ME597/PHYS57000
Fall Semester 2009
Lecture 23

FM-AFM Selected Results

Achieving Atomic Resolution with AFM

Seeing atoms with AFMs

Image of graphite using contact-mode AFM: G. Binnig, Ch. Gerber, E. Stoll, T.R. Albrecht, and C.F. Quate, Europhys. Lett. 3, 181 (1987).

Frequency modulation (FM) method – high Q, large amplitude: T.R. Albrecht, P. Grutter, D. Horne, D. Rugar, J. Appl. Phys. 69, 668 (1991).

1995

Si(111)-(7x7) using noncontact AFM: F.J. Giessibl, Science 267, 68 (1995).

Si(111)-(7x7) using noncontact AFM: S. Kitamura and M. Iwatsuki, Jpn. J. Appl. Phys. 34, L145 (1995)

Atomic point defects in cleaved InP(110): H. Ueyamam, M. Ohta, Y. Sugawara, and S. Morita, Jpn. J. Appl. Phys. 34, L1086 (1995)

Defect motion of atomic point defects in cleaved InP(110): Y. Sugawara, M. Ohta, H. Ueyamam and S. Morita, Science 270, 1647 (1995).

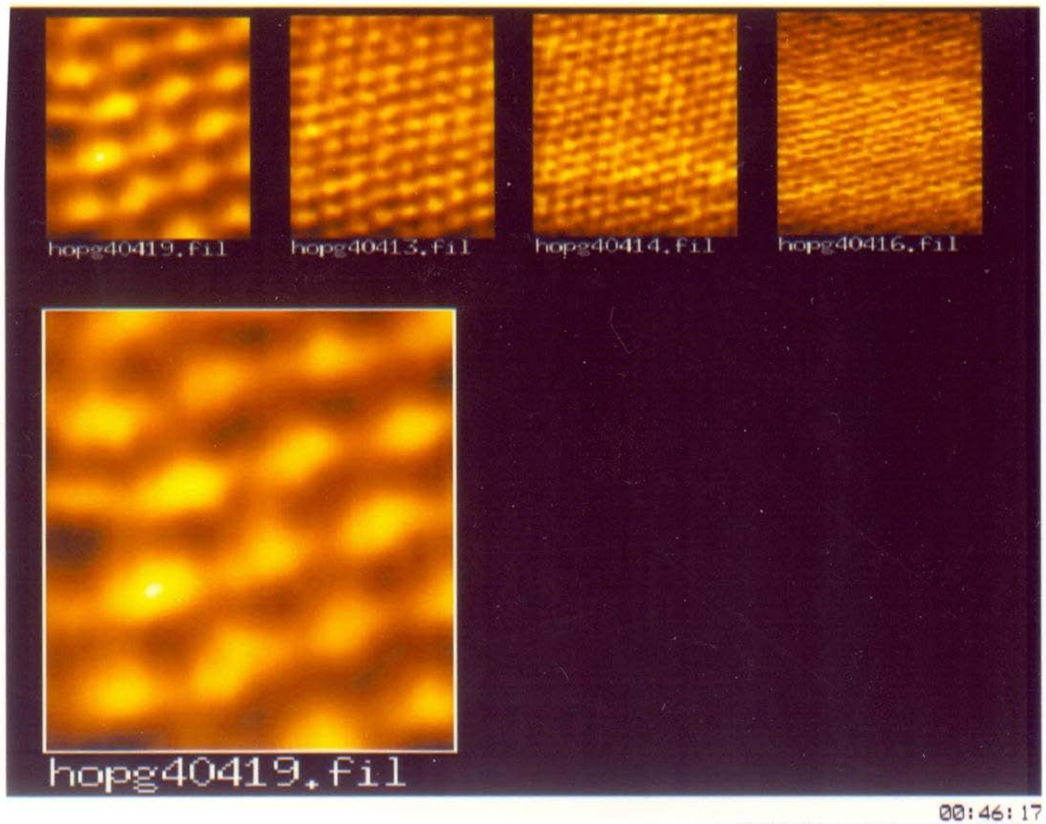
Si(111)-(7x7) using noncontact AFM: R. Luthi, et al., Z. Phys. B 100, 165 (1996).

First International Workshop on Noncontact AFM – 1998 – Proceedings published in Appl. Surf. Sci. 140, 243-456 (1999).

Non-contact Atomic Force Microscopy, Eds. S. Morita, R. Wiesendanger and E. Meyer, Springer (2002).

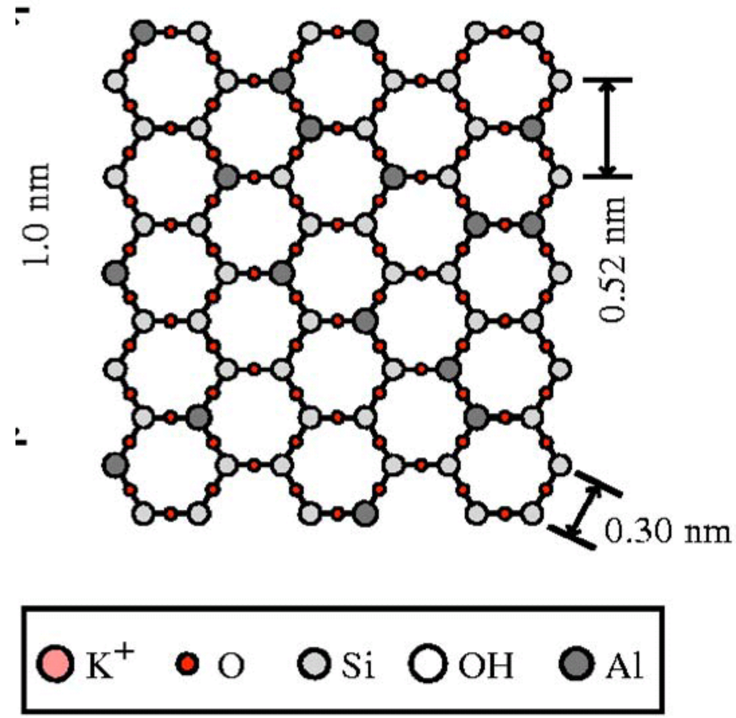
Atomic periodicity using contact mode AFM (constant applied force)

Contact AFM image of freshly cleaved mica



D. Schaefer, PhD thesis, Purdue University (1993)

Mica

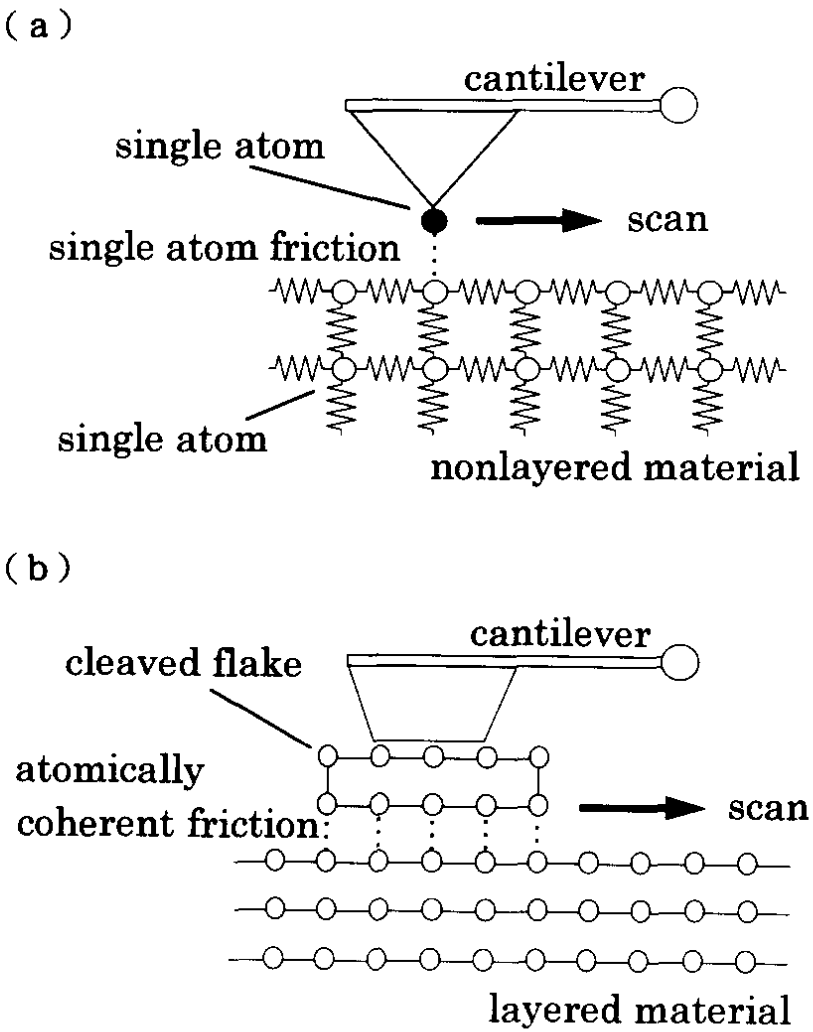


T. Fukuma, et al., Appl. Phys. Lett. 87, 034101 (2005).

Issues

- Large contact force required!
- Finite contact radius, r_c could be ~2 nm
- $\pi r_c^2 / a_o^2 >> 1$
- Large normal force —> high friction
- Coupling between lateral and normal force?
- Feedback loops are never perfect
- No defects?

Stick-Slip friction maps

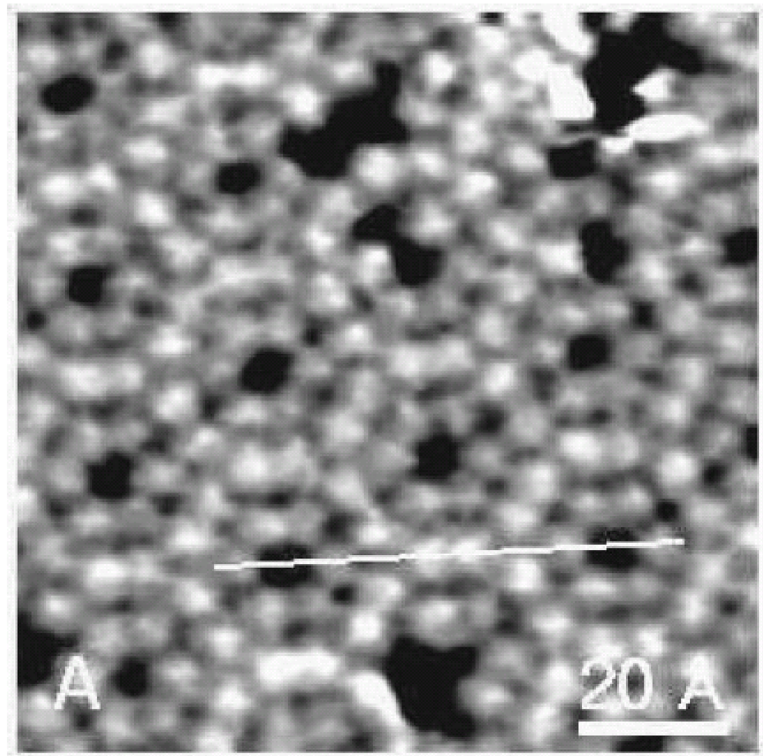


<u>Stick-Slip Model</u> Spatially quantized adhesion with a "jump" to next sticking point. Atomic periodicity results, but only a fraction of the unit cell is "imaged".

S. Morita, et al., Surf. Sci. Rep. 23, 1 (1996)

Seeing atoms with AM-AFM (constant amplitude)

Atomic resolution Si(111)

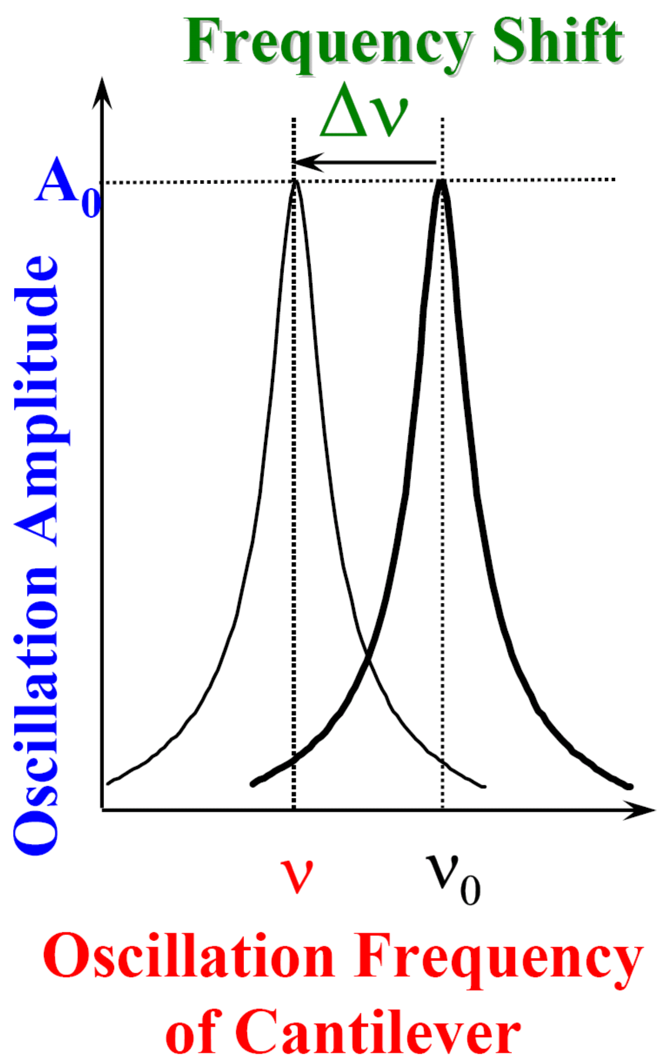


k=60 N/m; f_o=16.4 kHz; Q=550; A_o=0.8 nm

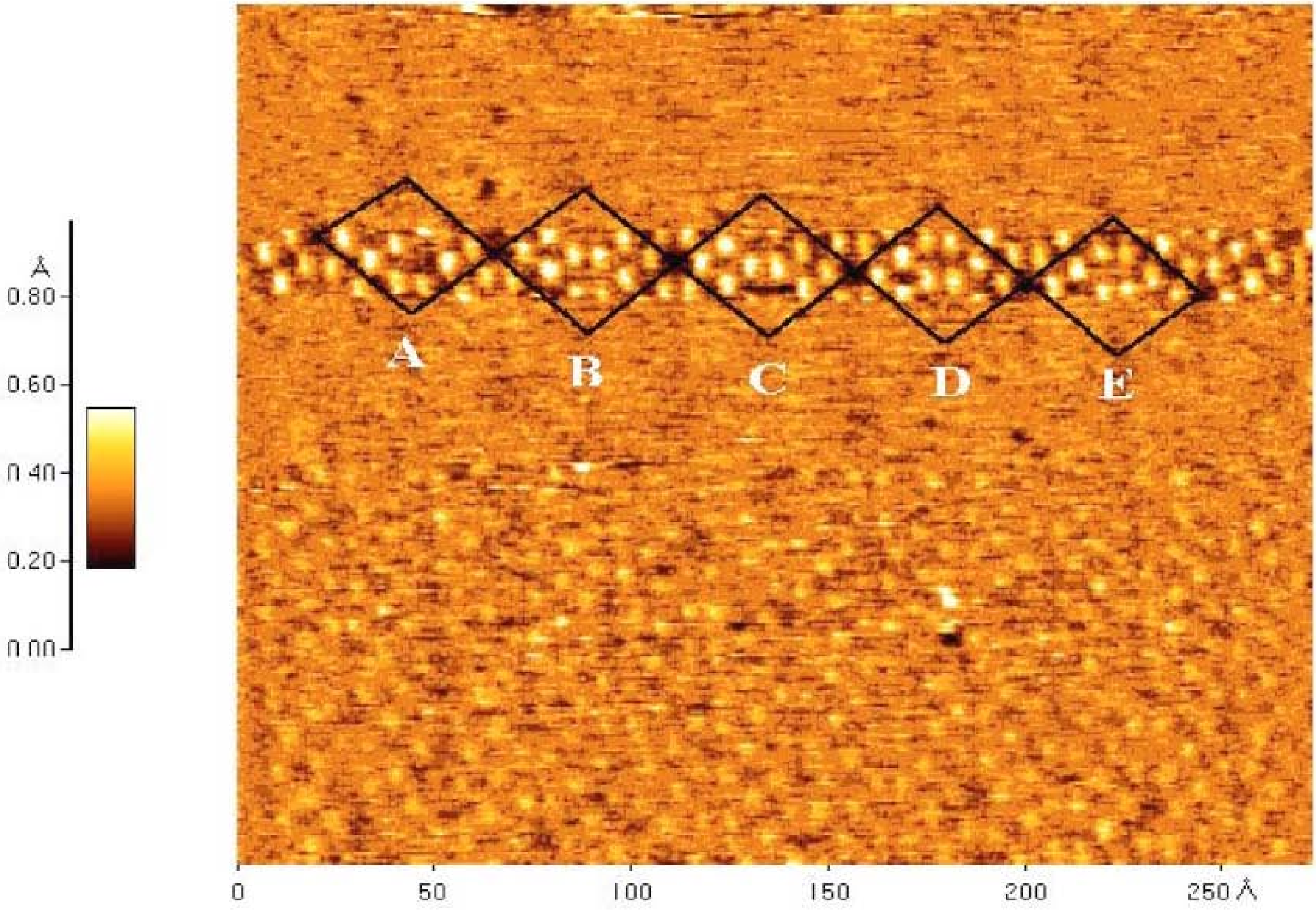
(not many reports! Why?)

Erlandsson et al. Phys. Rev. B**54**, R8309 (1997).

Seeing atoms with FM-AFM (constant frequency)

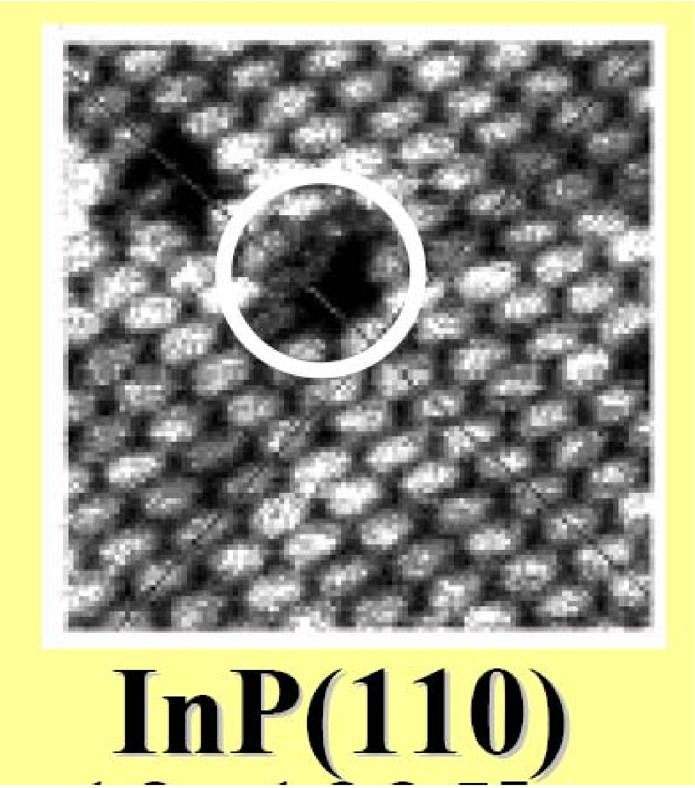


Atomically resolved FM-AFM Image of Si(111)-(7x7)



F.J. Giessibl, Science 267, 68 (1995).

Atomic Point Defects – FM-AFM

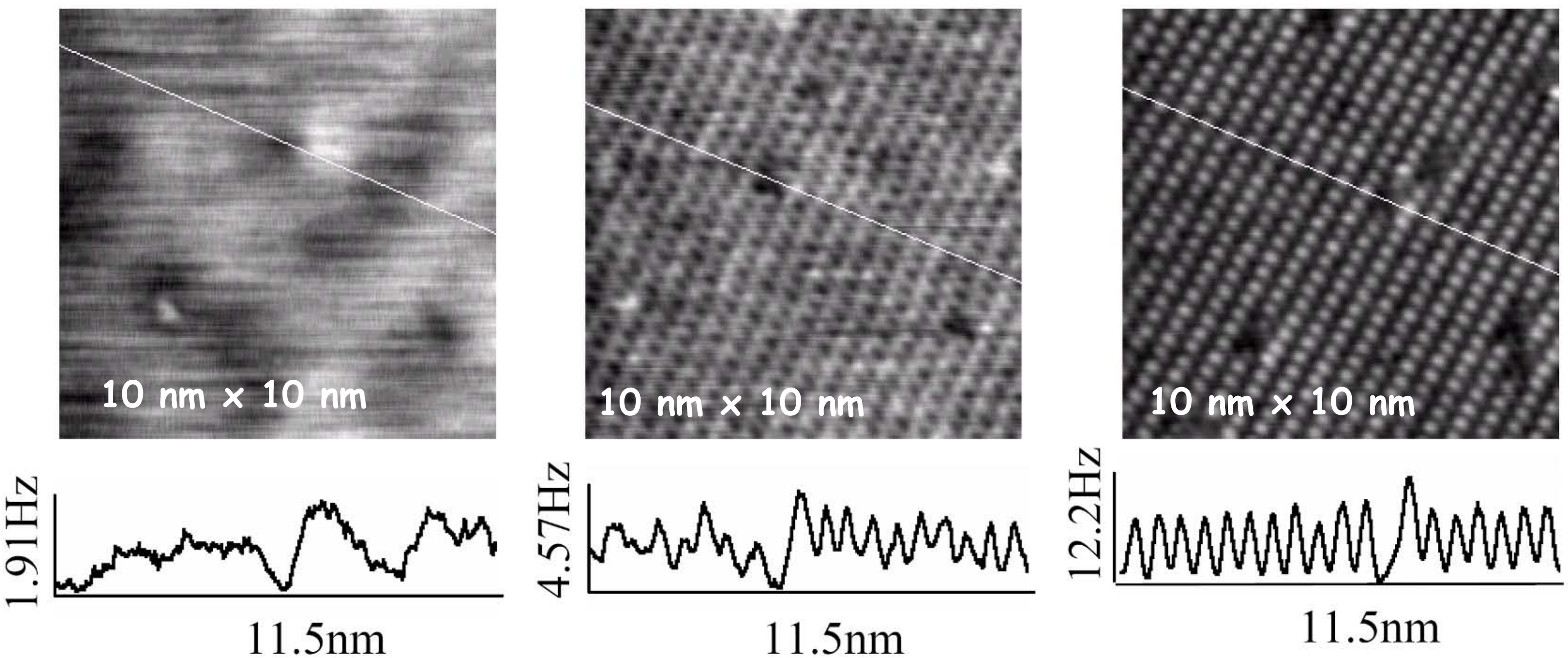


H. Ueyamam, M. Ohta, Y. Sugawara, and S. Morita, Jpn. J. Appl. Phys. 34, L1086 (1995).

Obtaining Atomic Resolution with FM-AFM

Cleaved p-doped-GaAs(001) in UHV

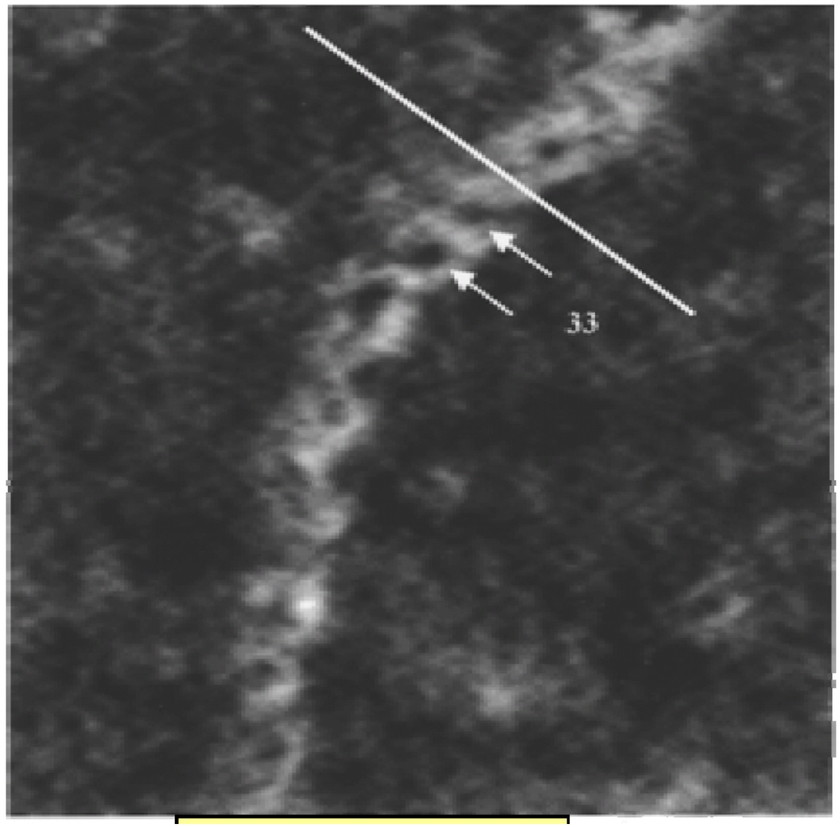
d_{min}=0.4 nm; Δf=-31 Hz **d_{min}=0.1 nm; Δf=-62 Hz** **d_{min}=0.08 nm; Δf=-70 Hz**



k = 35 N/m; f_o = 150 kHz; A_o=9 nm; Q=38,000

S. Morita, M. Abe, K. Yokoyama, Y. Sugawara, J. Crystal Growth **210**, 408 (2000).

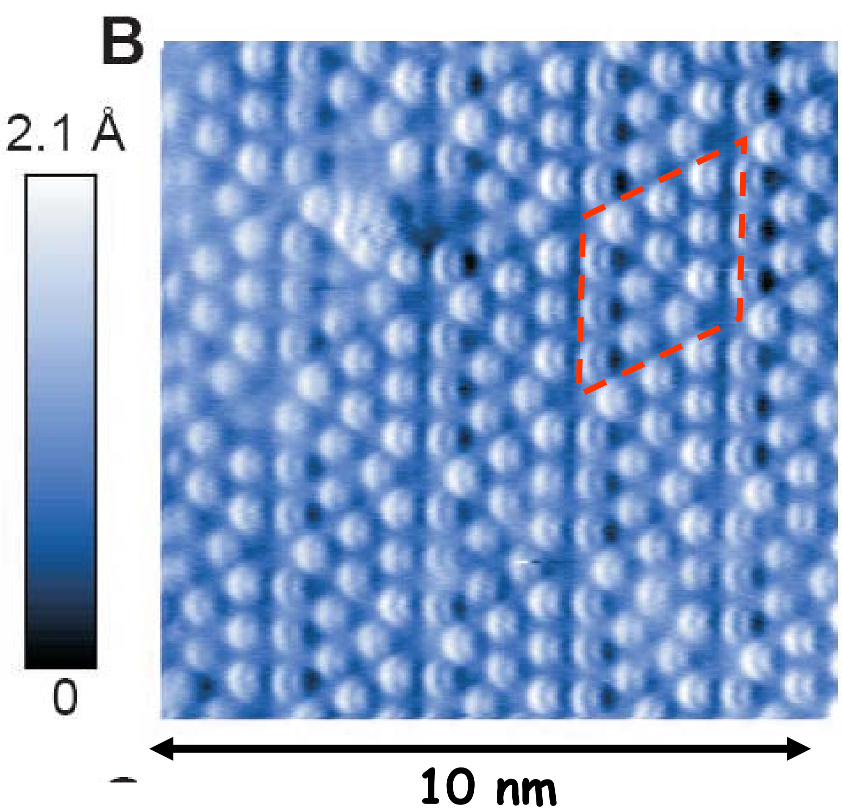
Imaging DNA with FM-AFM



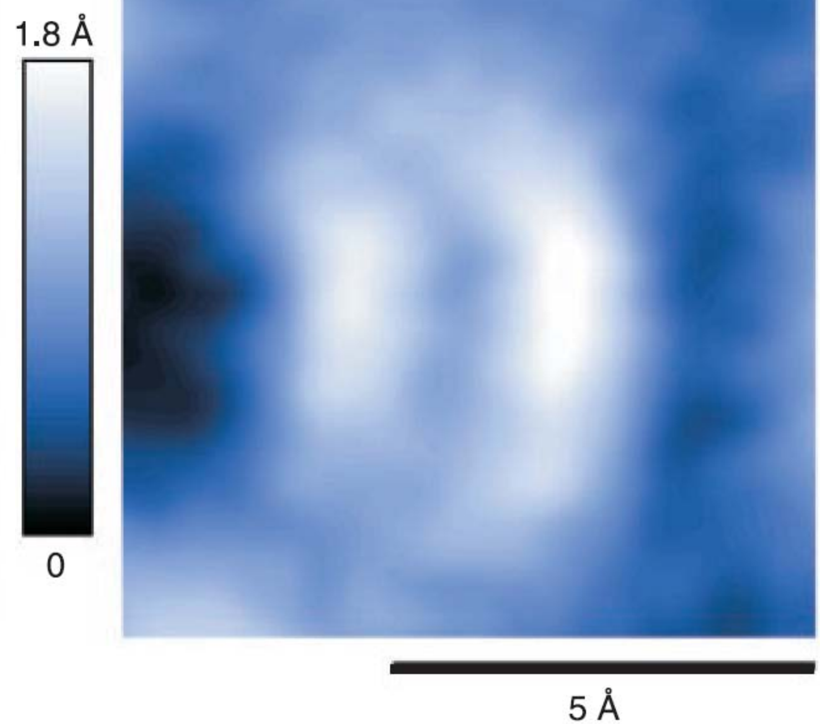
T. Uchihashi, M. Tanigawa, M. Ashino, Y. Sugawara, K. Yokoyama, S. Morita, and M. Ishikawa, Langmuir 16, 1349 (2000).

Sub-atomic resolution?

Δf=-160 Hz



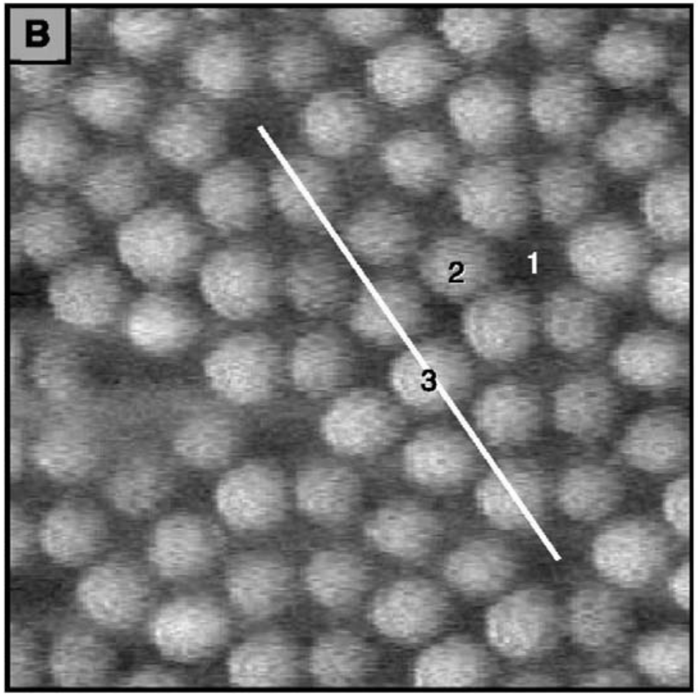
Enlargement a of single atom imaged by FM-AFM

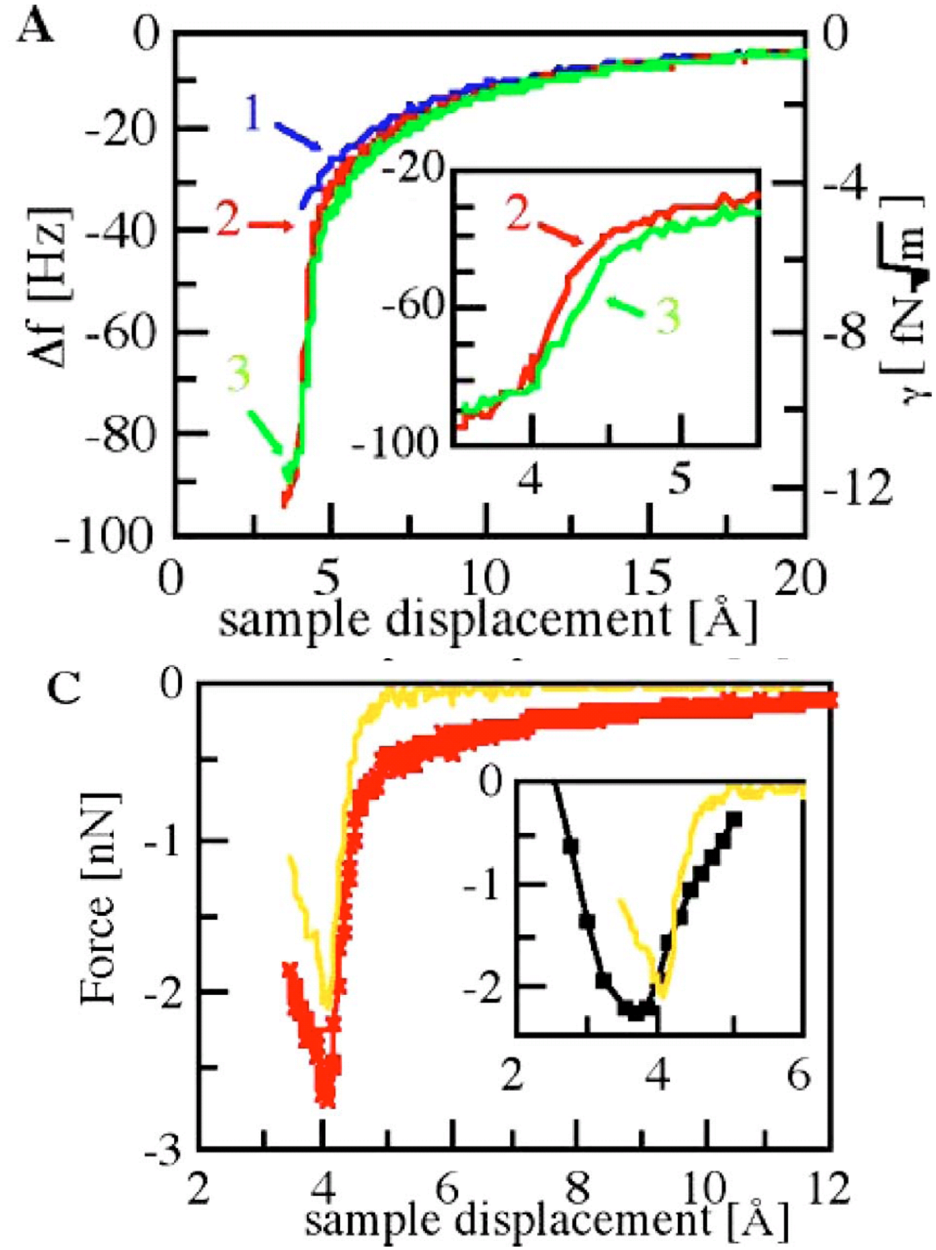


Crescents are interpreted as images of two atomic orbitals of the front atom of the tip

F.J. Giessibl, et al., Science **289**, 422 (2000)

Force Spectroscopy

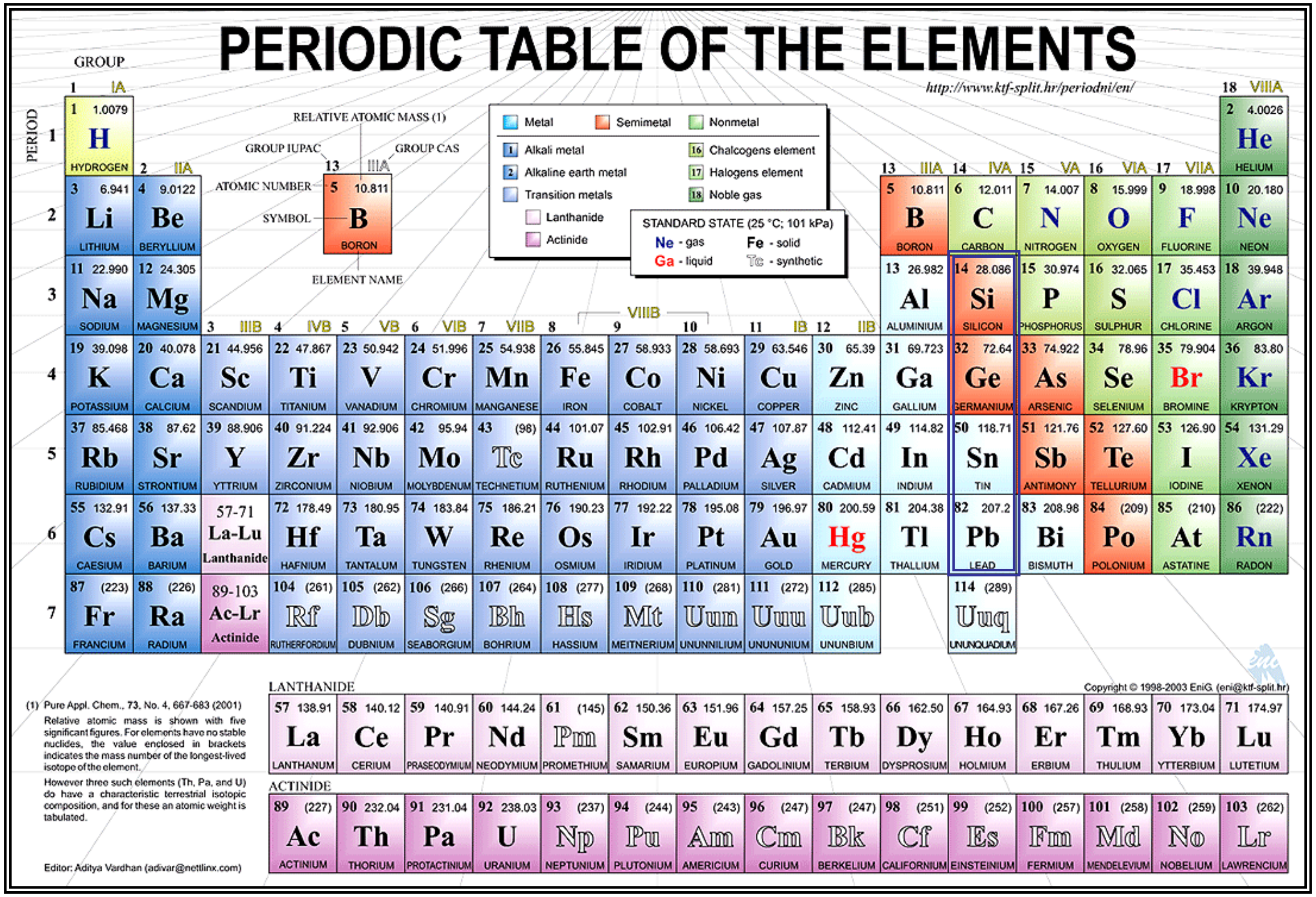




Si(111)-(7x7)

M. Lantz et al., Science 291, 2580 (2001).

2D Binary Alloys

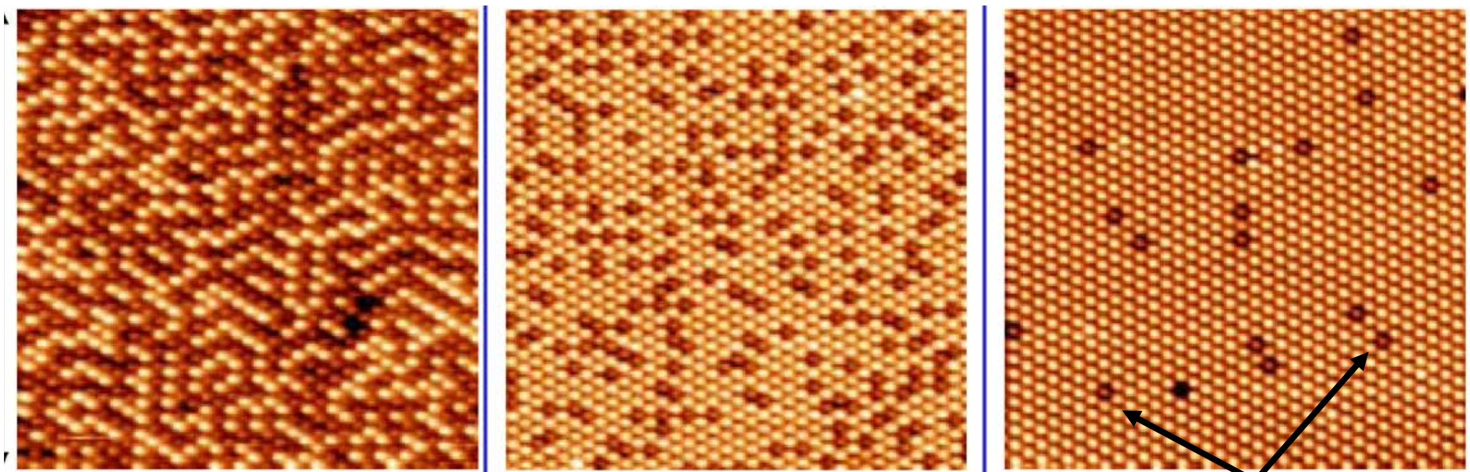


Intense interest because i) new surface structures and ii) possibility of tailoring the electronic properties of a surface

Increasing Sn coverage on Si(111) substrate

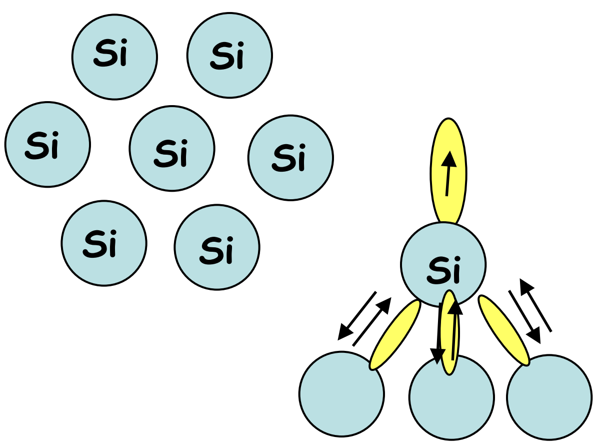
Sn – 1/6 ML → Sn – 1/4 ML → Sn – 1/3 ML

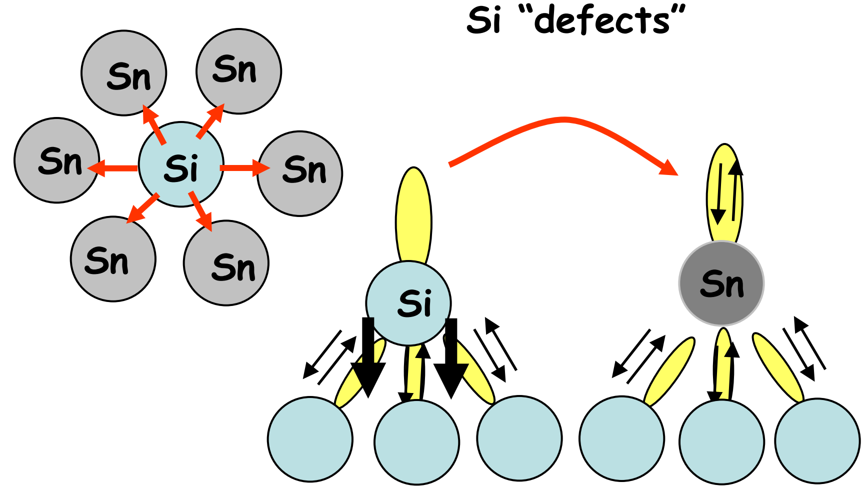
50% Sn; 50% Si | 75% Sn; 25% Si | 99% Sn; 1% Si



20 nm x 20 nm; 1ML on Si(111)=7.84×10^{14} atoms/cm^2

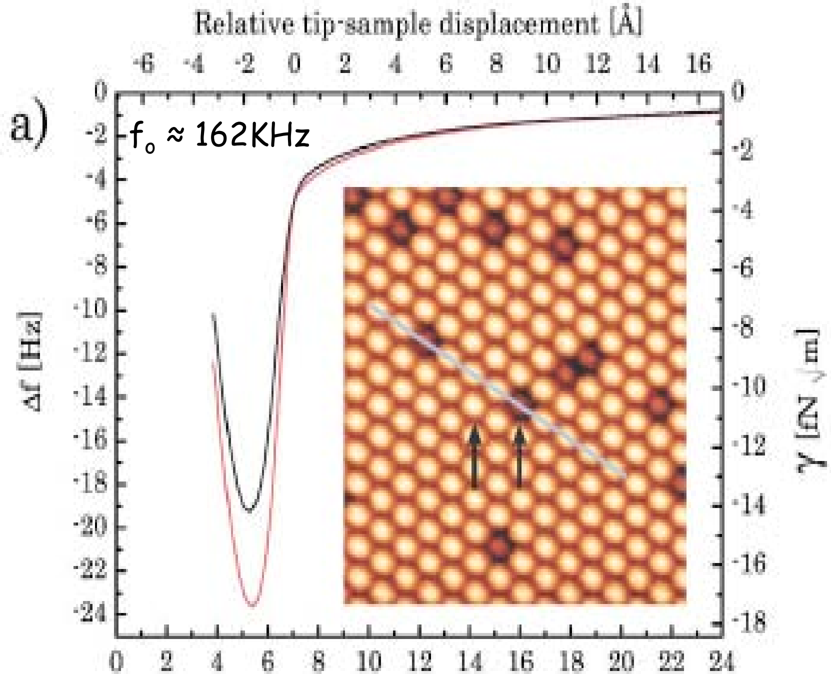
Si “defects”

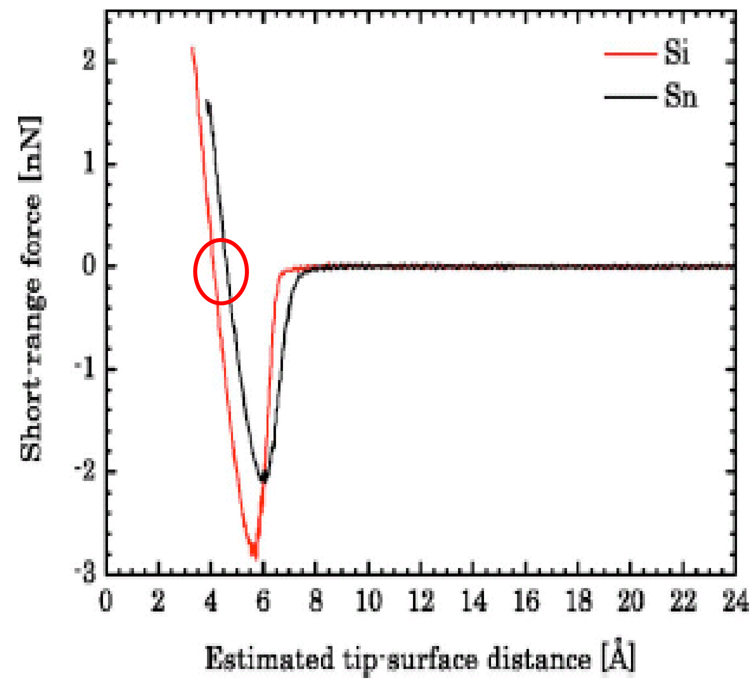




Y. Sugimoto, et al., Phys Rev. B**73**, 205329 (2006).

Measuring the Interaction Force

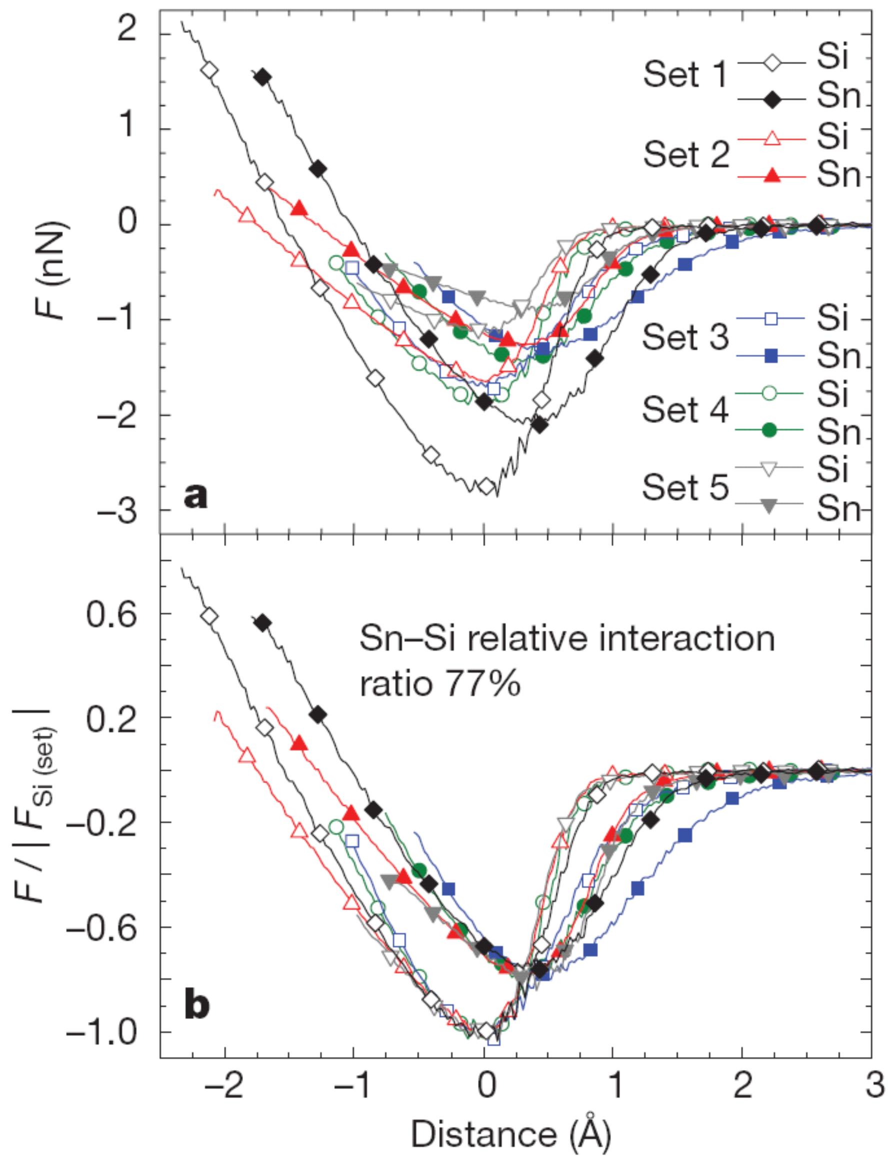




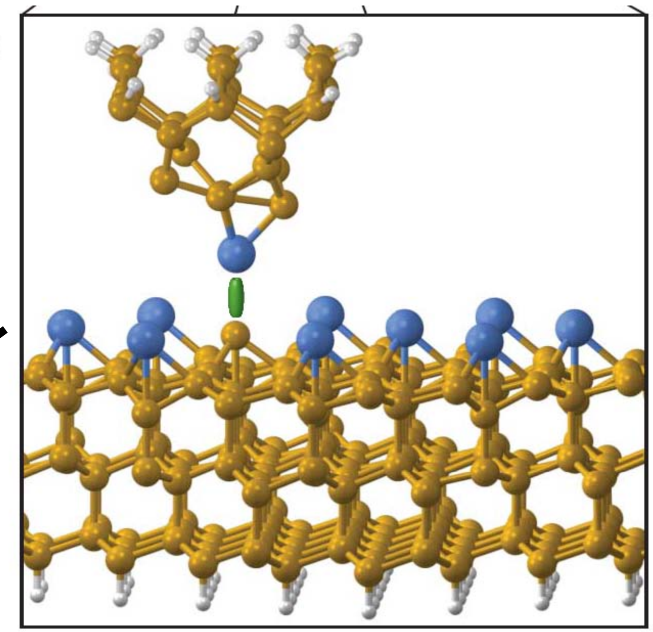
Y. Sugimoto, et al., Phys Rev. B**73**, 205329 (2006).

Atomic Fingerprints

Tip-to-tip variability



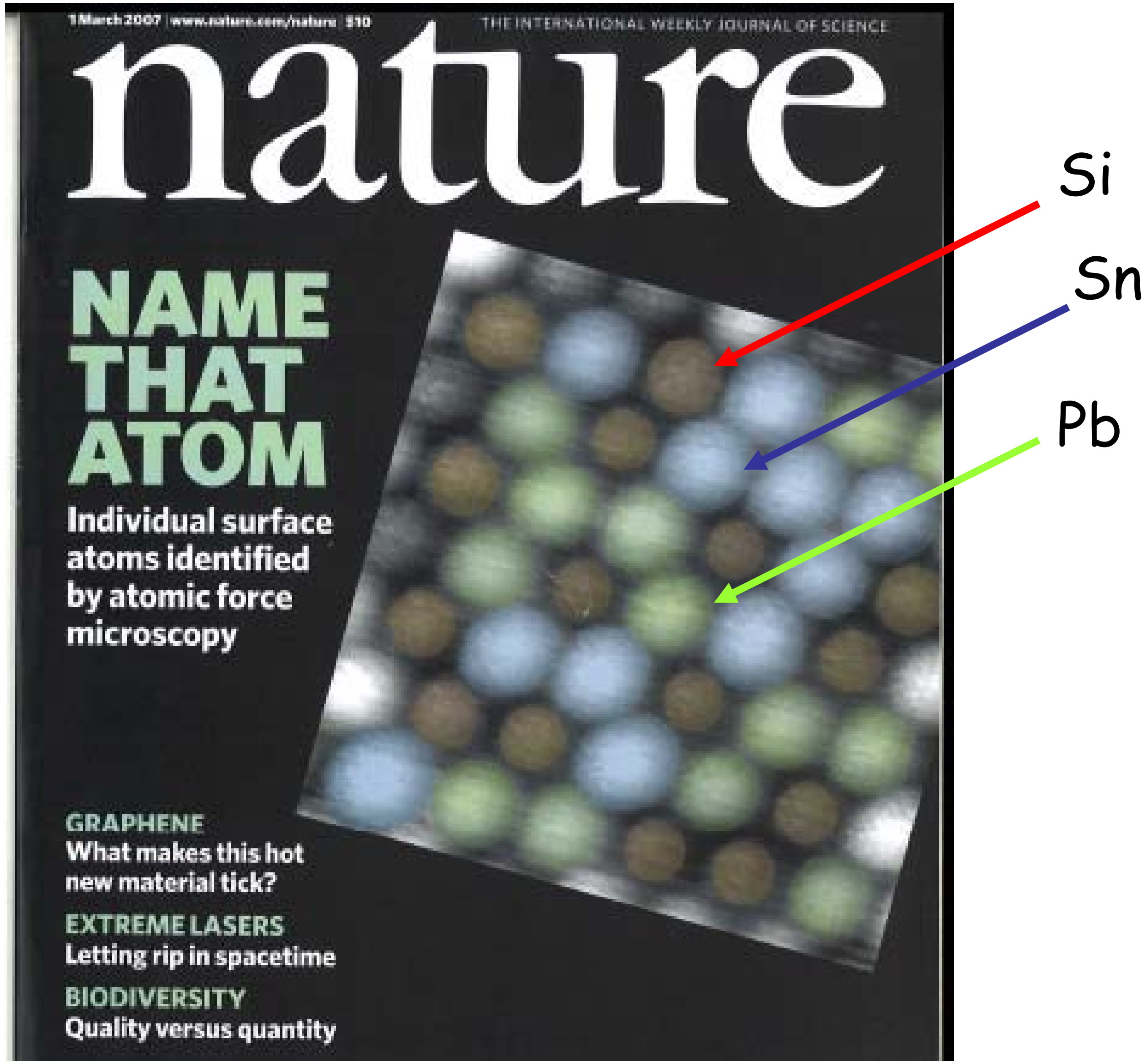
Precise tip structure?



Normalize maximum forces

Y. Sugimoto, et al., Nature **446**, 64 (2007).

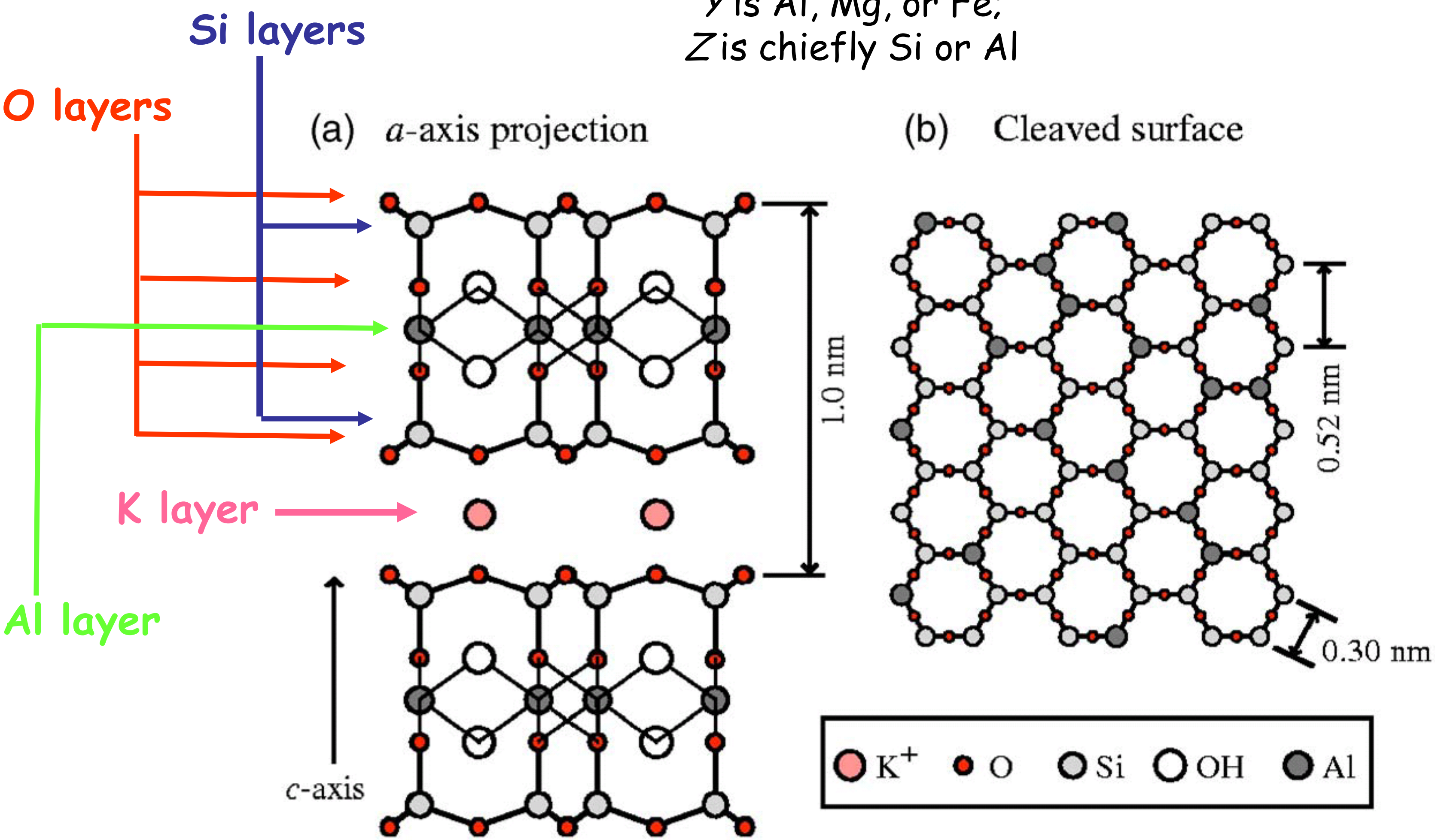
Chemical Identification



Y. Sugimoto, et al., Nature **446**, 64 (2007).

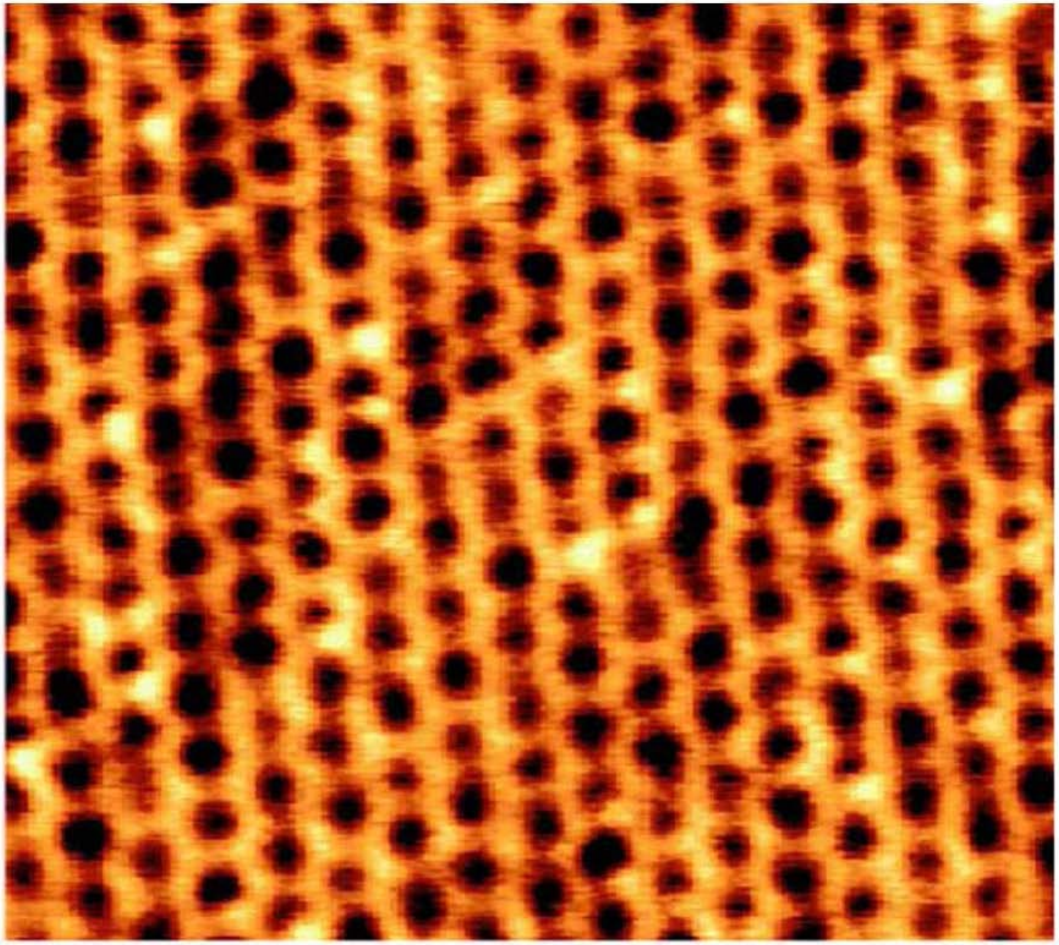
Mica Crystallographic Structure

$X_2 Y_{4\text{-}6} Z_8 O_{20}(OH,F)_4$
in which
X is K, Na, or Ca;
Y is Al, Mg, or Fe;
Z is chiefly Si or Al



T. Fukuma, et al., Appl. Phys. Lett. **87**, 034101 (2005).

Mica under Water



A_o = 0.16-0.33 nm

Vertical resolution 2-6 pm

Lateral resolution 300 pm

Q= 20-30

T. Fukuma, et al., Appl. Phys. Lett. **87**, 034101 (2005).