Зондовые методы

За пределами топографии

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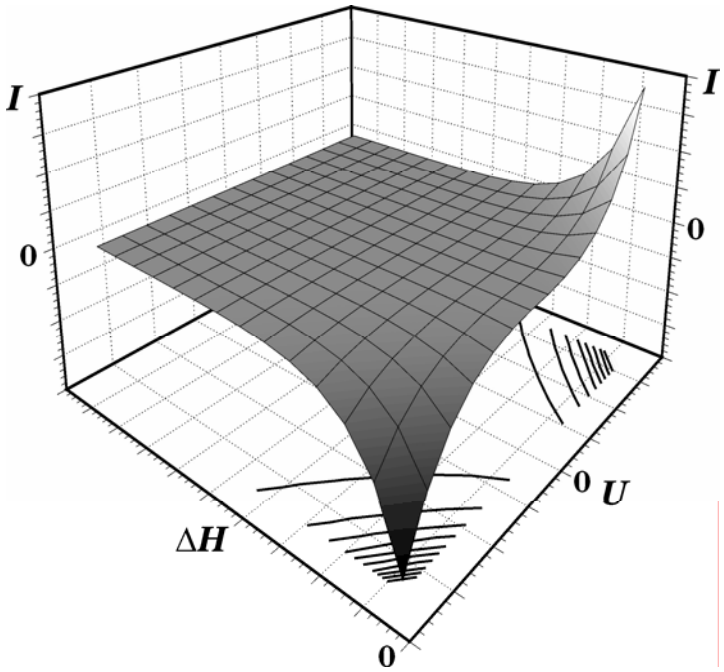
Презентация доступна в интернет:
http://www.elch.chem.msu.ru/wasq/zond2.pdf

СТМ: Локальные туннельные спектры



Вольтамперные спектры
$I=f(U)$, H=const

Плотность электронных состояний (LDOS)

Токвысотные спектры
$I=f(H)$, U=const

Высота туннельного барьера

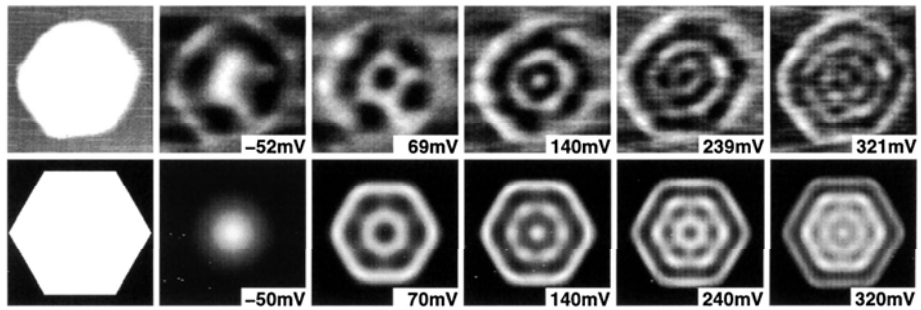
Вольтвысотные спектры
$H=f(U)$, I=const

Спектроскопическое картирование

Ag/Ag(111)

Current imaging tunneling spectroscopy (CITS)

Дифференциальное картирование dI/dU, dI/dH

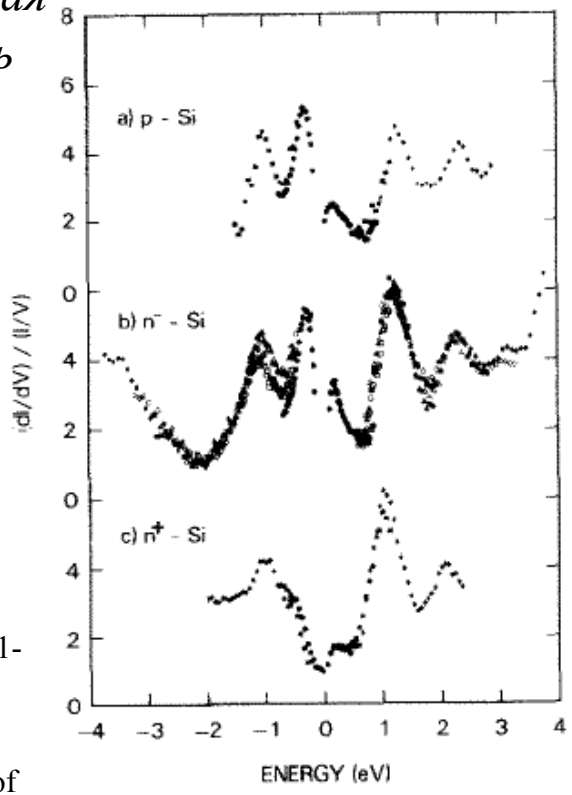


СТМ: Вольтамперные спектры

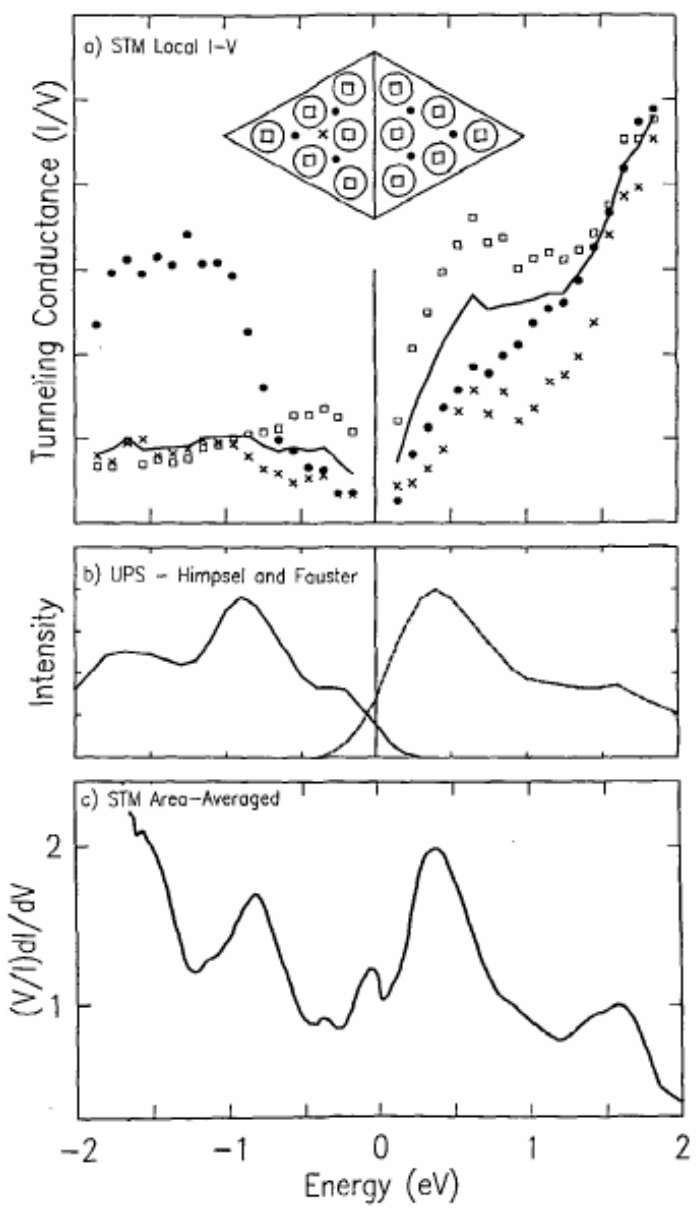
$$I(U) \propto \int_0^{eU} \rho_s(E)\rho_t(E-eU)T(E,U)\,\mathrm{d}E$$

$$\frac{\mathrm{d}I/\mathrm{d}U}{I/U} = \frac{\rho_s(eU)\rho_t(0)+A(U)}{B(U)}$$

Нормализованная проводимость



Si(111)-(7x7)



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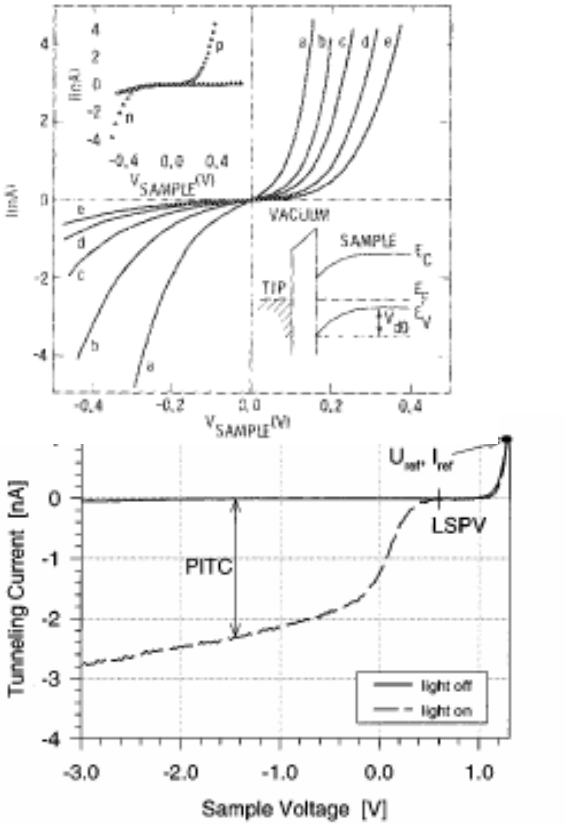
R.M.Feenstra, J.A.Stroscio, A.P.Fein, Tunneling spectroscopy of the Si(111)2x1 surface, Surf.Sci. 181(1987)295-306

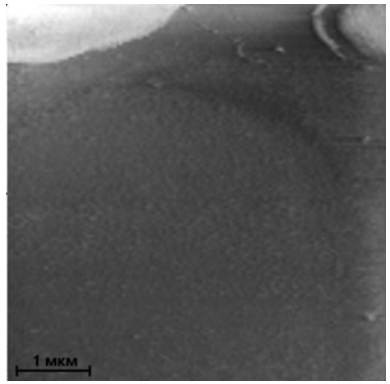
СТМ: Вольтамперные спектры: полупроводники

Гетероструктура металл/ изолятор/полупроводник (MIS) Барьер Шоттки

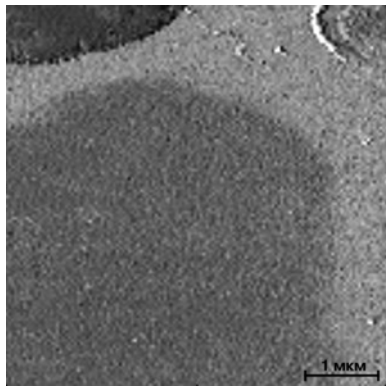


Керамика SnO_2

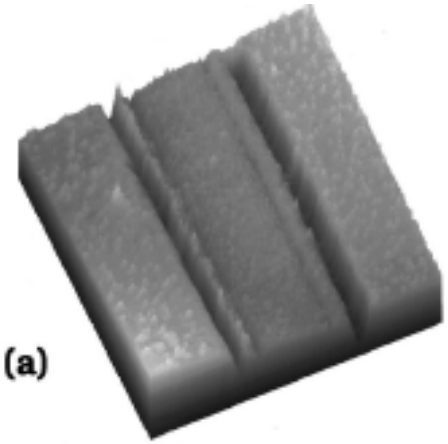
топография

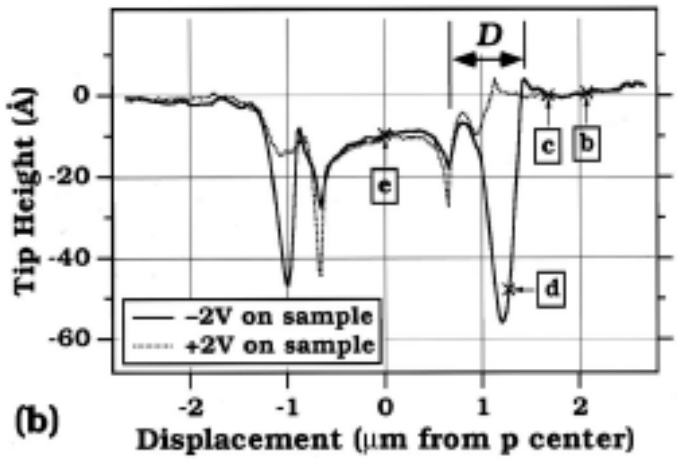


d*I*/d*U*



pn-переход





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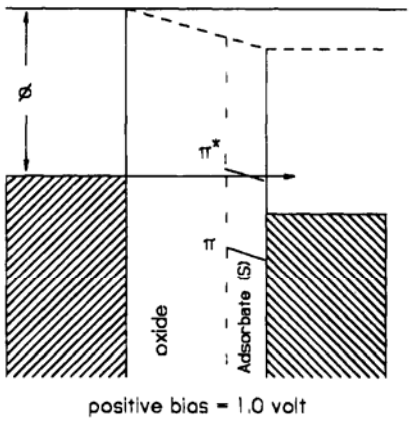
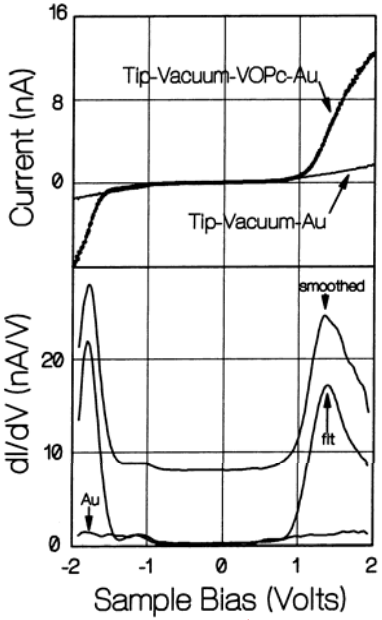
M.L.Hildner, R.J.Phaneuf, E.D.Williams, Imaging the depletion zone in a Si lateral *pn* iunction with scanning tunneling microscopy, Appl.Phys.Lett. 72(1998)3314-3316

СТМ: Вольтамперные спектры: частицы в зазоре

Молекулы

Orbital mediated tunneling
Negative differential resistance

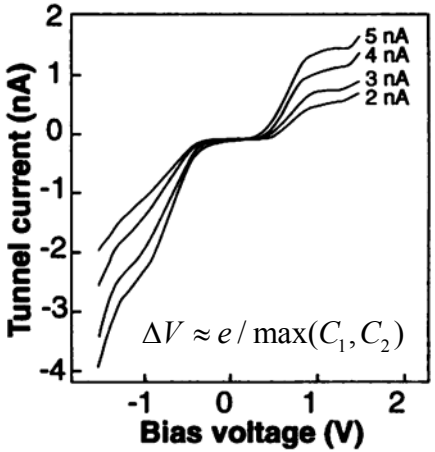


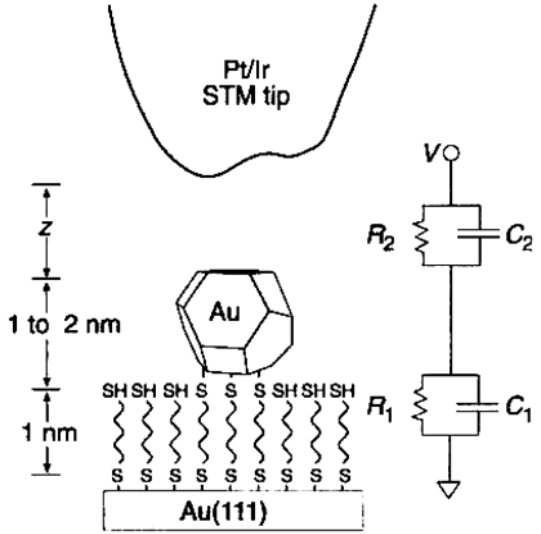


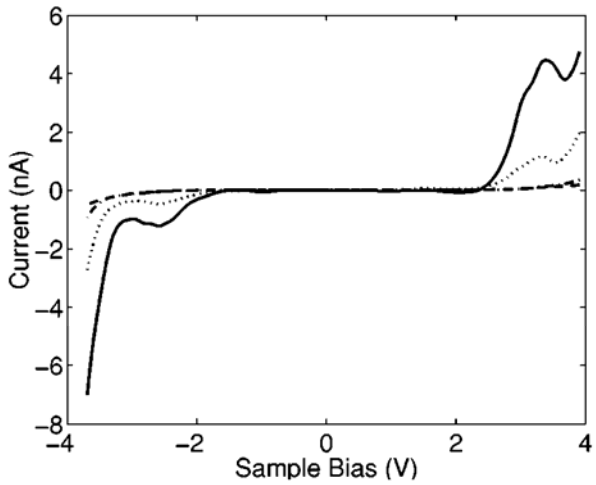
Наночастицы

Coulomb blockade
Coulomb staircase

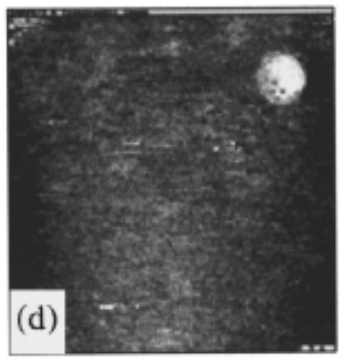
$$e^2 / 2(C_1 + C_2) \gg kT$$

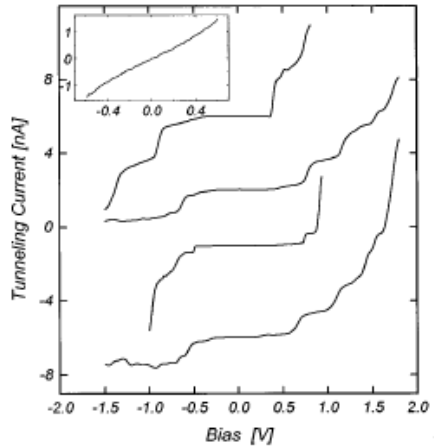






C_{60}

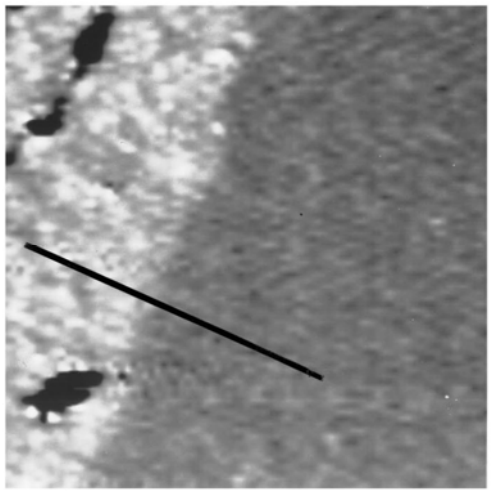


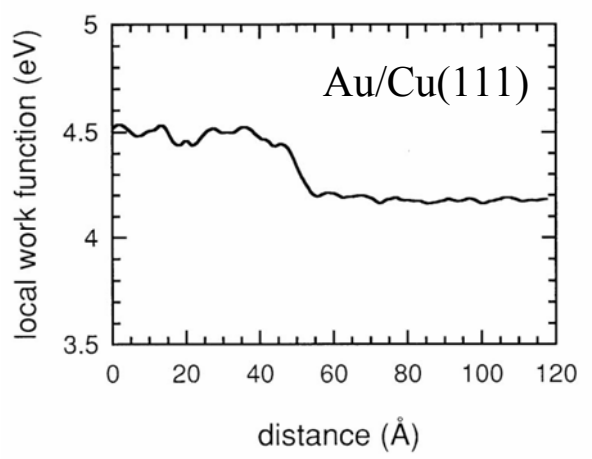


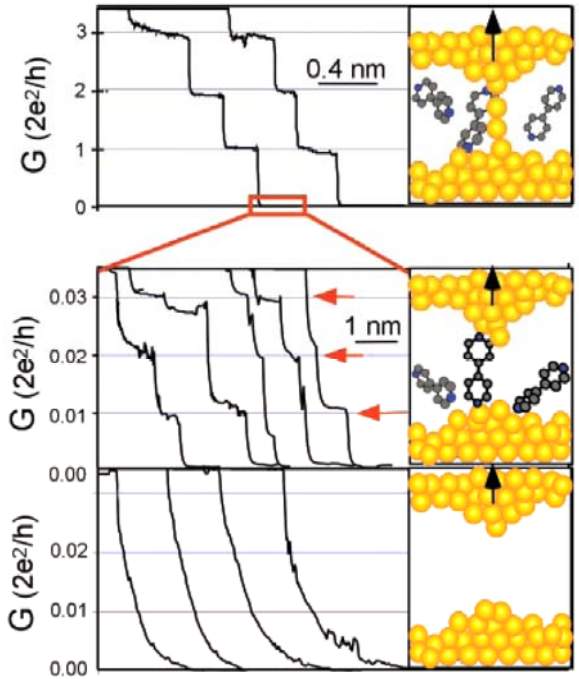
СТМ: Токвысотные спектры

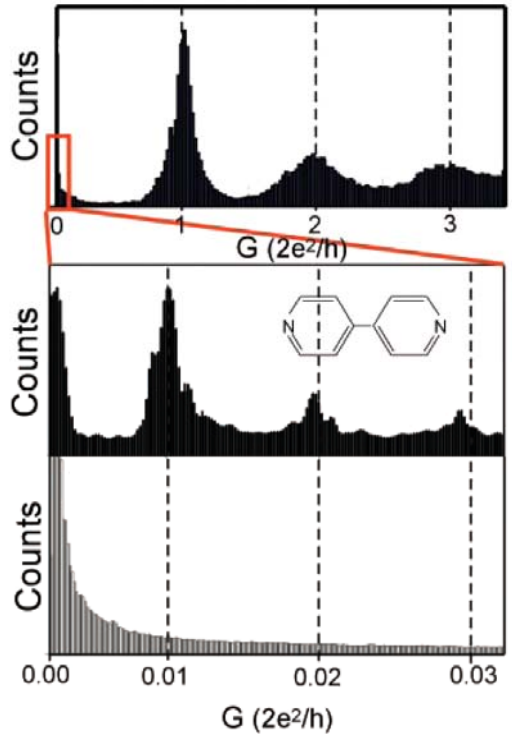
$$G = \frac{I}{U} \propto \exp(-1.025\sqrt{\phi}H)$$

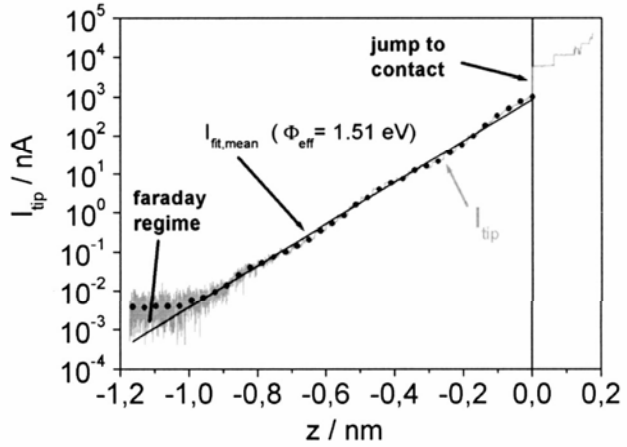
$$\phi = \left(\frac{1}{1.025}\frac{\mathrm{d}\ln G}{\mathrm{d}H}\right)^2 = \left(\frac{1}{1.025}\left(\frac{\mathrm{d}\ln I}{\mathrm{d}H}\right)_{U=\mathrm{const}}\right)^2$$

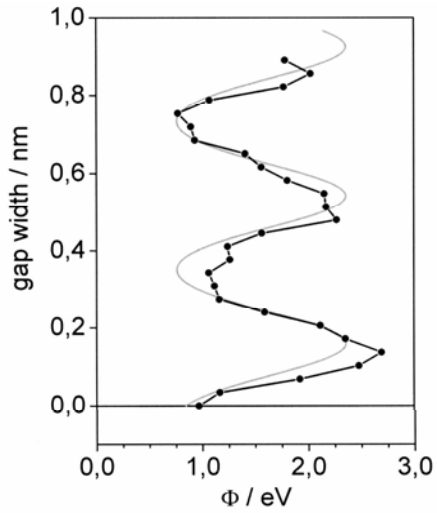




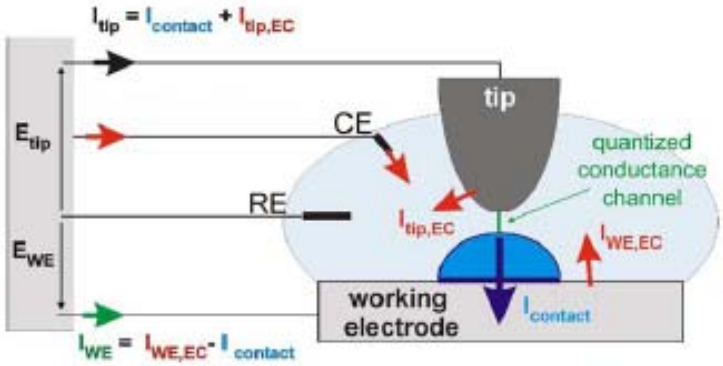


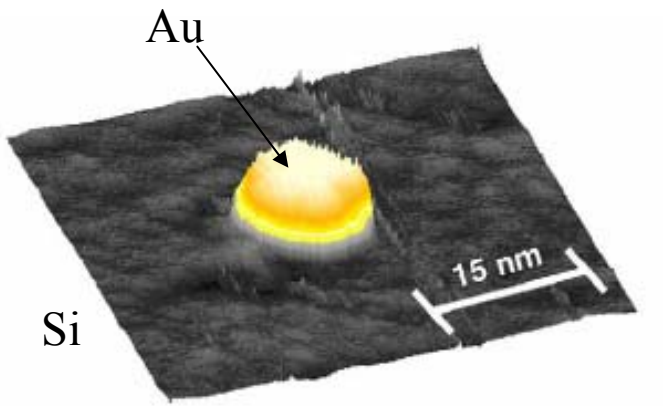


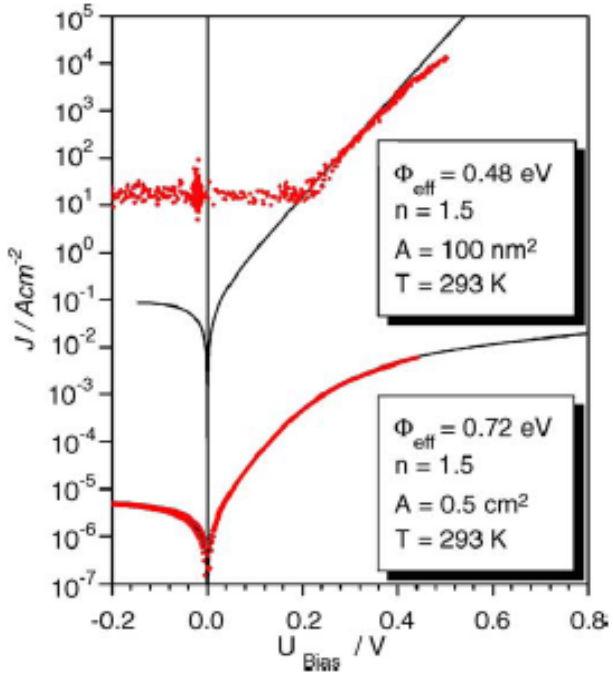




CTM: Локальный контакт



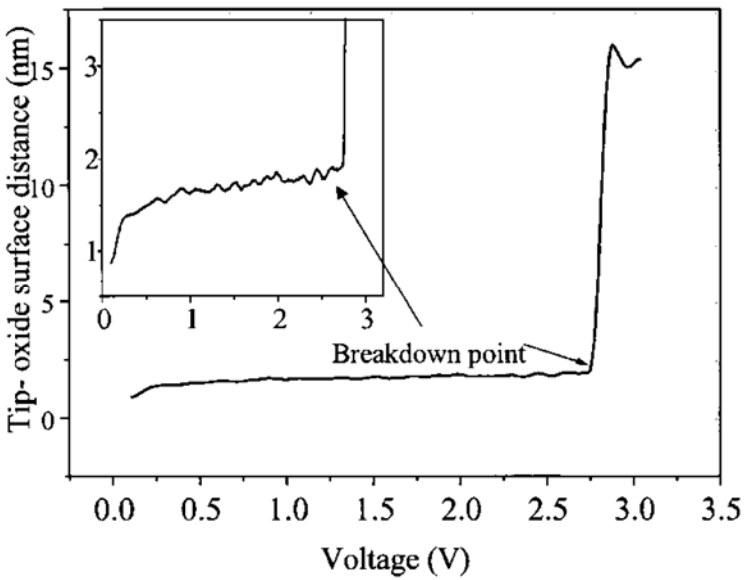


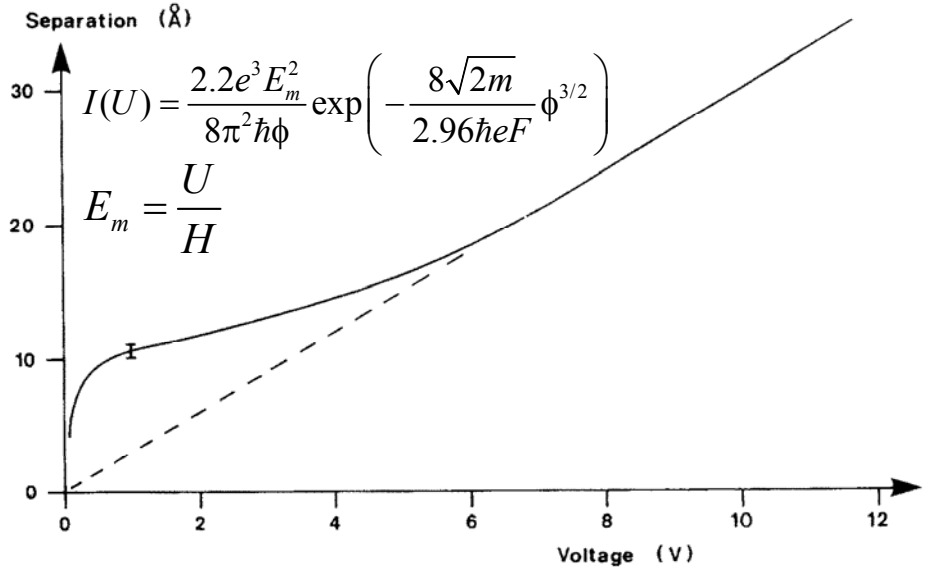


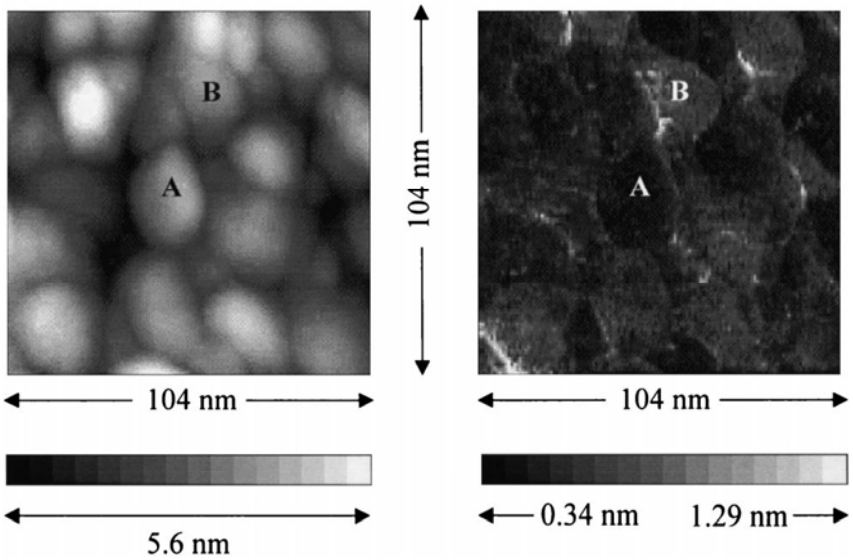
W.Schindler, M.Huggelmann, P.Hugelmann, In situ scanning probe spectroscopy at nanoscale solid/liquid interfaces, Electrochim.Acta 50(2005)3077-3083

СТМ: Вольтвысотные спектры

$$I \propto U \cdot \exp\left(\frac{\sqrt{2m\phi}}{\hbar} H\right) \qquad \left(\frac{\mathrm{d}\ln U}{\mathrm{d}H}\right)_{I=\mathrm{const}} = 2\frac{\sqrt{2m\phi}}{\hbar}$$







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СТМ: Неупругое туннелирование (d^2I/dU^2)

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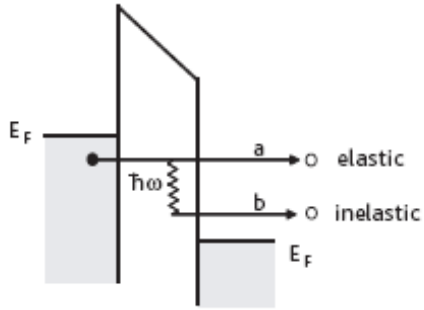

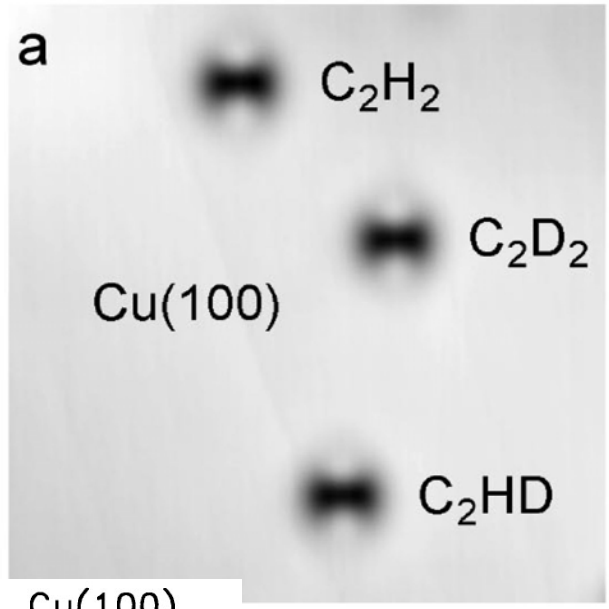

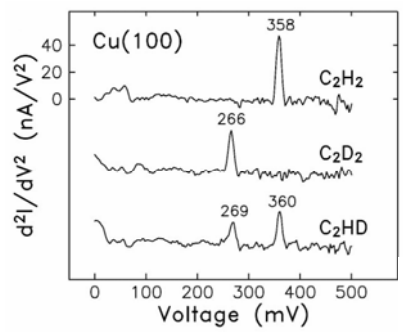

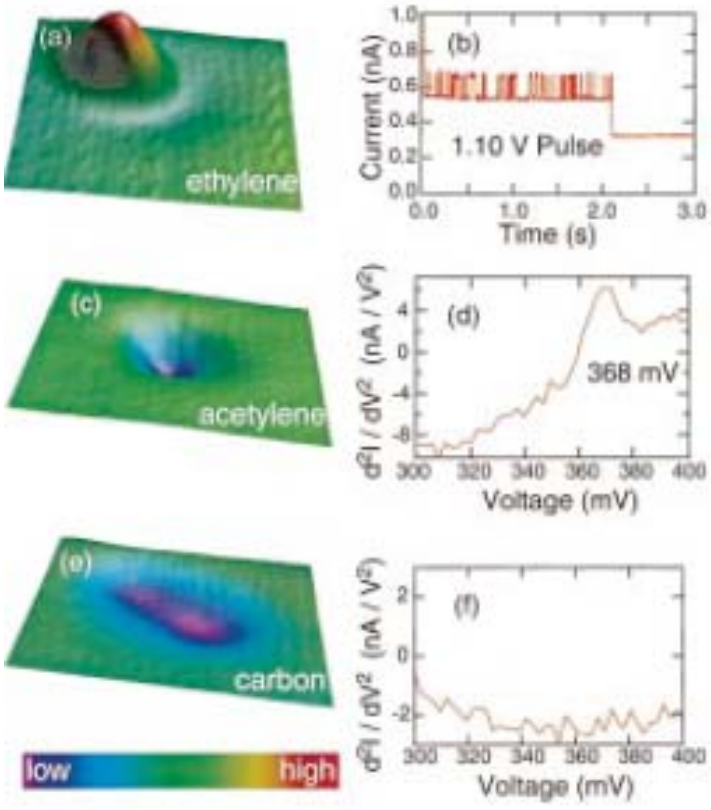

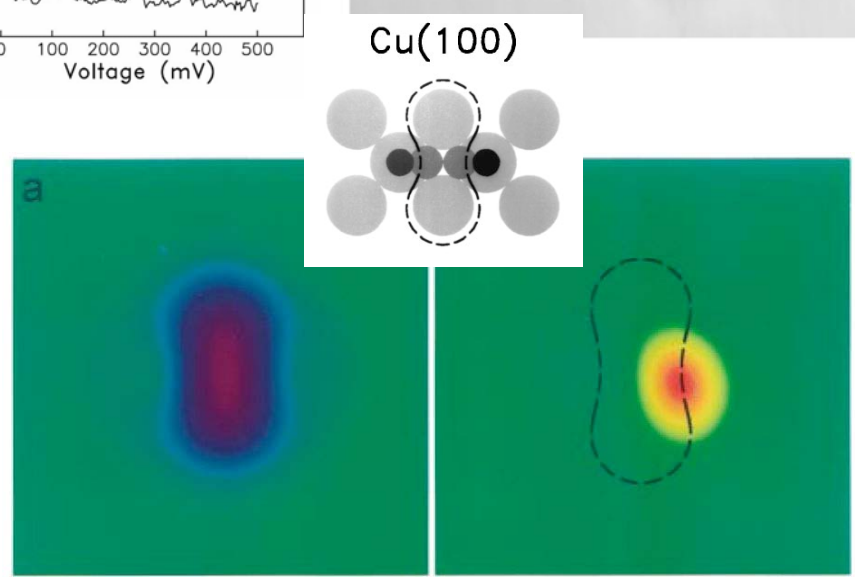

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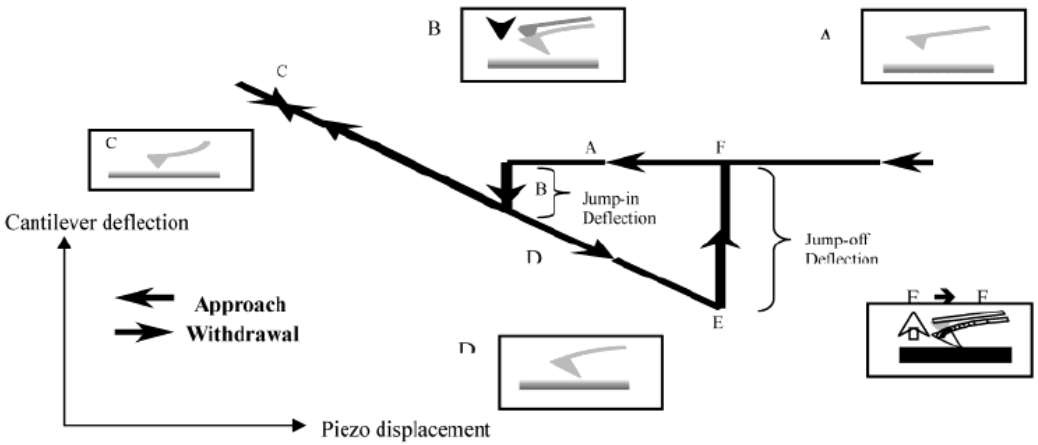
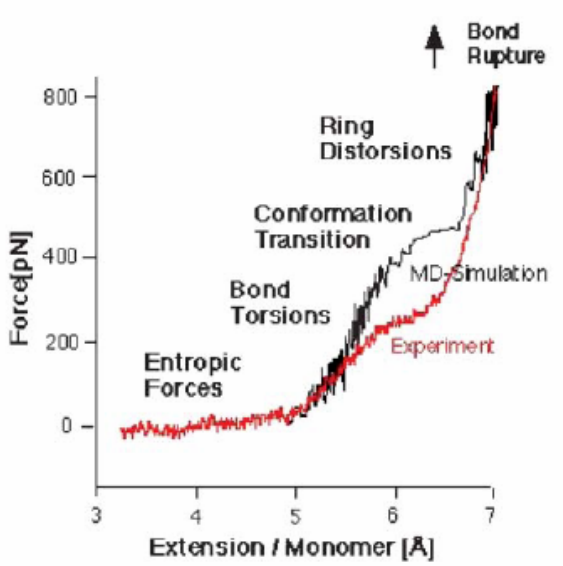
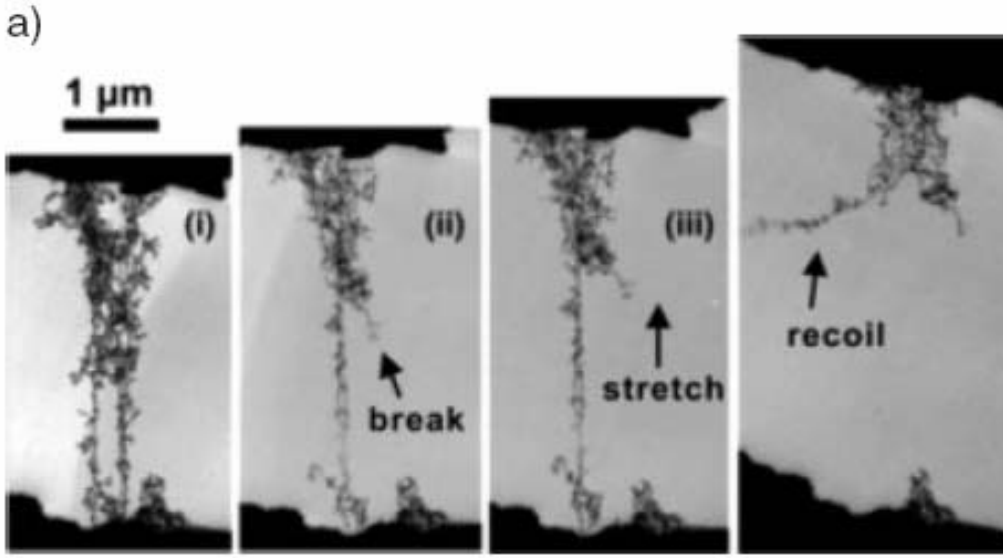
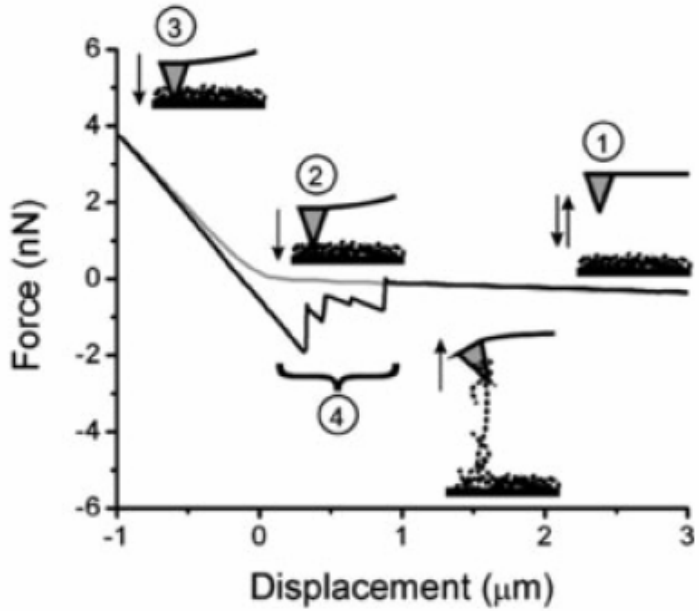
B.C.Stipe, M.A.Rezaei, W.Ho, Localization of Inelastic Tunneling and the Determination of Atomic-Scale Structure with Chemical Specificity, Phys.Rev.Lett. 82(1999)1724-1727

АСМ: Силовые кривые









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P.Samori, Scanning probe microscopies beyond imaging, J.Mater.Chem. 14(2004)1353

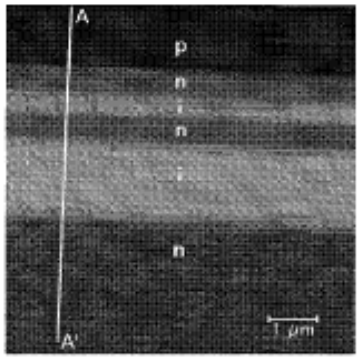
АСМ: Локальное сопротивление

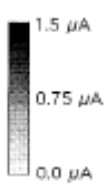
conducting atomic force microscopy (C-AFM)
current-sensing atomic force microscopy
tunneling atomic force microscopy (TUNA)
scanning spreading resistance microscopy (SSRM)

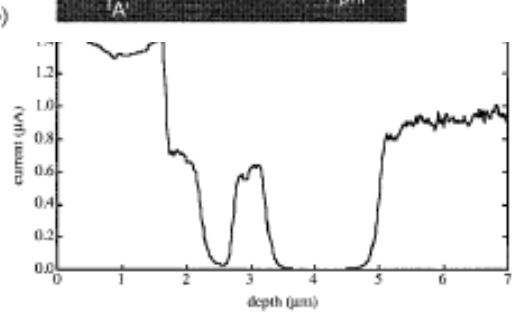
Молекулярная проводимость

Наноизделия

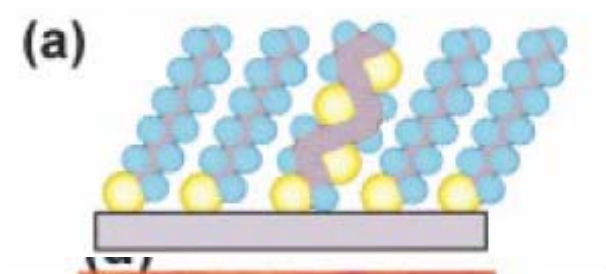
Гетероструктуры

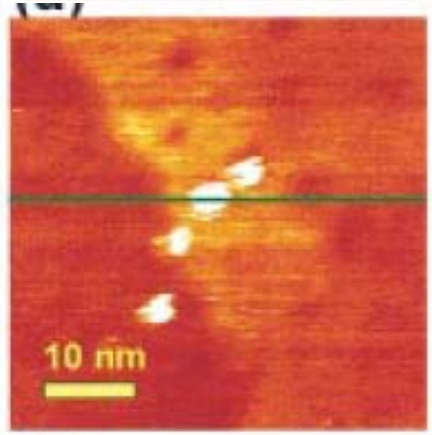


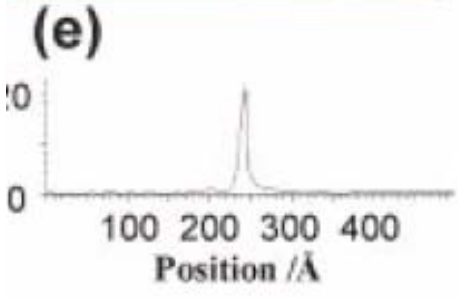




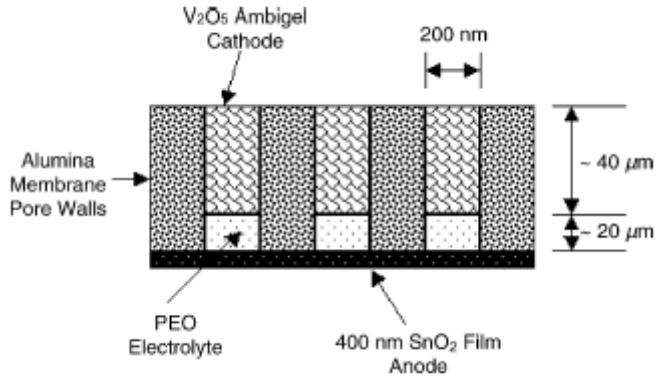
P.DeWolf, M.Geva, T.Hantschel, W.Vandervorst, R.B.Bylsma, Two-dimensional carrier profiling of InP Structures using scanning spreading resistance microscopy, Appl.Phys.Lett. 73(1998)2155

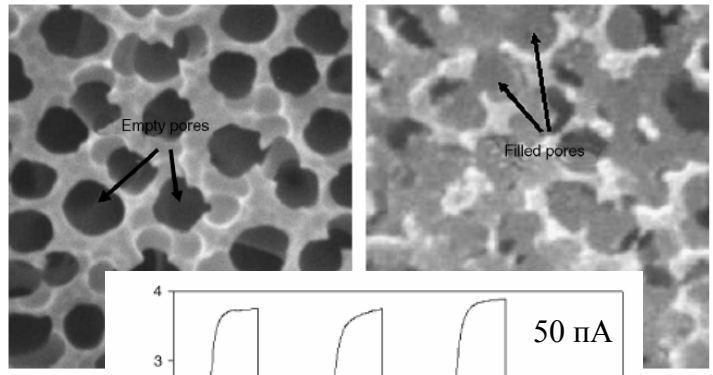


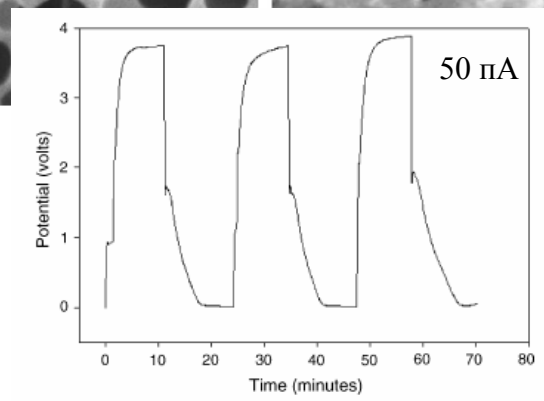




H.Sakaguchi, A.Hirai, F.Iwata, A.Sasaki, T.Nagamura, E.Kawata, S.Nakabayashi, Determination of perfomance on tunnel conduction through molecular wire using a conductive atomic force microscope, Appl.Phys.Lett. 79(2001)3708







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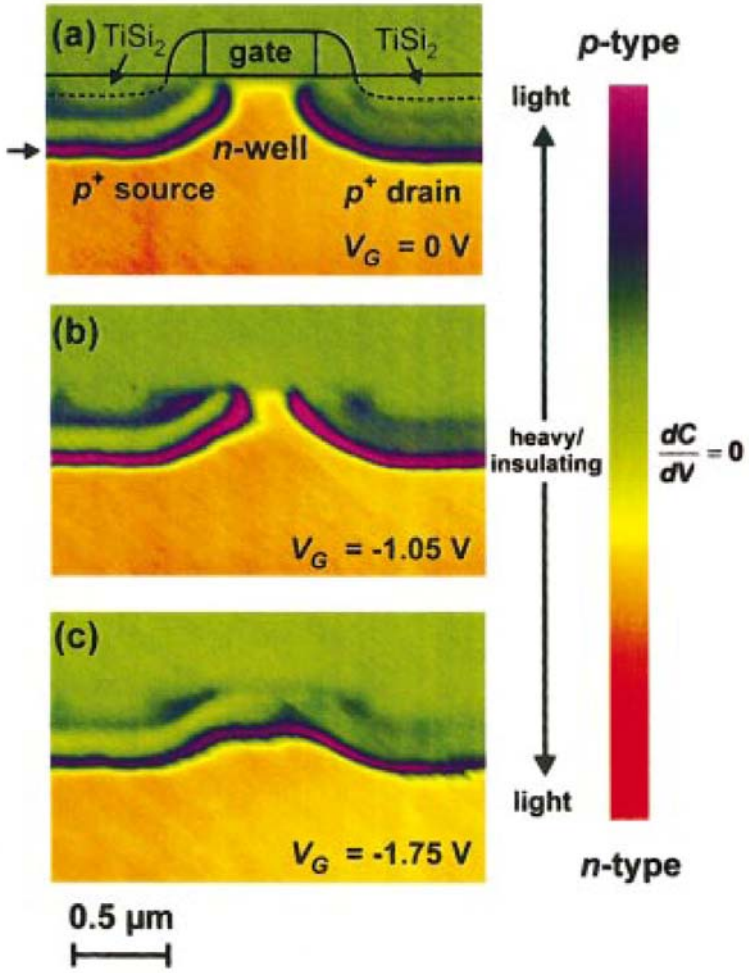
ACM: Локальная емкость

Scanning capacitance microscopy (SCM)



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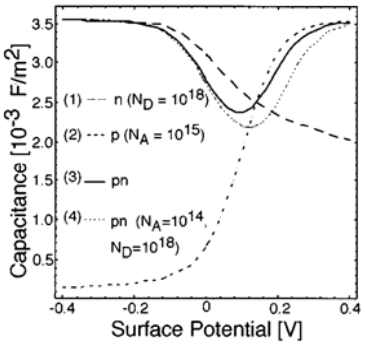

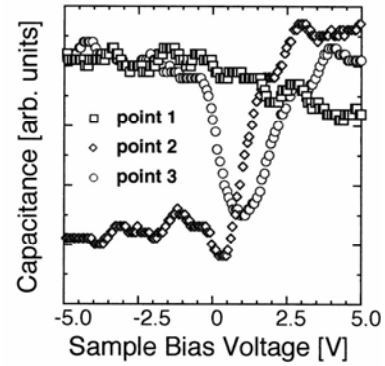

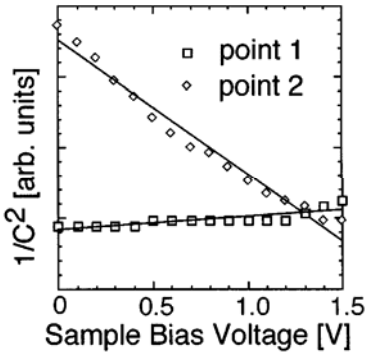

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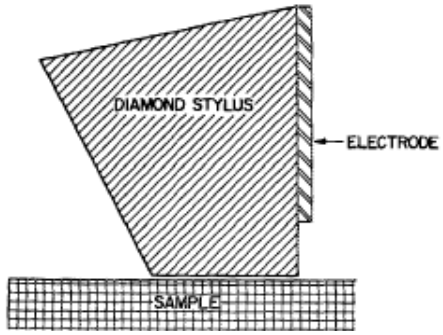
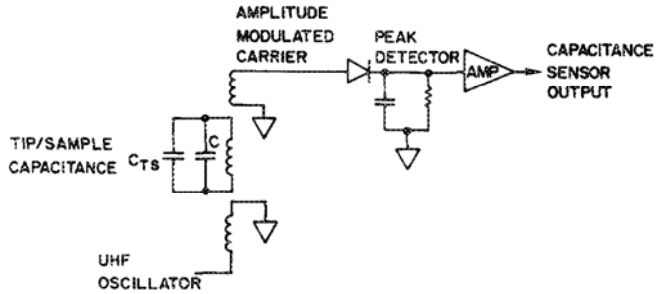
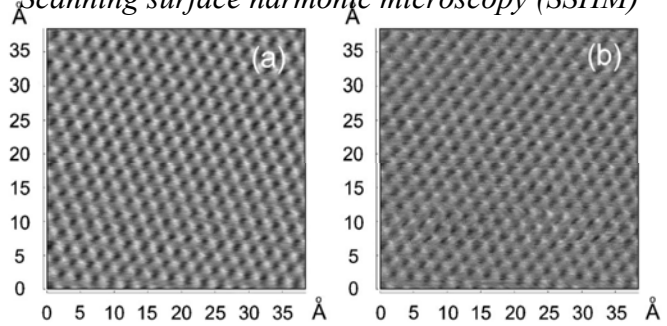




Alternating-current scanning tunneling microscopy (AC-STM)

Scanning surface harmonic microscopy (SSHM)

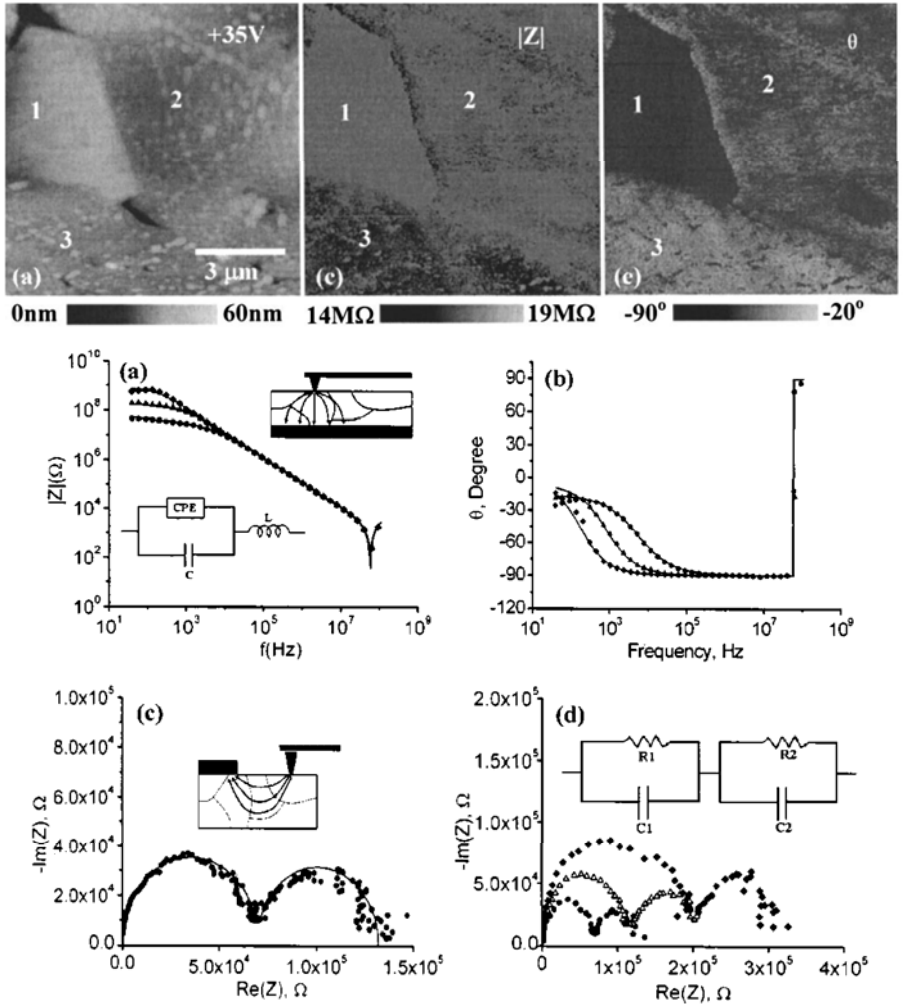


J.Schmidt, D.H.Rapoport, H.J.Frohlich,Rev.Sci.Instrum., 70(1999)3377-3380

АСМ: Локальный импеданс

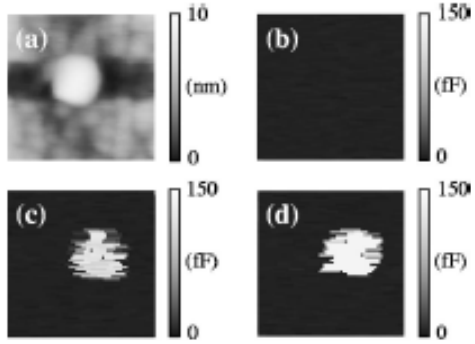
Nanoscale impedance microscopy (NIM)

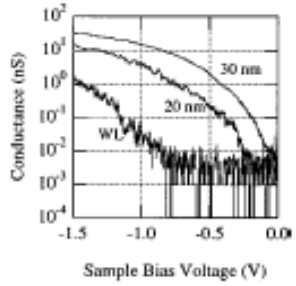
Керамические материалы



R.Shao, S.V.Kalinin, D.A.Bonnell, Local impedance imaging and spectroscopy of polycrystalline ZnO using contact atomic force microscopy, Appl.Phys.Lett. 82(2003)1869-1871

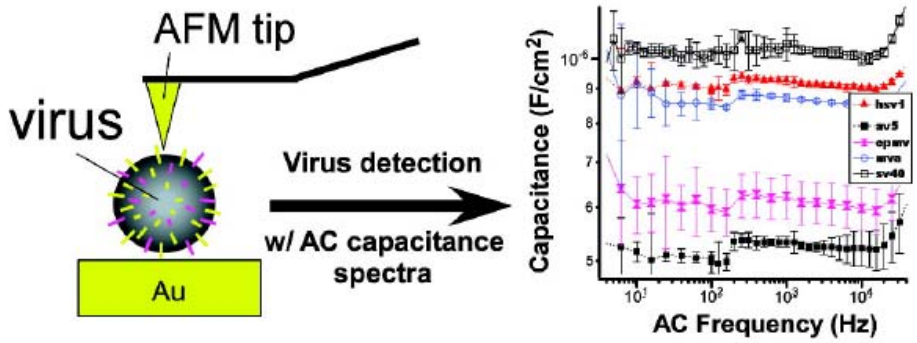
Квантовые точки





H.Yamamoto, T.Takahashi, I.Kamiya, Local capacitance measurements on InAs dot-covered GaAs surfaces by scanning capacitance microscopy, Appl.Phys.Lett. 77(2000)1994-1996

Вирусы



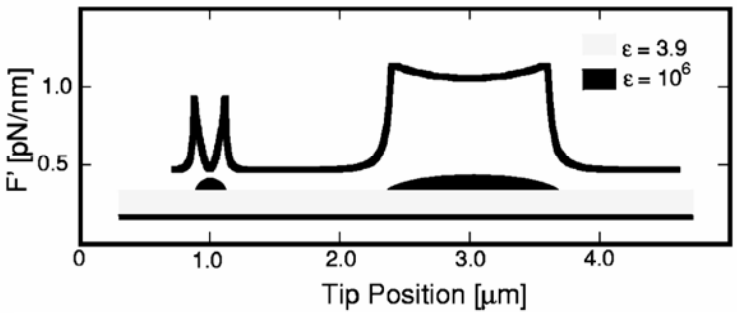
R.I.MacCuspie, N.Nuraje, S.Y.Lee, A.Runge, H.Matsui, Comparison of Electrical Properties of Viruses Studied by AC Capacitance Scanning Probe Microscopy, J.Am.Chem.Soc. 130(2008)887

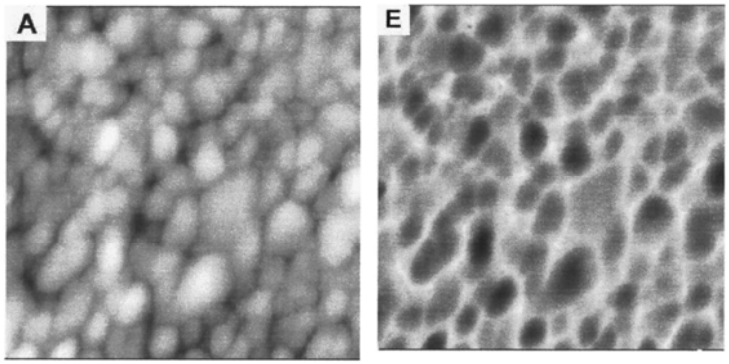
АСМ: Электростатика

electrostatic force microscopy (EFM)
scanning surface potential microscopy (SSPM)
Kelvin probe force microscopy (KFM, KPFM)

$$F_E = \frac{1}{2}\cdot\frac{\partial C}{\partial H}\cdot(U_{surf} - U_0)^2$$

$$F_E = \frac{1}{2}\cdot\frac{\partial C}{\partial H}\left(\Delta U^2 + \frac{U_{ac}^2}{2}\right) + \frac{\partial C}{\partial H}\cdot\Delta U\cdot U_{ac}\cos(\omega t) - \frac{\partial C}{\partial H}\frac{U_{ac}^2}{4}\cos(2\omega t)$$





A.Efimov, S.R.Cohen, Simulation and correction of geometric distortions in scanning Kelvin probe microscopy, J.Vac.Sci.Technol.A 18(2000)1051-1055

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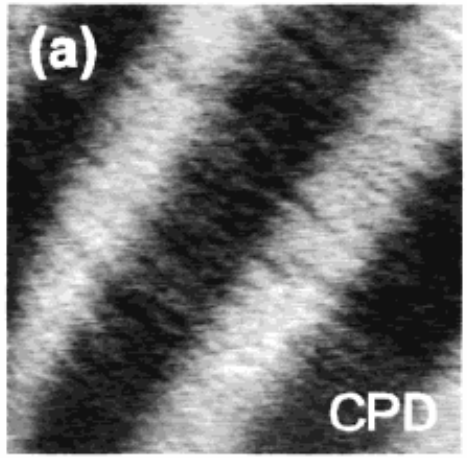
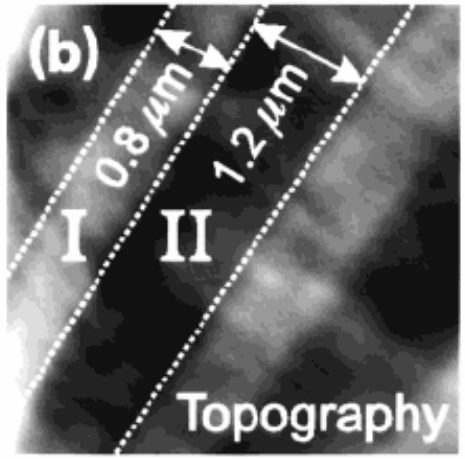
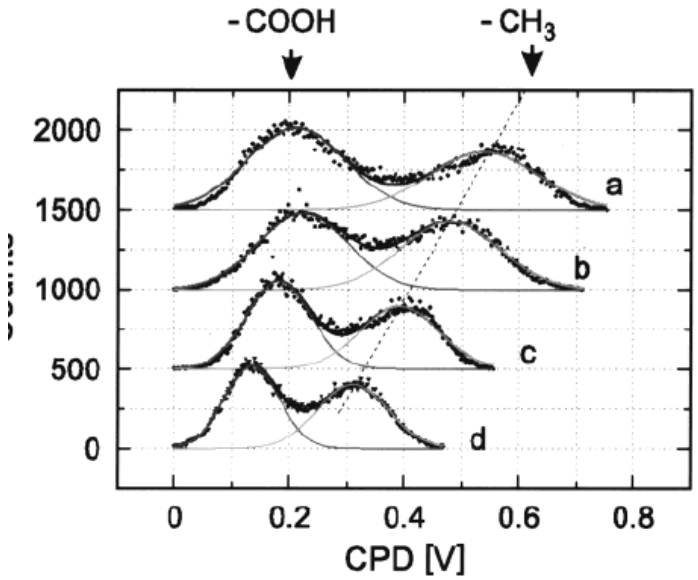


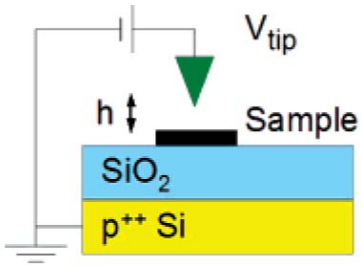




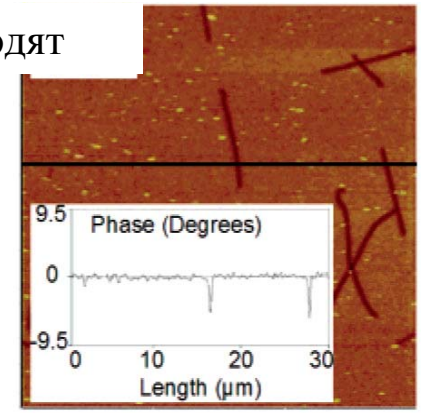
J.Lu, E.Delamarche, L.Eng, R.Bennewitz, E.Meyer, H.J.Guntherodt, Langmuir 15(1999)8184

АСМ: Электростатика

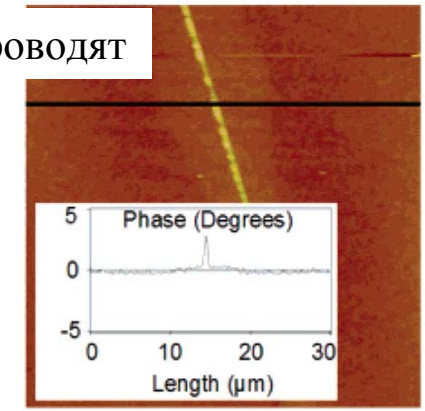
scanning conductance microscopy



проводят

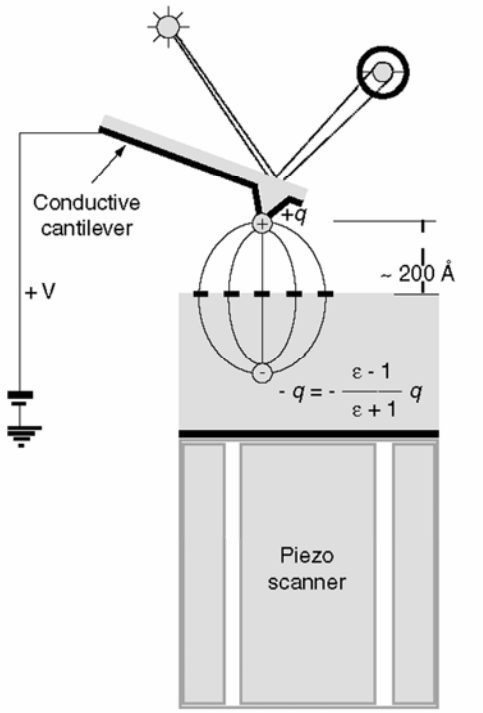


не проводят



C.Staii, A.T.Johnson Jr., N.J.Pinto, Quantitative Analysis of Scanning Conductance Microscopy, Nanolett. 4(2004)859-862

scanning polarization force microscopy (SPFM)

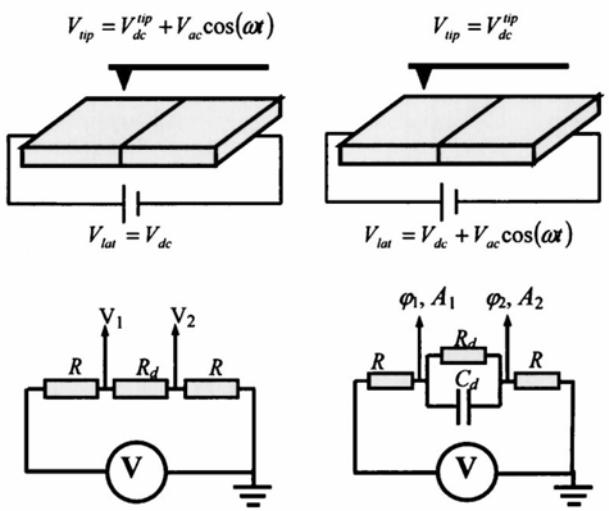


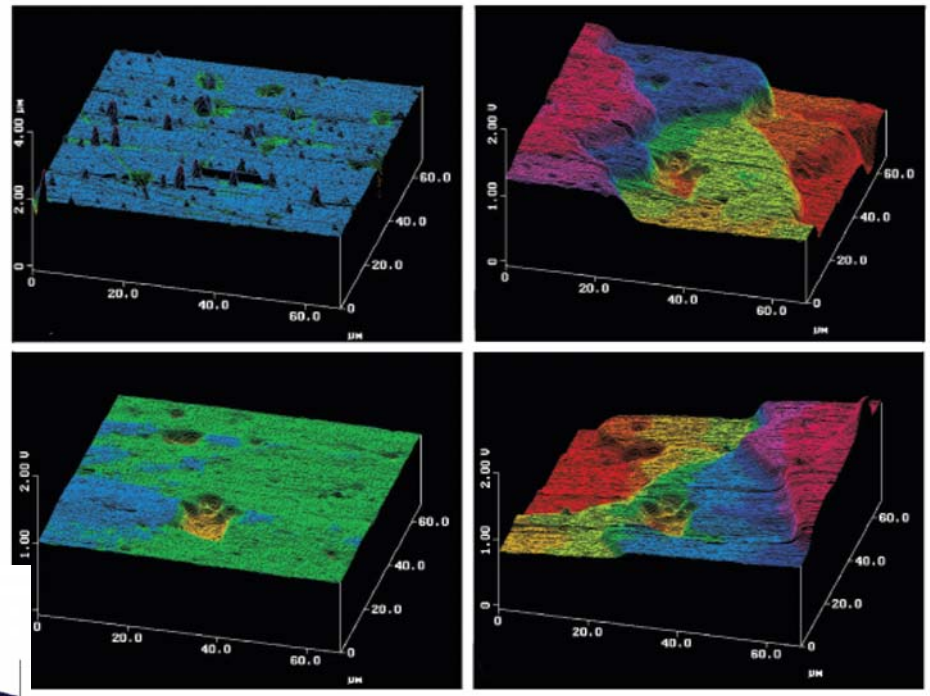
пленка воды на слюде

J.Hu, X.D.Xiao, M.Salmeron, Scanning polarization force microscopy: A technique for imaging liquids and weakly adsorbed layers, Appl.Phys.Lett. 67(1995)476-478

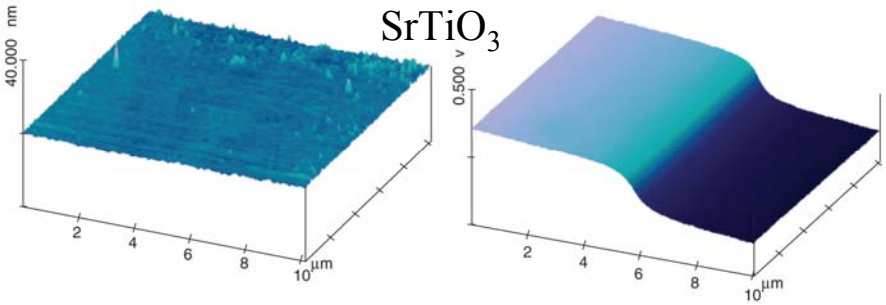
АСМ: Электростатика

scanning impedance microscopy (SIM)





ZnO



$SrTiO_3$

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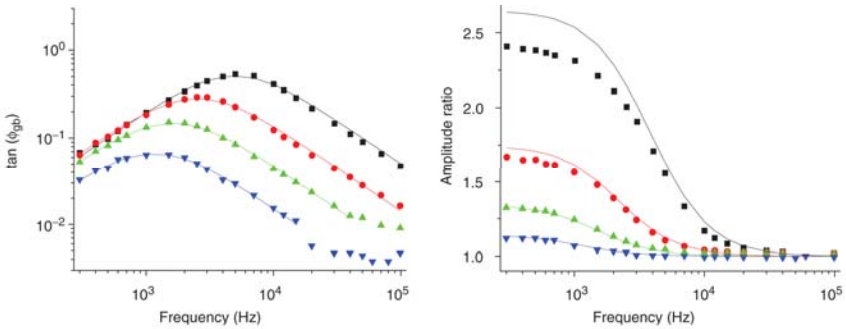
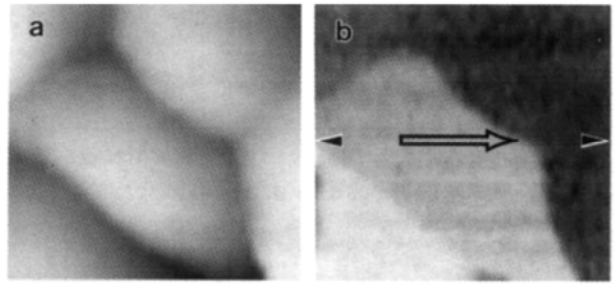


Scanning tunneling potentiometry



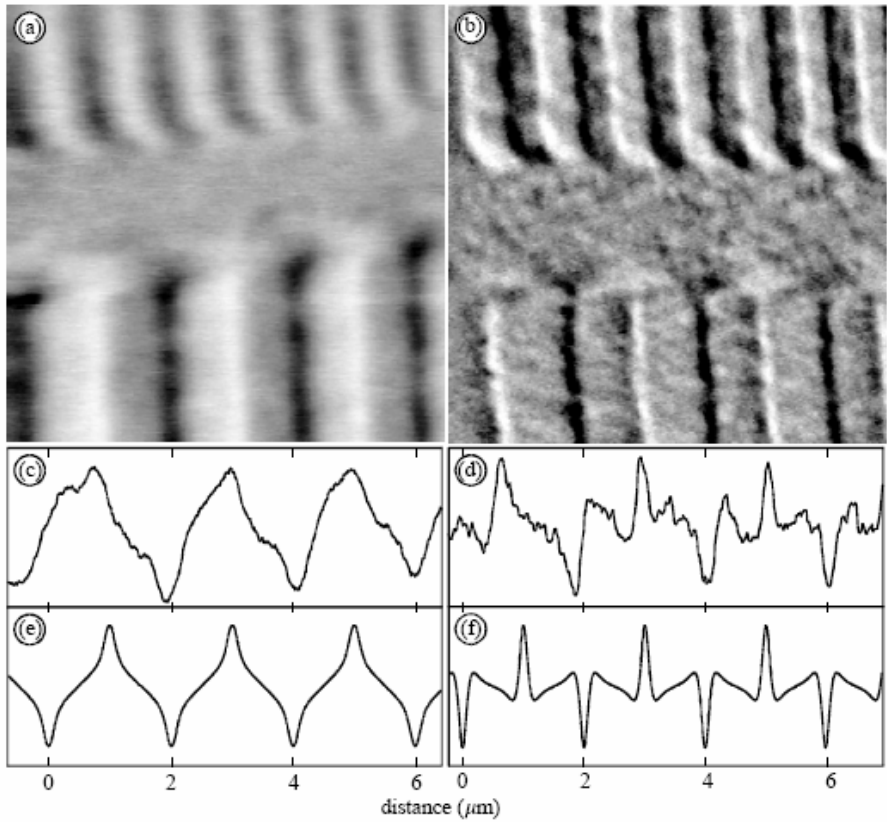
$Au_{60}Pd_{40}$

J.R.Kirtley, S.Washburn, M.J.Brady, Direct Measurement of Potential Steps at Grain Boundaries in the Presence of Current Flow, Phys.Rev.Lett. 60(1988)1546-1549

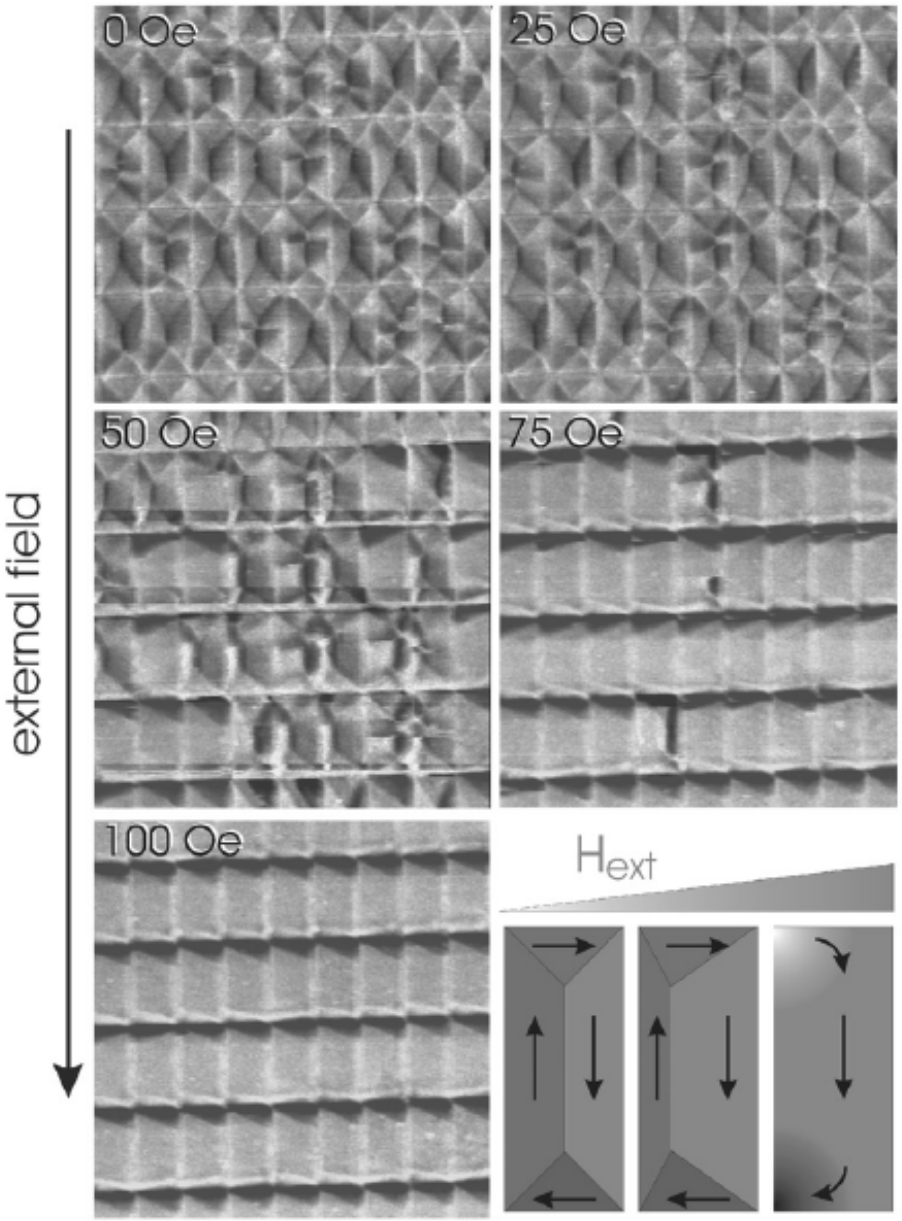
ACM: Магнитные взаимодействия

magnetic force microscopy (MFM)

HDD



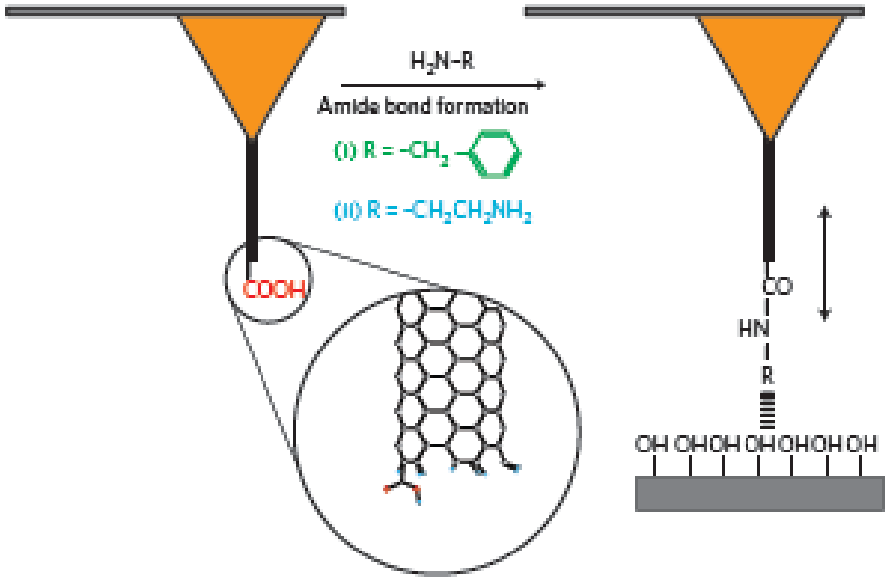
Пермаллой

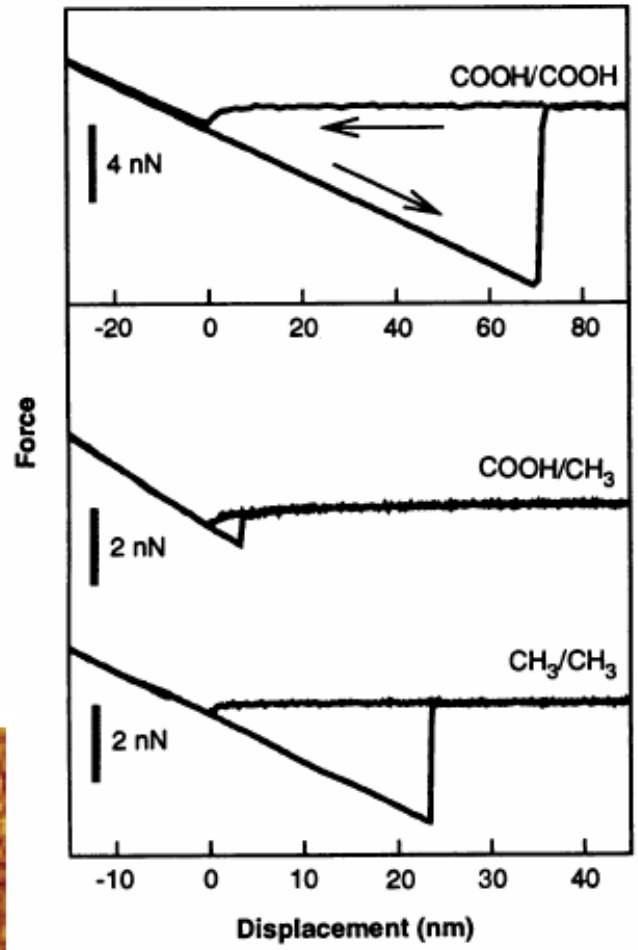


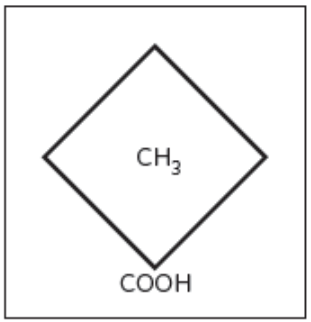
M.R.Koblischka, U.Hartmann, Recent advances in magnetic force microscopy, Ultramicroscopy, 97(2003)103

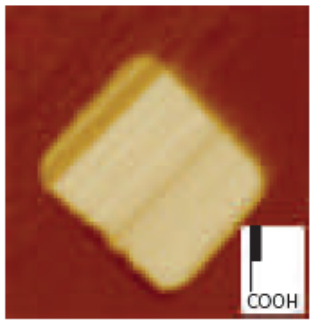
АСМ: Химическая природа объекта

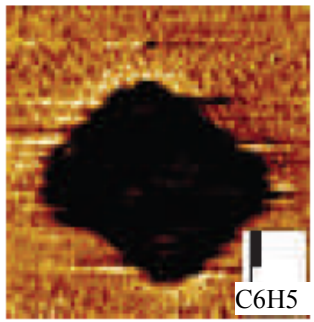
chemical force microscopy (CFM)











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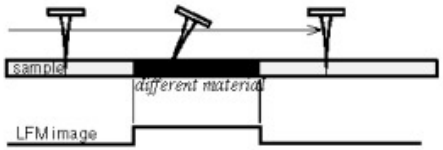
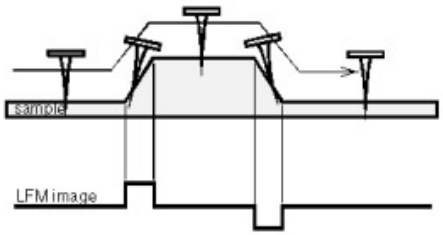
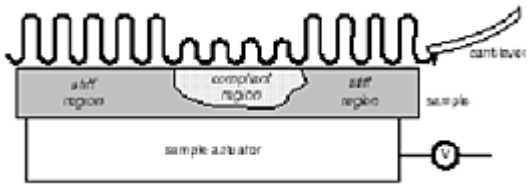
C.D.Frisbie, L.F.Rozsnyai, A.Noy, M.S.Wrighton, C.M.Lieber, Functional group imaging by chemical force microscopy, Science 265(1994)2071

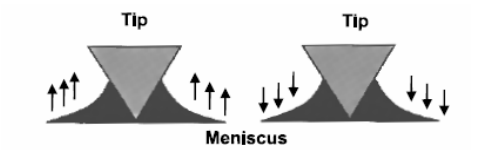
ACM: Механические свойства

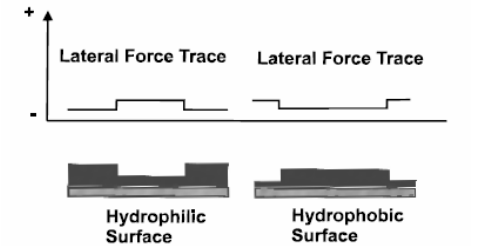
lateral force microscopy (LFM)
friction force microscopy (FFM)
force modulation microscopy (FMM)





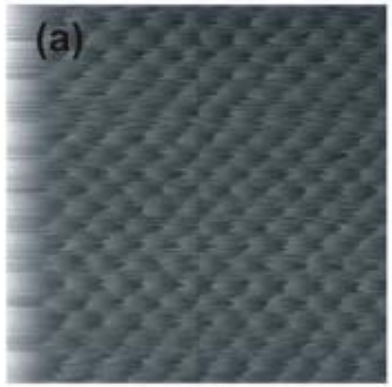


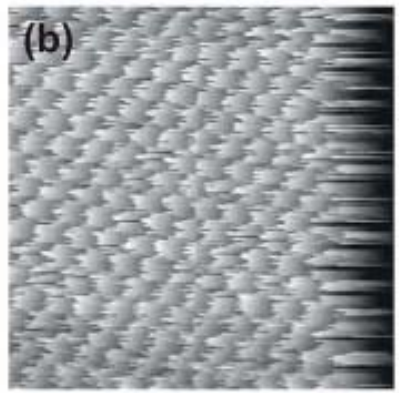


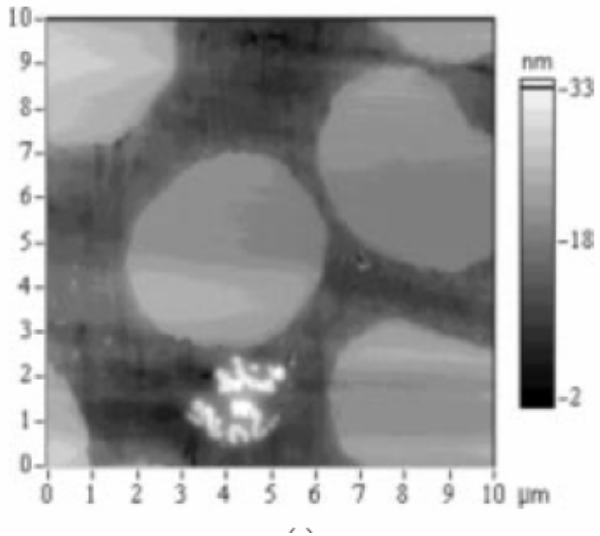


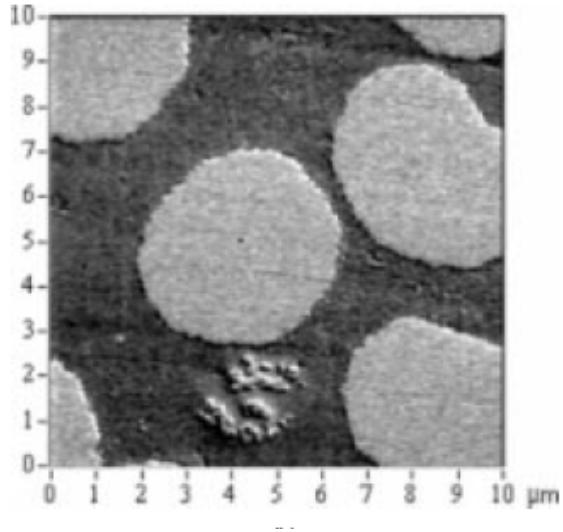
NaCl

Cu(111)







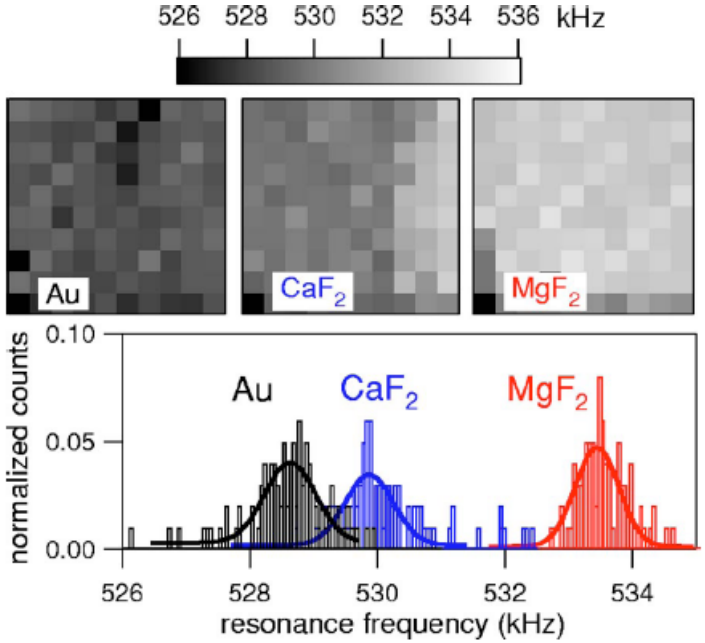


R.Bennewitz, Friction force microscopy, Materials Today, (2005)42

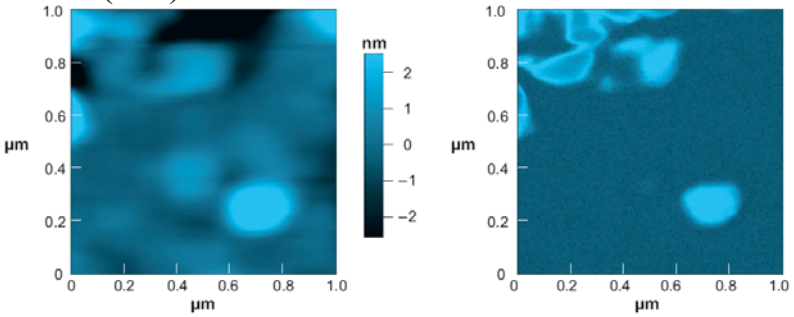
P.E.Mazeran, J.L.Loubet, Normal and lateral modulation with a scanning force microscope, an analysis: implication in quantitative elastic and friction imaging, Tribology Letters 7(1999)199

ACM: Механический отклик

Atomic force acoustic microscopy (AFAM)
Ultrasonic force microscopy (UFM)



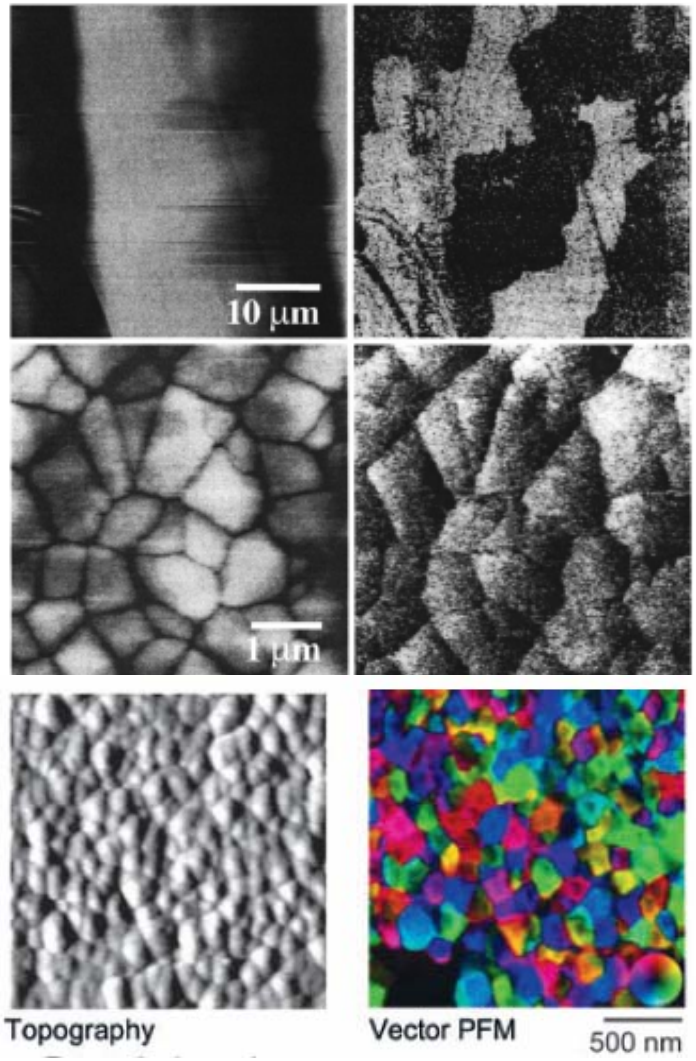
Au/Si(111)



G.Stan, W.Price, Quantitative measurements of indentation moduli by atomic force acoustic microscopy using a dual reference method, Rev.Sci.Instrum. 77(2006)103707

B.D.Huey, AFM and Acoustics: Fast, Quantitative Nanomechanical Mapping, Annu.Rev.Mater.Res. 37(2007)351

Piezoresponse force microscopy (PFM)

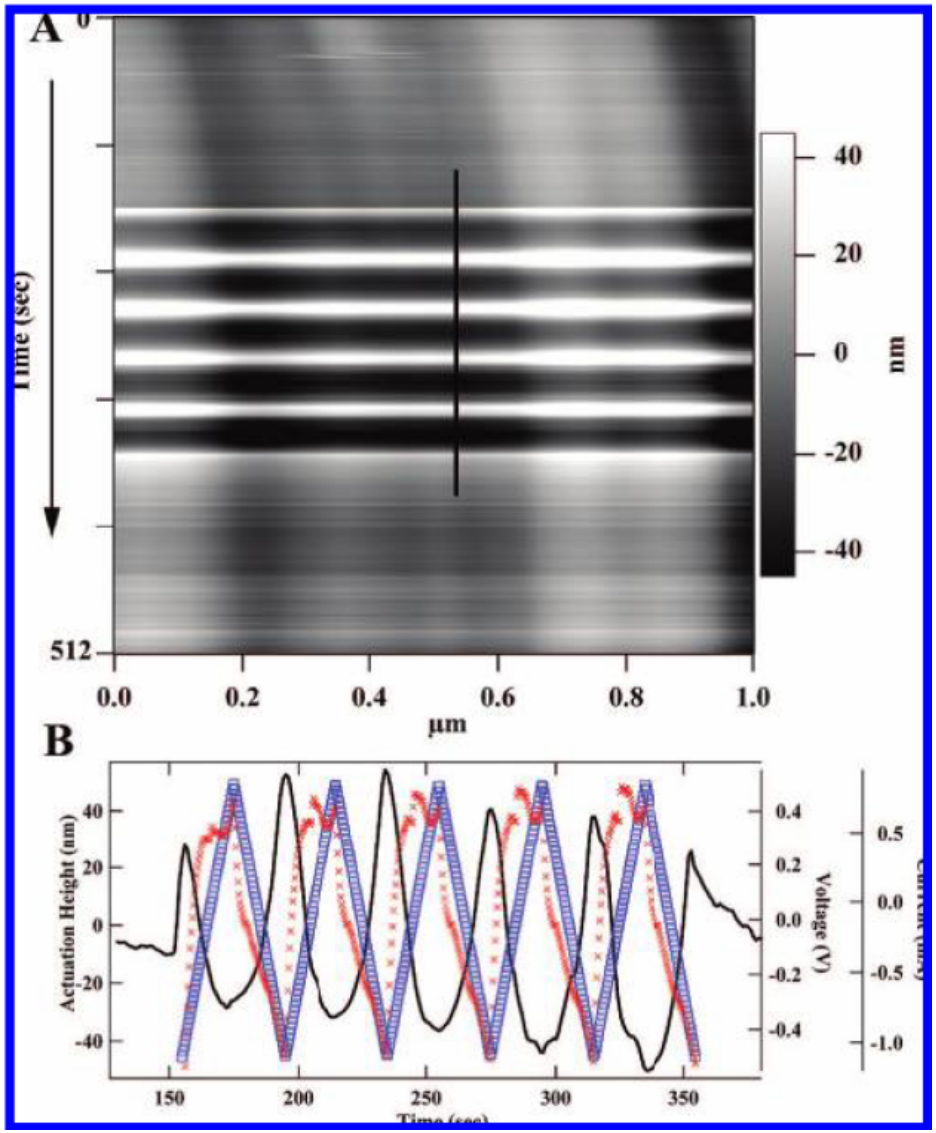


S.V.Kalinin, D.A.Bonnell, Imaging mechanism of piezoresponse force microscopy of ferroelectric surfaces, Phys.Rev.B. 65(2002)125408

S.V.Kalinin, B.J.Rodriguez, S.Jesse, E.Karapetian, B.Mirman, E.A.Eliseev, A.N.Morozovska, Nanoscale Electromechanics of Ferroelectric and Biological Systems: A New Dimension in Scanning Probe Microscopy, Annu.Rev.Mater.Res. 37(2007)189

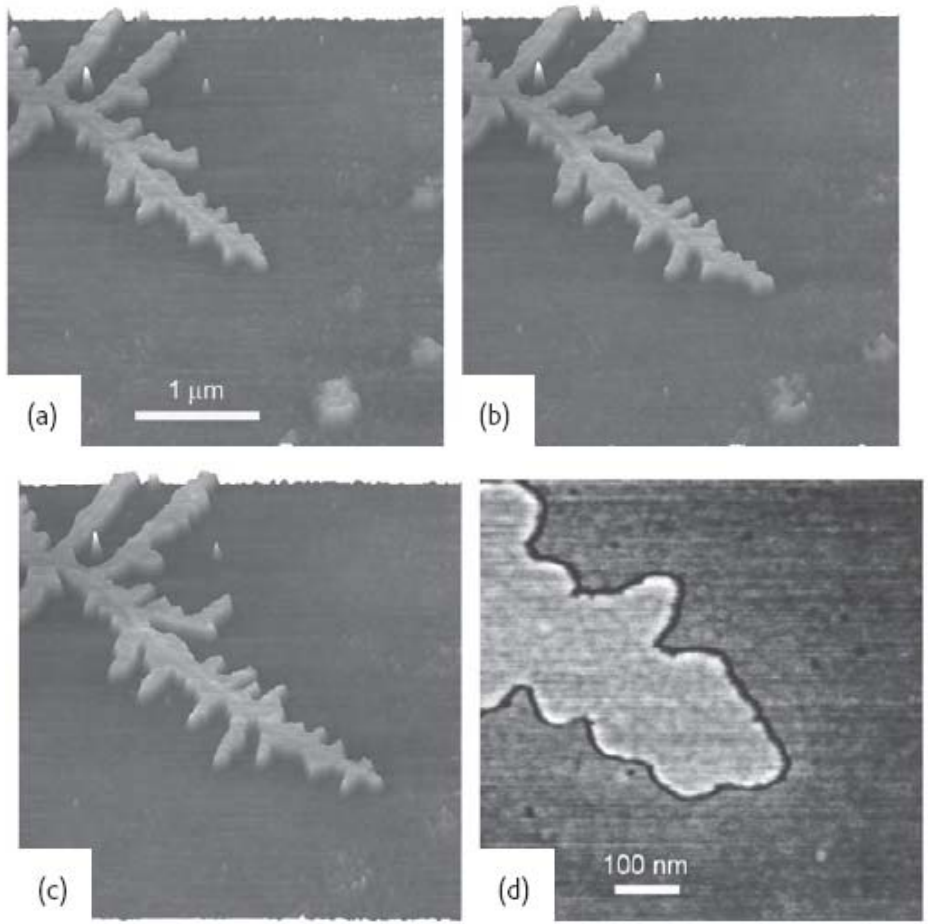
СТМ/АСМ: Мониторинг процессов

В объеме



M.J.Higgins, S.T.McGovern, G.G.Wallace, Langmuir 25(2009)3627

На поверхности

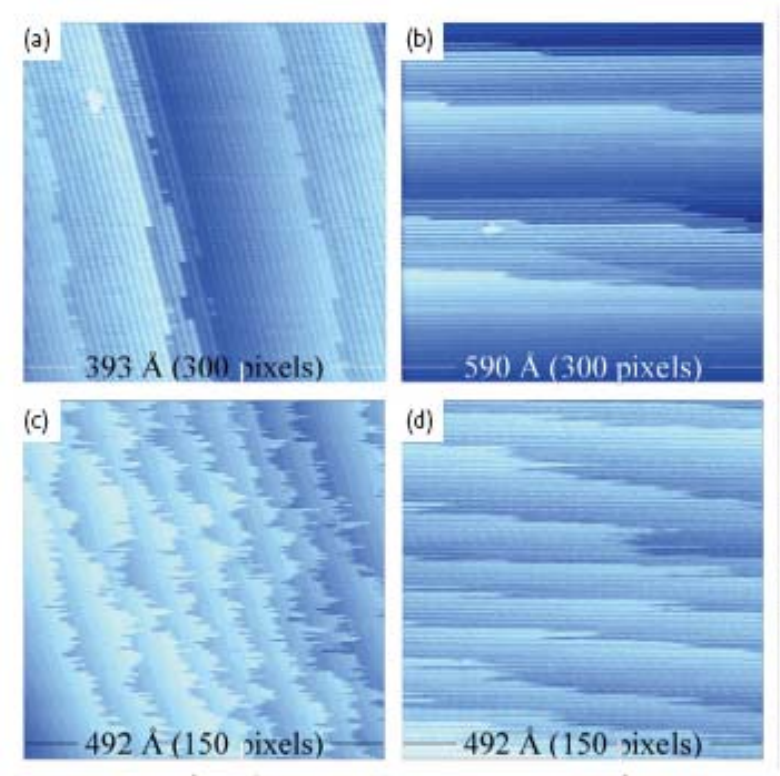


J.K.Hobbs, N.Mullin, C.H.M.Weber, O.E.Farrance, C.Vasilev, 'Watching' processes in soft matter with SPM, Materials Today, 12(2009)26

CTM/ACM: Мониторинг процессов

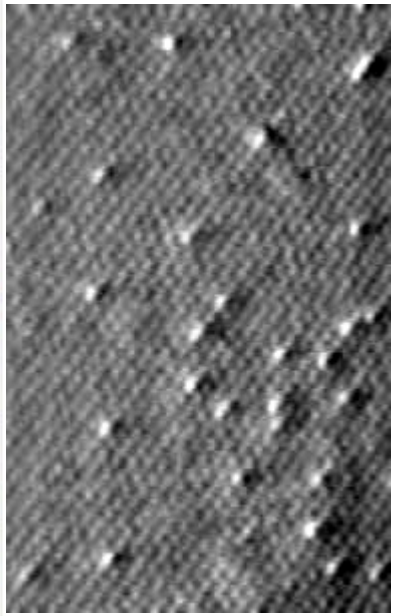
	Video-rate SPM	High-speed SPM	Intermediate speed
Pixel resolution	256 x 256 pixel	256 x 256 pixel	100 x 100 pixel
Frame rate	25 frames/s	10 frames/s	10 frames/s
Scan requirements			
Z-direction	3.3 MHz	1.3 MHz	200 kHz
X-direction	6.4 kHz	2.6 kHz	1 kHz
Y-direction	12.5 Hz	5 Hz	5 Hz

Au(110)

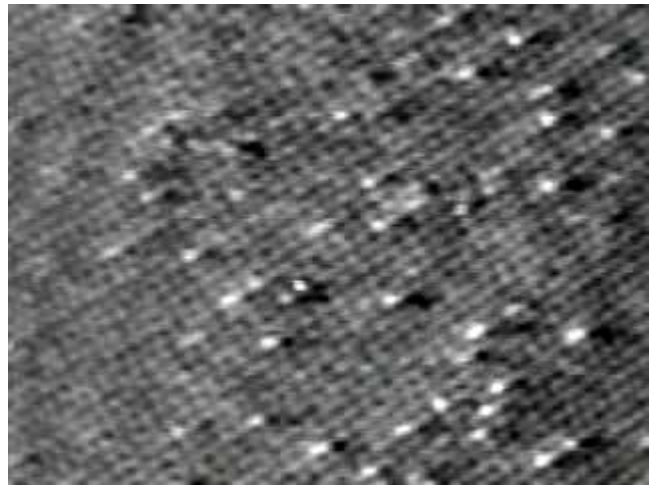


S^{2-}/Cu(100)

–0.38 V (SCE)



–0.42 V (SCE)



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T.Tansel, O.M.Magnussen, VideoSTM Studies of Adsorbate Diffusion at Electrochemical Interfaces, Phys.Rev.Lett. 96(2006)026101

Возможности метода

1) **Метрологическая характеристика:** размер частиц, толщина слоя, размерное распределение, локализация на поверхности…..

2) **Электрические параметры:** проводимость, тип и число носителей заряда, полупроводниковые свойства, электрическая емкость, диэлектрическая проницаемость, работа выхода, поверхностный потенциал, строение межзеренных границ…….

3) **Механические параметры:** трение, упругость, эластичность, твердость…..

4) **Молекулярная характеристика:** идентификация молекул, электронная структура, колебательная спектроскопия, проводимость, энергия химической связи, манипулирование отдельными молекулами…..

5) **Магнитная структура**

6) **Электромеханические свойства**

7) **Кинетика различных процессов**

8) **Локальная модификация поверхности, нанолитография**

И многое, многое другое…..