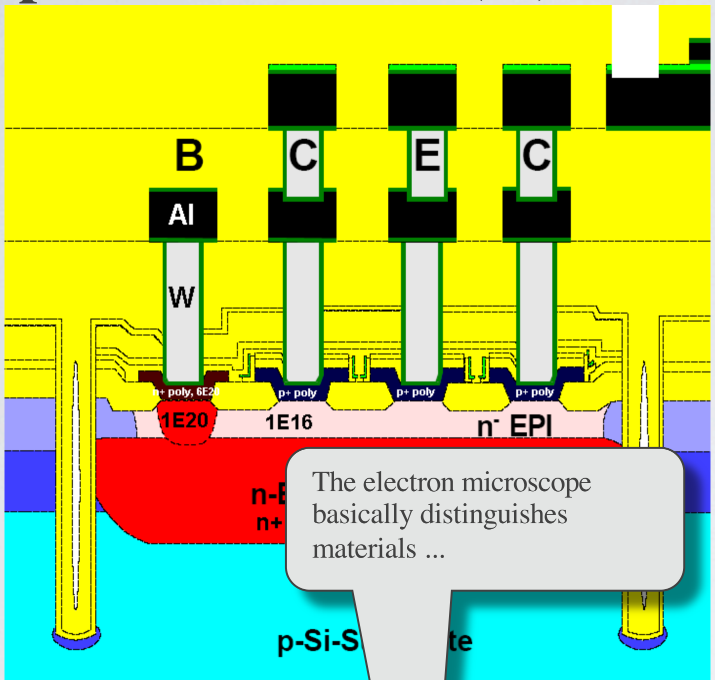
NTEGRA IR



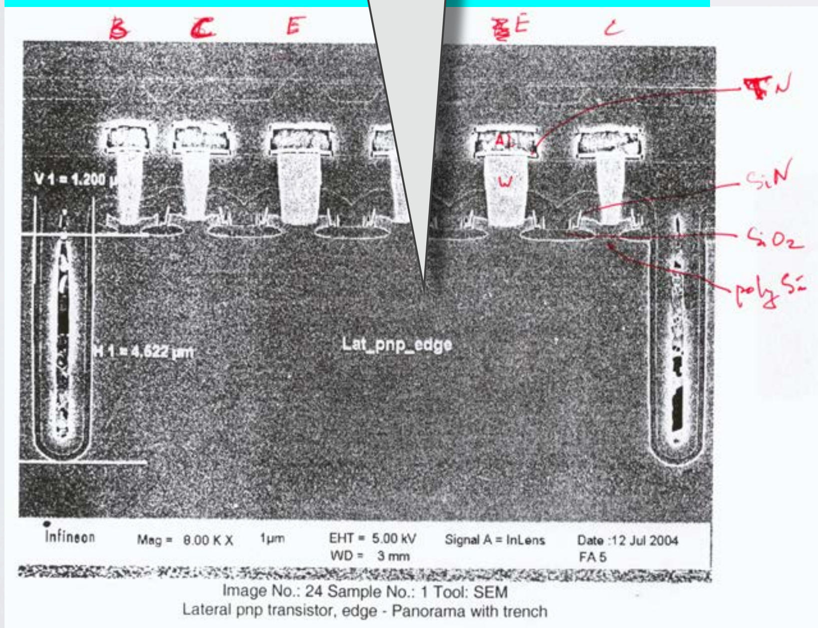
NTEGRA IR principal scheme

- IR microscopy and spectroscopy with 10 nm resolution
- Wide spectral range of operation: 3-12 µm
- Incredibly low thermal drift and high signal stability
- Versatile AFM with advanced modes: SRI (conductivity), KPFM (surface potential), SCM (capacitance), MFM (magnetic properties), PFM (piezoelectric forces)
- HybriD Mode - quantitative nanomechanical mapping
- Integration with Raman (optionally)

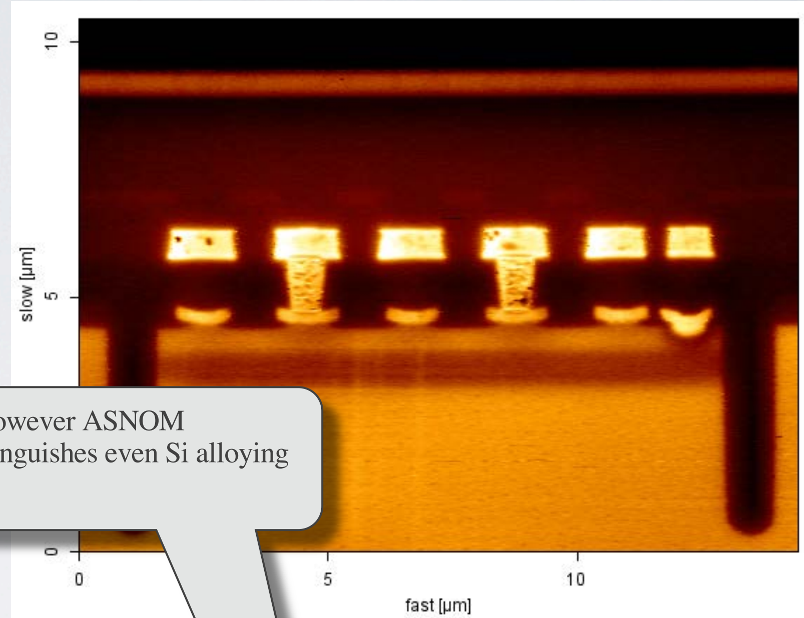
Bipolar transistor (Si) Skew plate with a planar p-n-p transistor

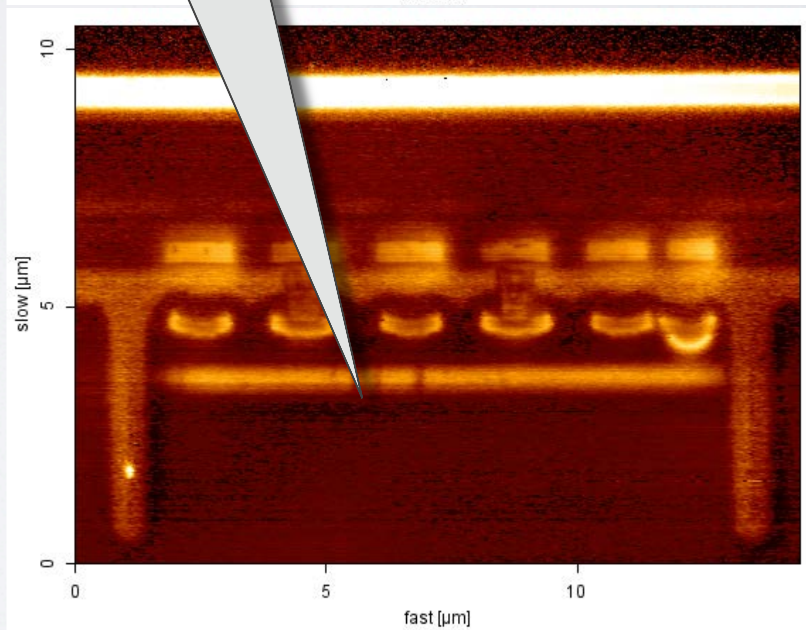


The electron microscope basically distinguishes materials ...



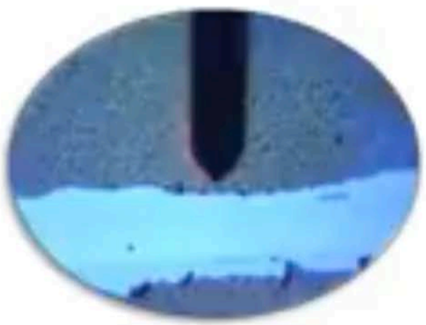
... however ASNOM distinguishes even Si alloying



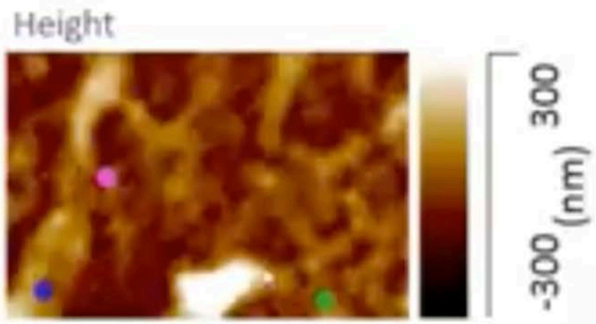


NT-MDT Spectrum Instruments

*Fast*Spectra: Reverse Osmosis Membrane



Optical Image



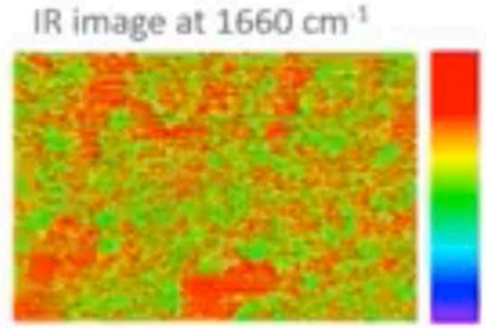
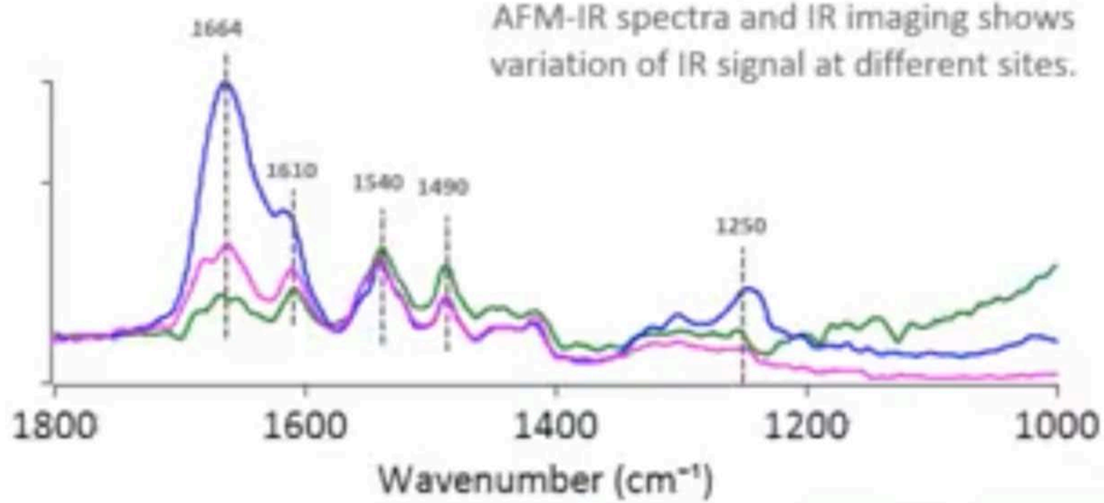


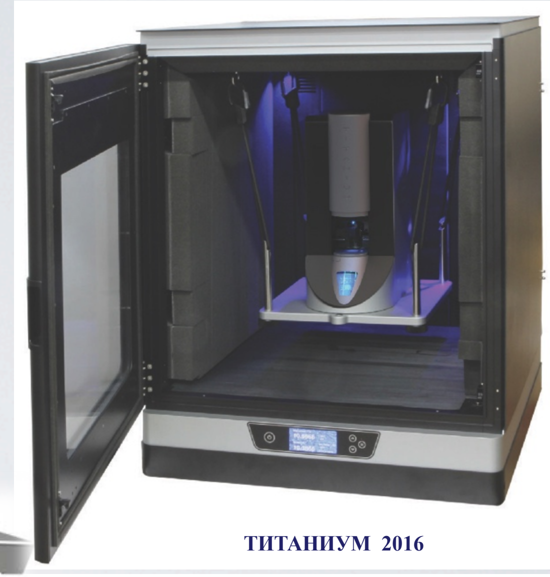
Image size: 15 um x 10 um

AFM-IR spectra and IR imaging shows variation of IR signal at different sites.



NT-MDT Spectrum Instruments Product Line

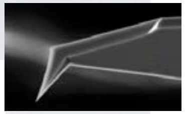
IR ALSNOM,
2016 - 2017



ТИТАНИУМ 2016

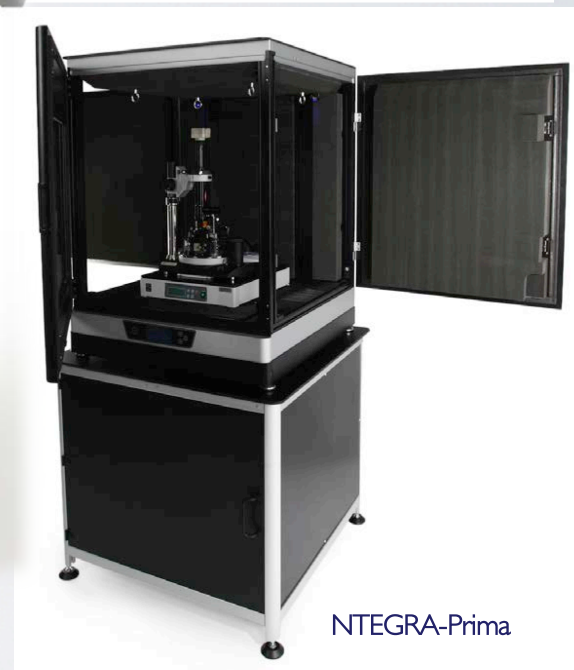
ИНТЕГРА-СПЕКТРА-4Р 2016

polySi-Technology, R_c- 3-5 nm



Новые типы кантилеверов (2015 -2016 г.г.)

SOLVER-Pipe -2017

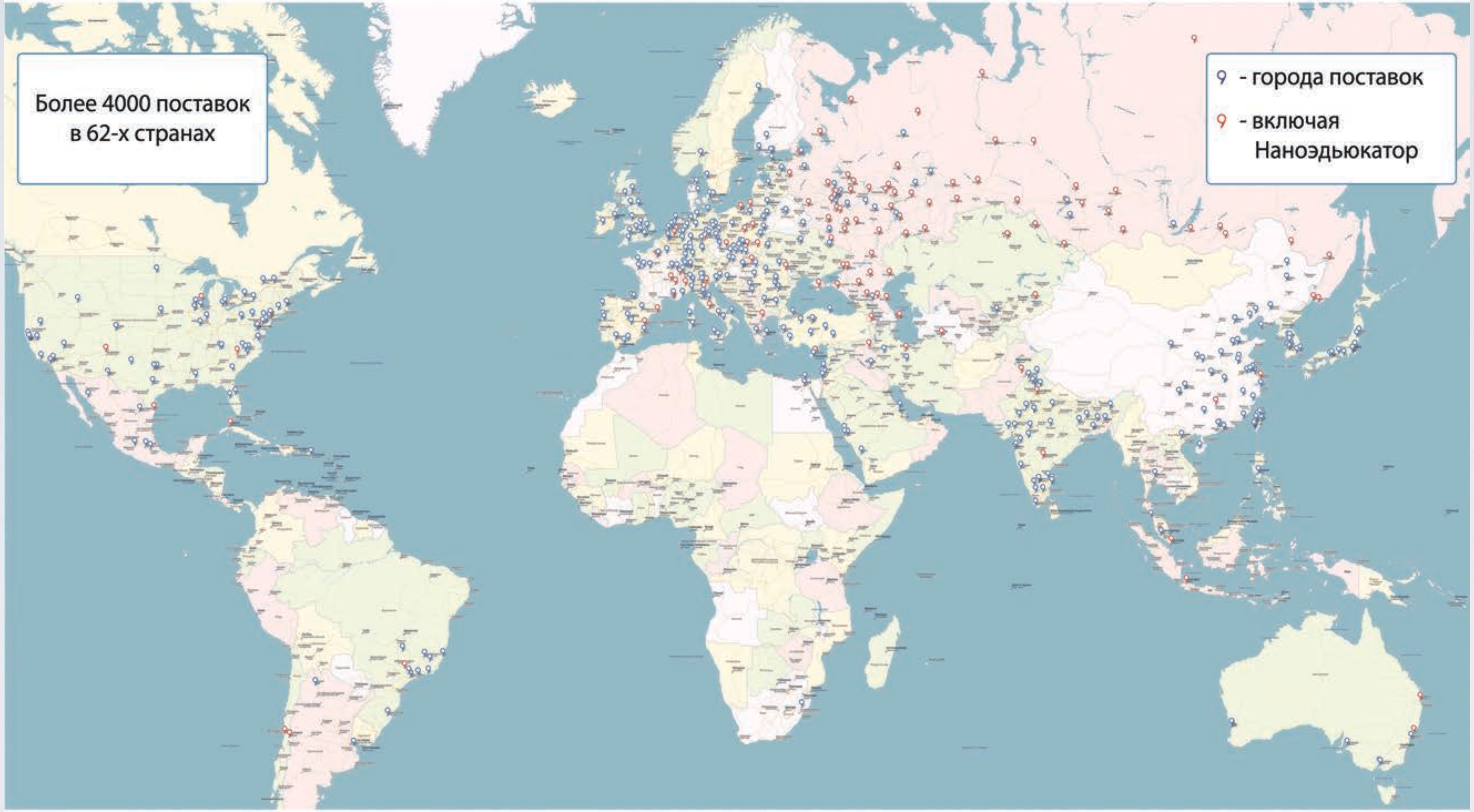


NTEGRA-Prima

NT-MDT
Spectrum Instruments

NT-MDT
Spectrum Instruments

География поставок оборудования по России и миру



NT-MDT

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