MOLECULAR NANOSTRUCTURES
Lecture

- **Intro**
- **Nanotechnology**
- **High resolution microscopy**

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Please note, I did not show many slides. I used the blackboard. Therefore, the slides below just provide some supporting information.

Best regards
Thomas

Carbon nanotube oscillators toward zeptogram detection

Mitsumasa Nishio, Shintaro Sawaya, and Seiji Akita[a)]
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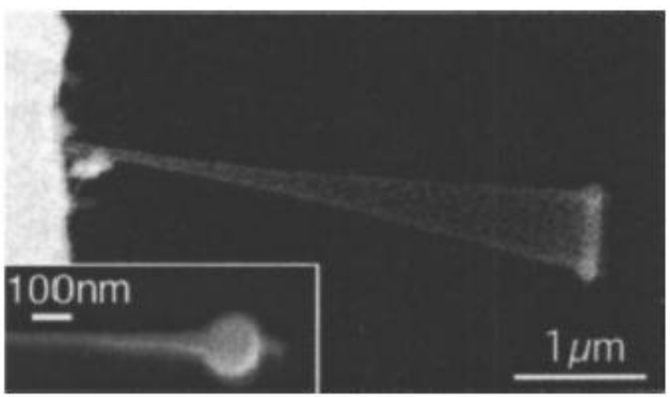
(Received 20 September 2004; accepted 15 February 2003; published online 24 March 2005)

We demonstrate an application of a nanotube cantilever for zeptogram-level mass detection. This letter presents a quantitative method to measure the oscillation amplitude of a nanotube cantilever using a focused electron beam of a scanning electron microscope. The quality factor of ~1000 for the nanotube cantilever is revealed and the resolution of the resonant frequency is achieved to be ~10 Hz, which corresponds to a mass range of less than 100 zg at room temperature. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1896426]



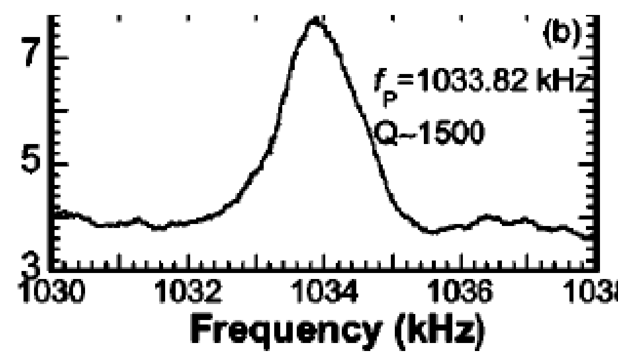
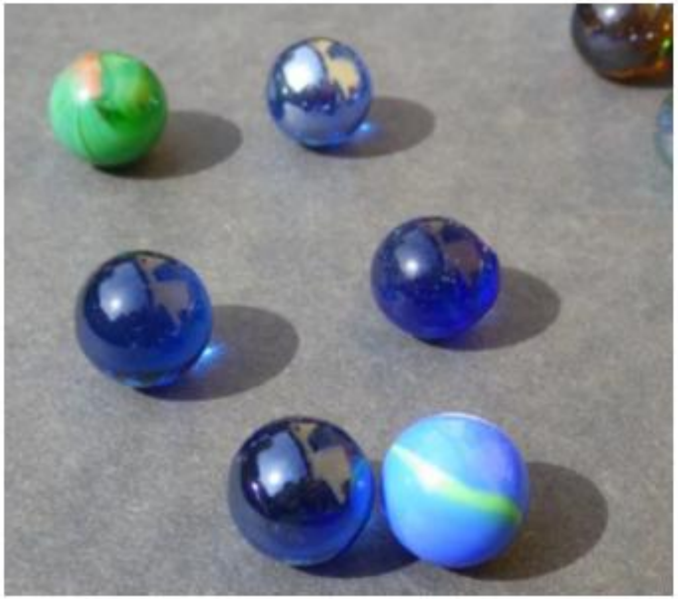
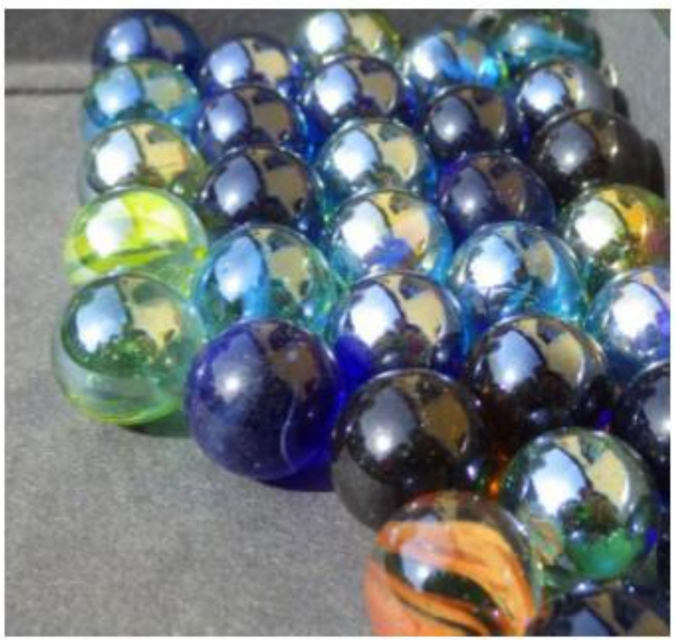


FIG. 2. SEM image of a carbon nanotube oscillator. The inset shows the deposit induced by an electron beam deposition process.

A) Bottom up approach:



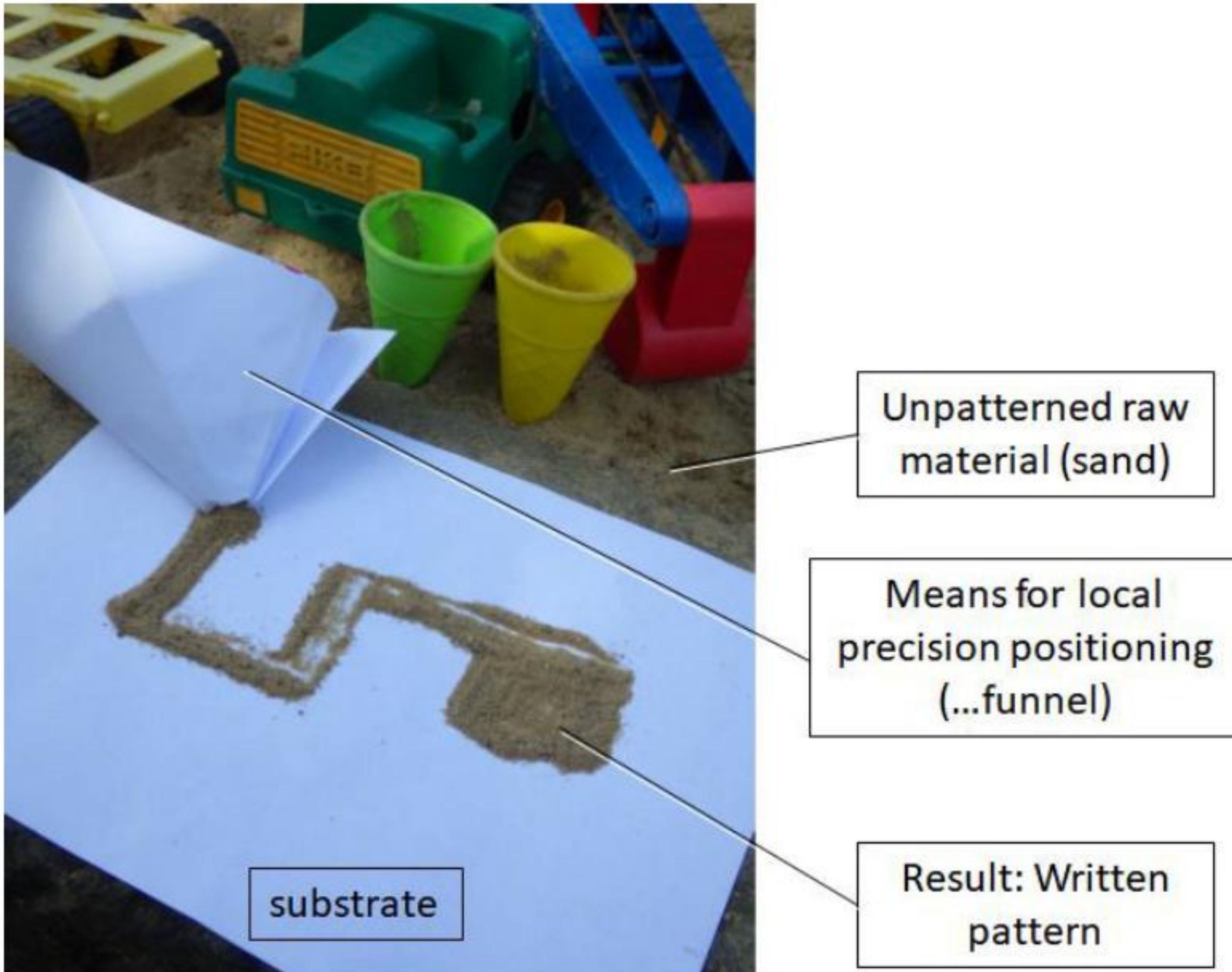
Nano-sized building blocks (pre-existing, well-defined nanostructures)



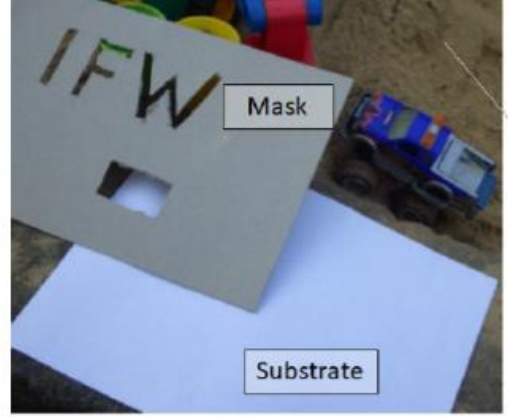
Spontaneous organization of pre-existing molecular units in pattern (in our example: a two-dimensional lattice) mediated by a weak interaction. Here, I am simply using gravity.

<u>B) Top-down approach</u>:

B1) Serial pattern fabrication (flexible but slow process)



B2) Parallel fabrication process (fast, can be repeated easily)



Unpatterned raw material (sand)

Mask on top of the substrate. Thin film deposition of raw material

Pattern on the substrate after mask removal

International Technology Roadmap for Semiconductors

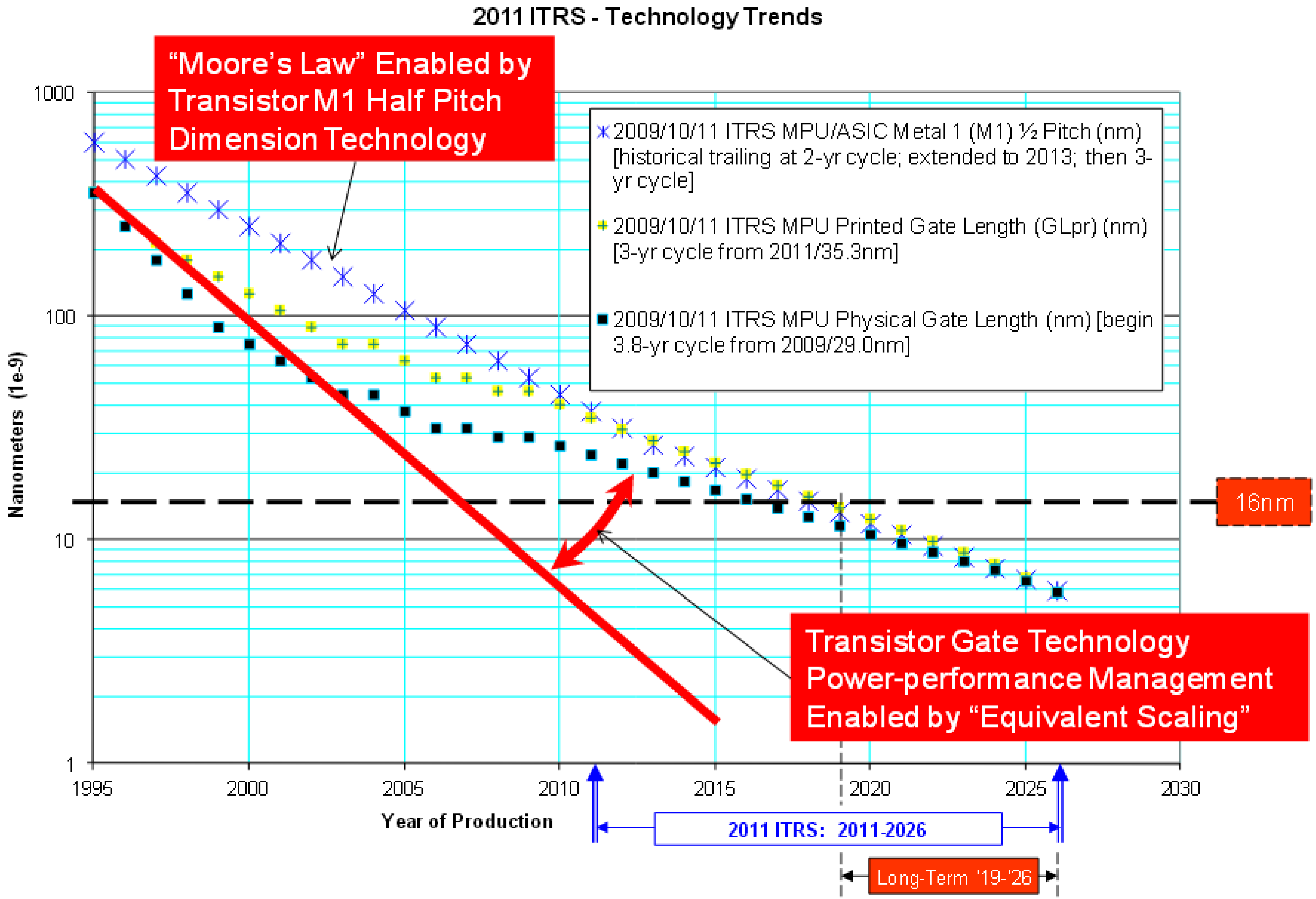
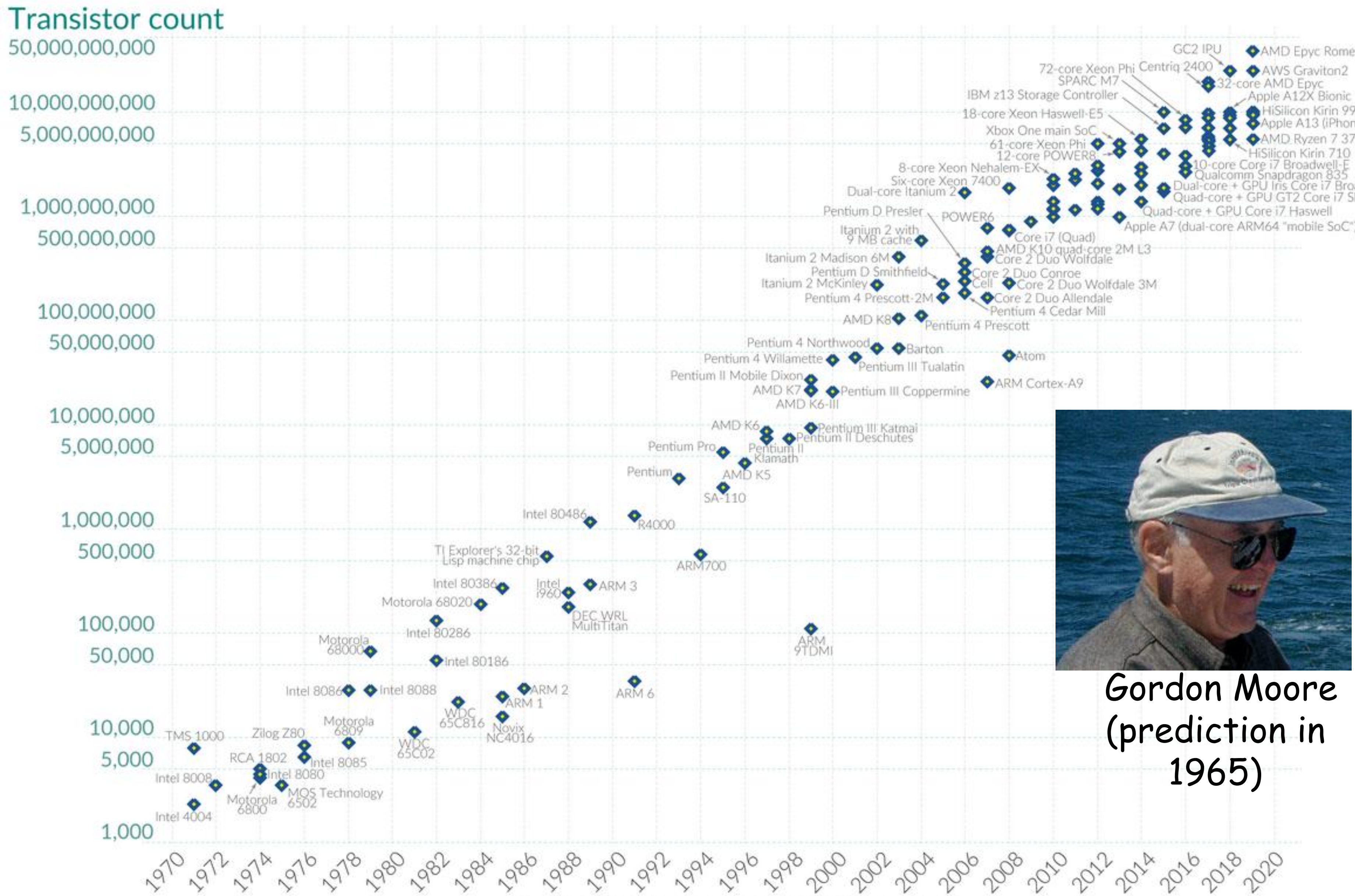


Figure 11 2011 ITRS—MPU/High-performance ASIC Half Pitch and Gate Length Trends

Moore's Law: The number of transistors on microchips doubles every two years

Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years.
This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

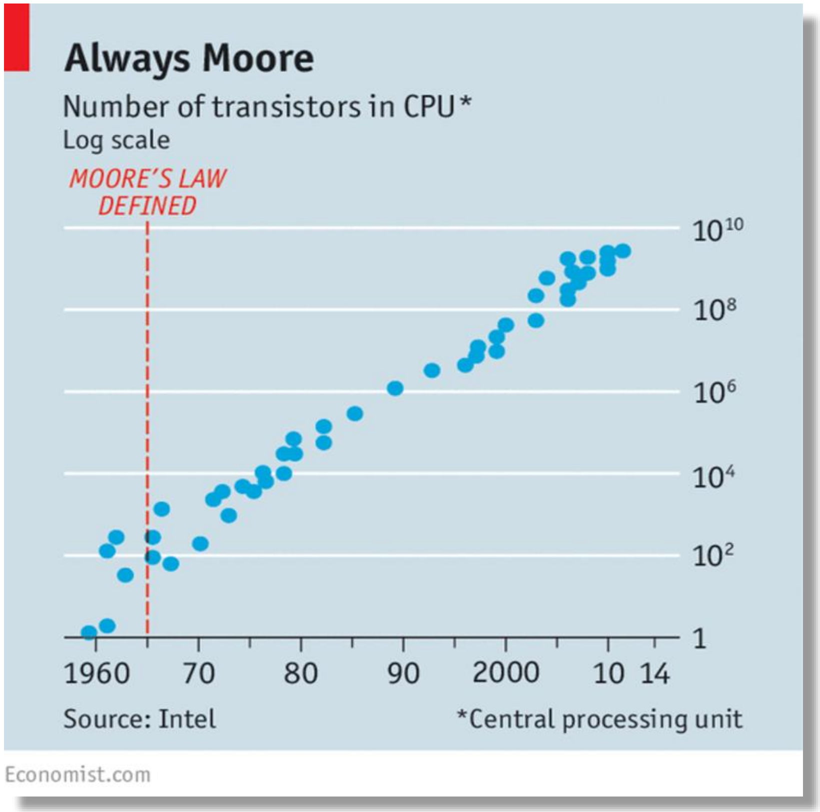


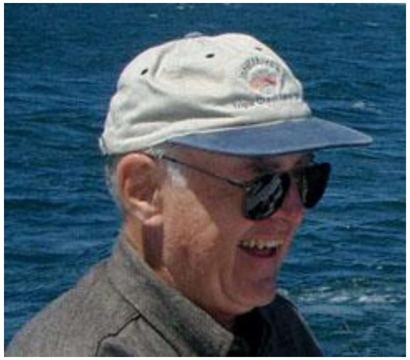
Gordon Moore (prediction in 1965)

Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

OurWorldinData.org – Research and data to make progress against the world's largest problems.

Moore's law:



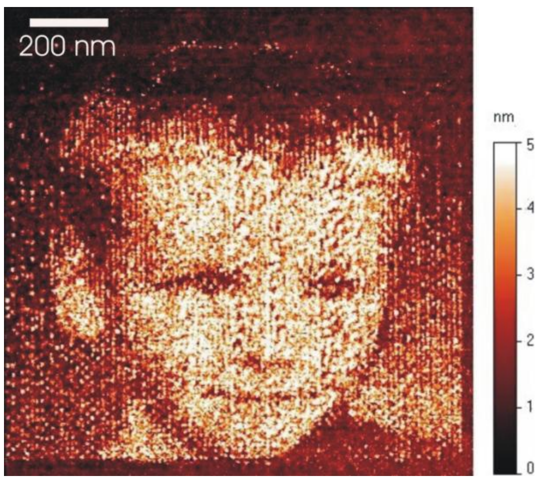


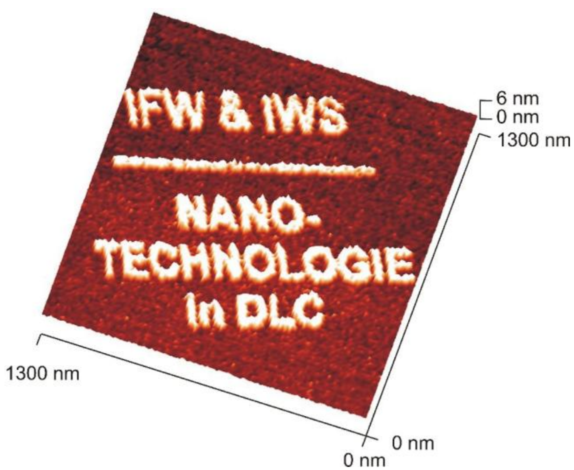
Gordon E. Moore (Jan. 1929 – March 2023)

- B.S. degree in chemistry
- PhD degree in physical chemistry
- 69 years ago: One of the founders of Fairchild Semiconductor
- 67 years ago: Became director of the research and development laboratories
- 61 years ago: Published "Moore's law"
- 58 years ago: Co-founded Intel
- Passed away three years ago

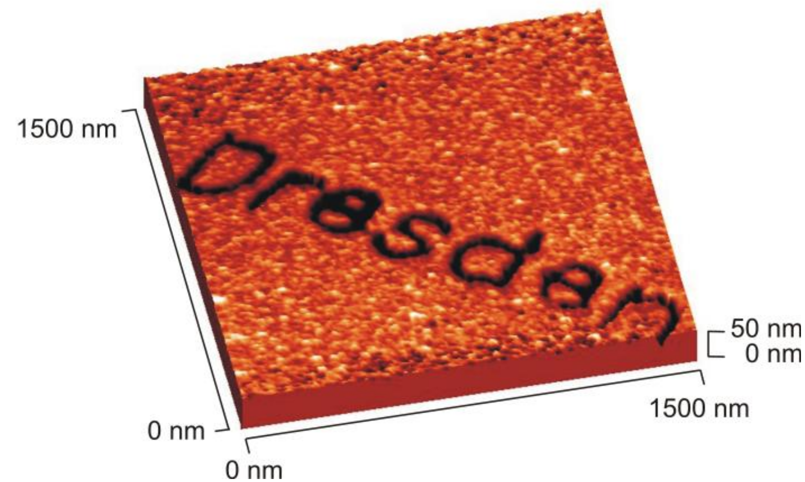
STM-based Nanolithography

Local phase chance in DLC





Local oxidation of DLC



Mühl, APL **85**, 5727 (2004)

Artificial Gold Chains

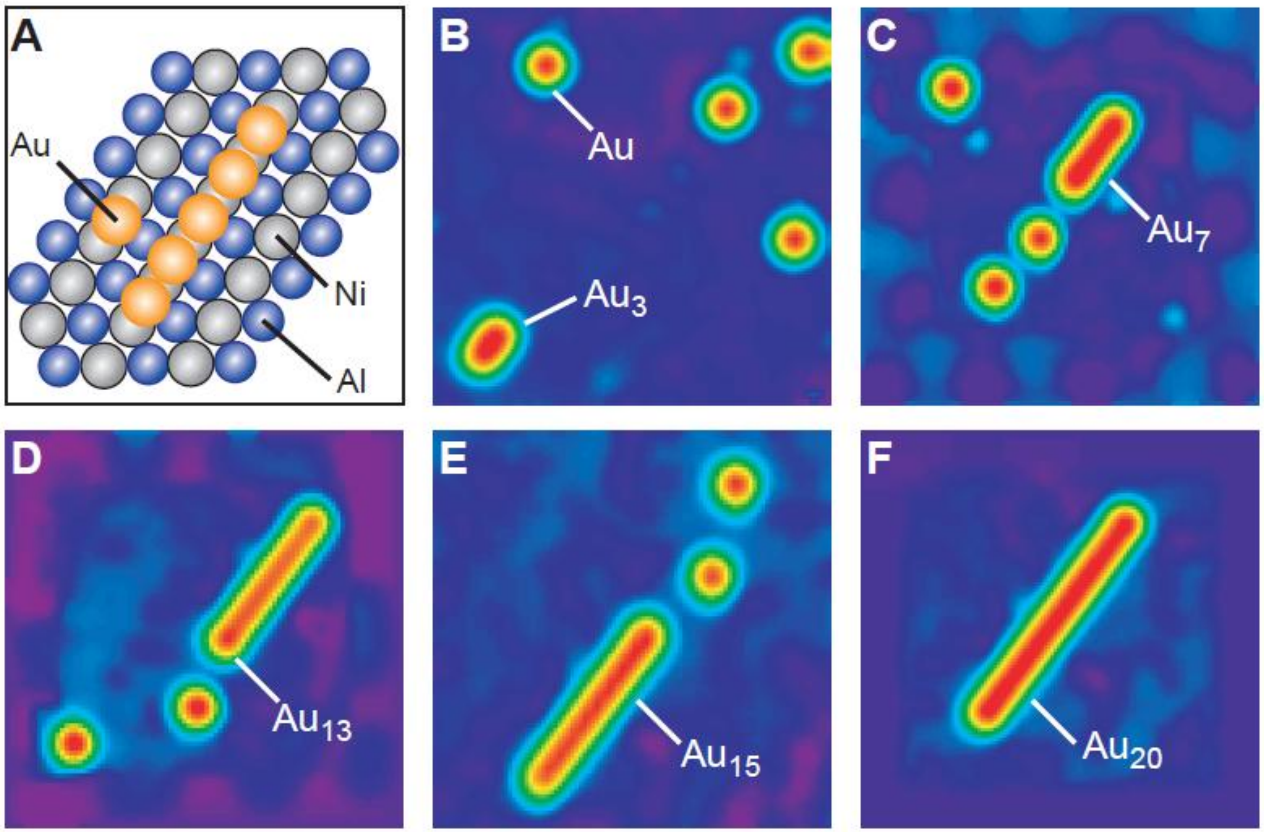


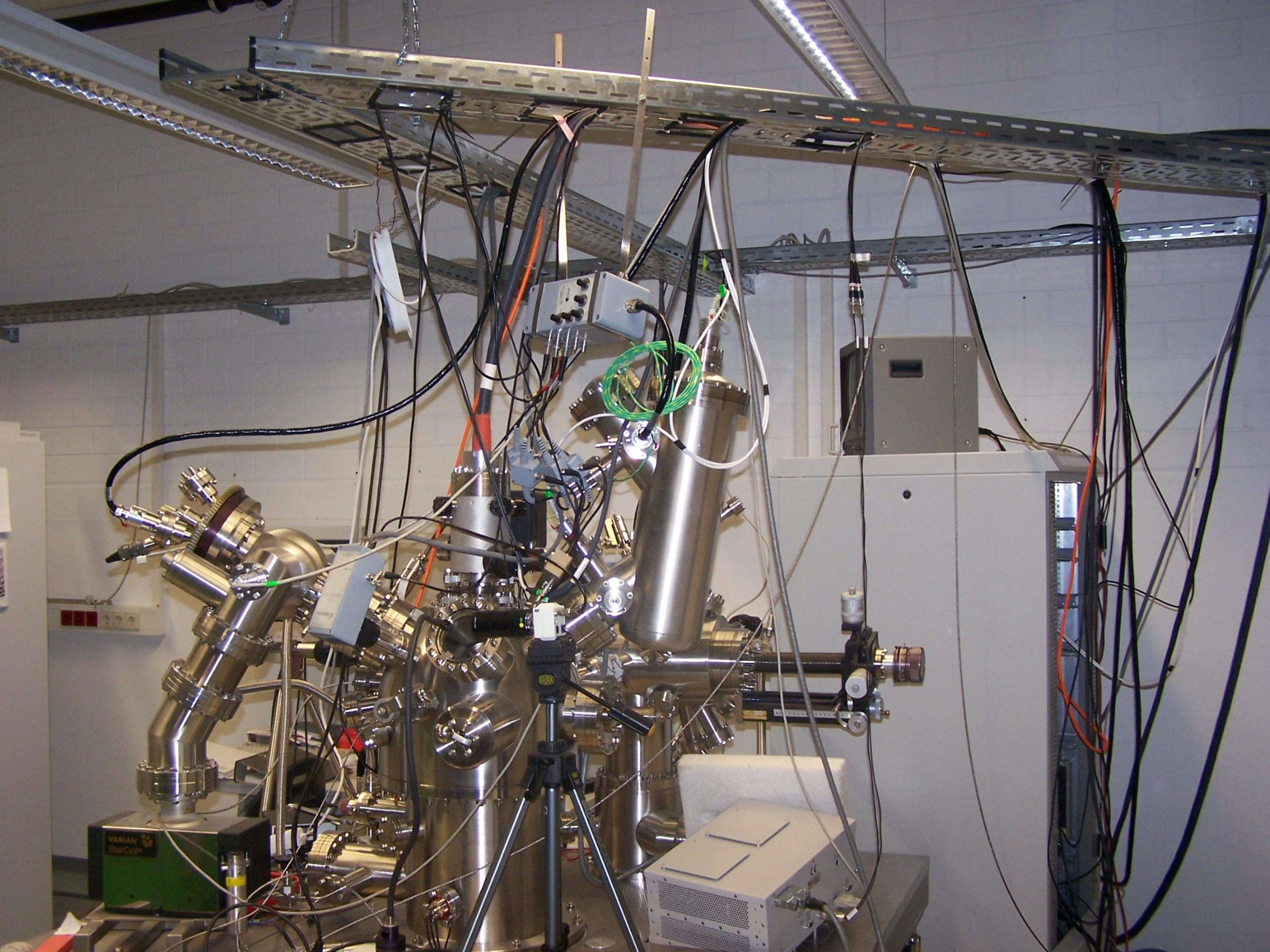
Fig. 1. (**A**) Structure model of a Au_5 chain and a Au atom on NiAl(110). (**B** to **F**) STM topographic images showing intermediate stages of building a Au_{20} chain. Single Au atoms were manipulated with the STM tip and attached on both sides to the chain (image sizes 95 Å by 95 Å, V_{sample} = 2.1 V, I = 1 nA).

Nilius et al., Science **297**, 1853 (2002)

Literature

- E. L. Wolf "Nanophysics and Nanotechnology", 2006 WILEY-VCH

- M. Köhler, W. Fritzsche "Nanotechnology", 2007 WILEY-VCH


VARIAN
StarCell

Shape-Dependent Thermal Switching Behavior of Superparamagnetic Nanoislands

M. Bode,* O. Pietzsch, A. Kubetzka, and R. Wiesendanger
Institute of Applied Physics and Microstructure Research Center, University of Hamburg,

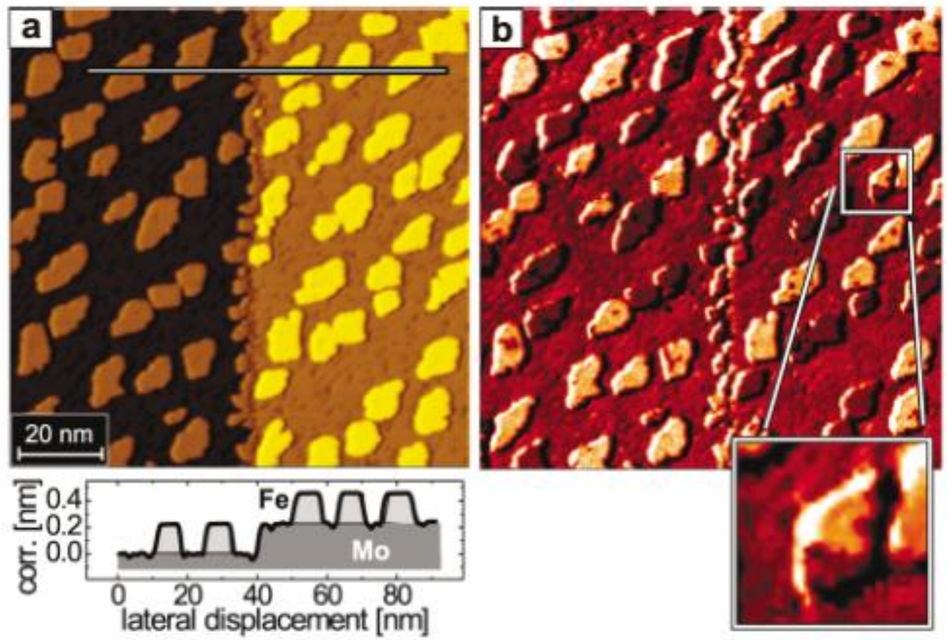


FIG. 1 (color). (a) Topographic STM image and (b) the simultaneously measured out-of-plane sensitive magnetic dI/dU signal of two Mo(110) terraces decorated with Fe islands (overall coverage 0.25 ML). The line section (lower panel) reveals that the substrate's step edge and the islands are of monatomic height (≈ 2 Å). During image recording one island switches from dark to bright (inset). Measurement parameters are $T = 13$ K, $U = 90$ mV, and $I = 1$ nA.

ELSEVIER

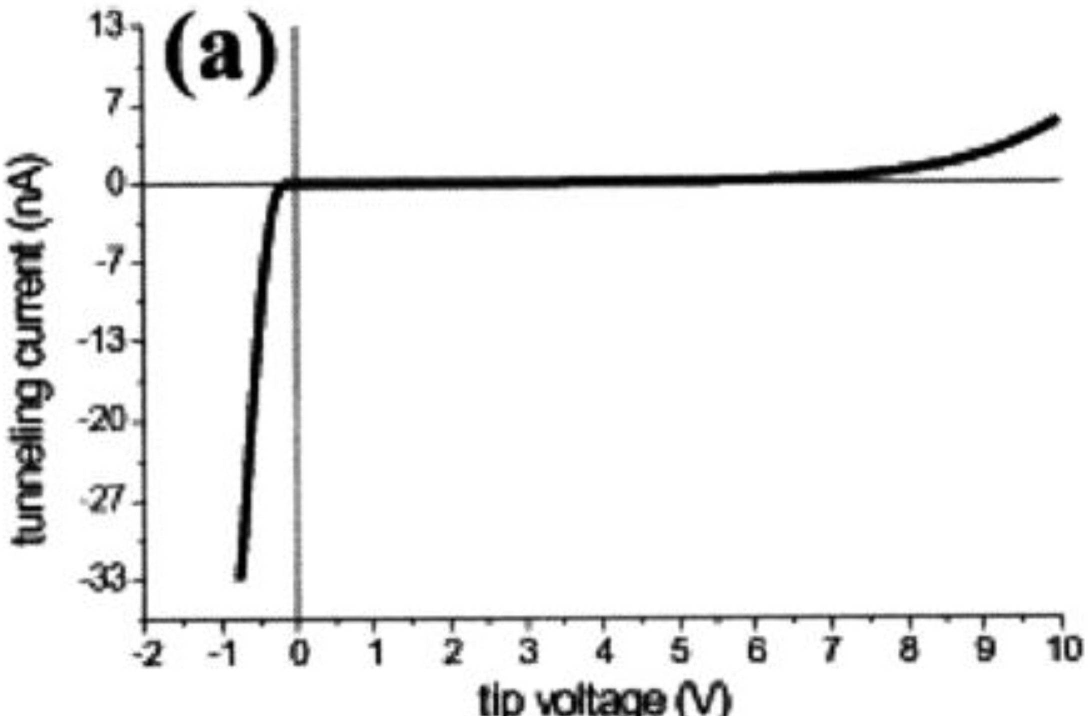
Diamond and Related Materials 11 (2002) 212–217

DIAMOND AND RELATED MATERIALS

www.elsevier.com/locate/diamond

Influence of annealing on the electronic properties of chemical vapor deposited diamond films studied by high vacuum scanning tunneling microscopy and spectroscopy

M. Cannaerts[a,*], M. Nesladek[b], K. Haenen[b], L. De Schepper[b], L.M. Stals[b], C. Van Haesendonck[a]



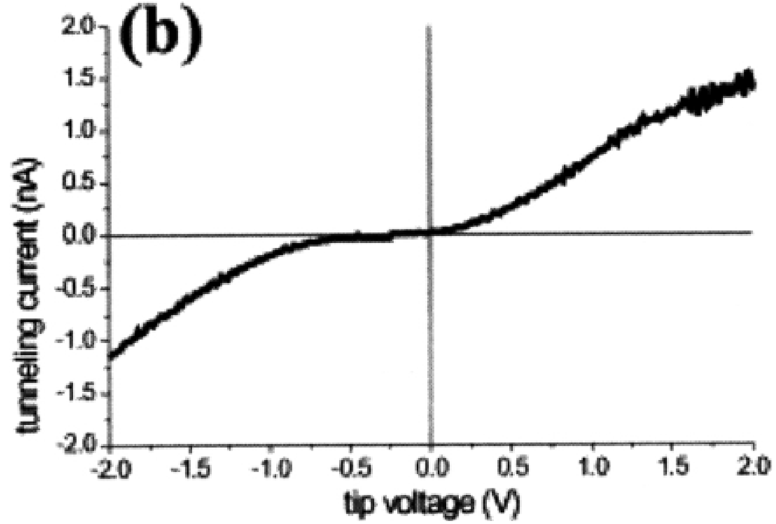


Fig. 2. Two distinctly different $I(V)$ spectra can be measured on the diamond films, a strongly asymmetric tunneling spectrum (a) or a nearly symmetric spectrum (b). The tunneling spectra are obtained with a tip setpoint voltage of -1 V, and a setpoint current of 1 nA for the tip approach.

Electronic effects in scanning tunnelling microscopy of metal-filled multiwalled carbon nanotubes

Richard Czerw, Jiwen Liu and David L Carroll

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E-mail: czerwr@wfu.edu, jiwenliu1@juno.com and carroldl@wfu.edu

New Journal of Physics **6** (2004) 31

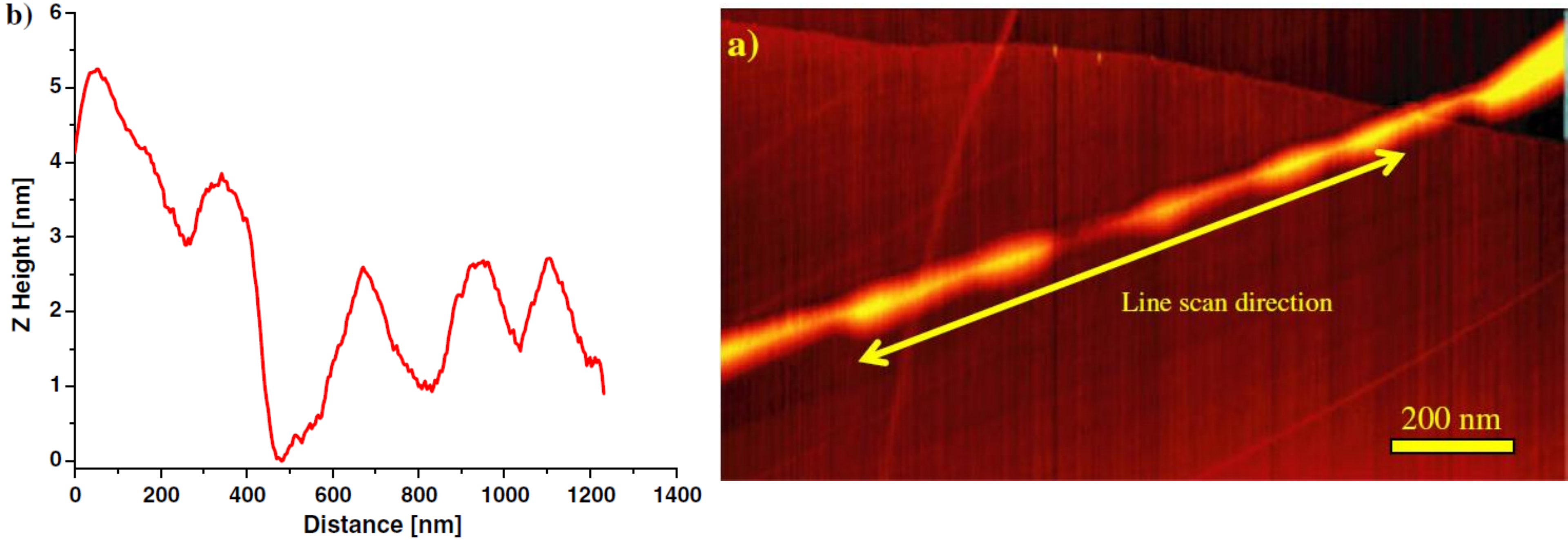
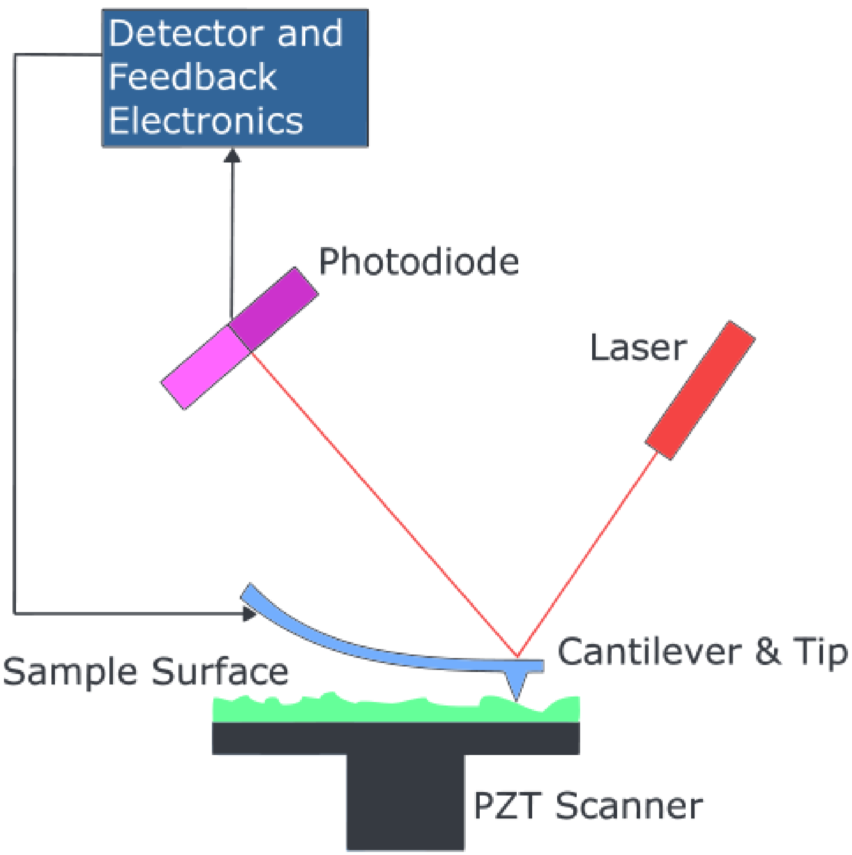


Figure 4. (a) An STM image of a Fe-filled MWCNT imaged at 0.7 V and 0.5 nA. The support substrate is HOPG. (b) A line scan taken along the tube axis for 1400 nm shows strong variations in the image contrast.

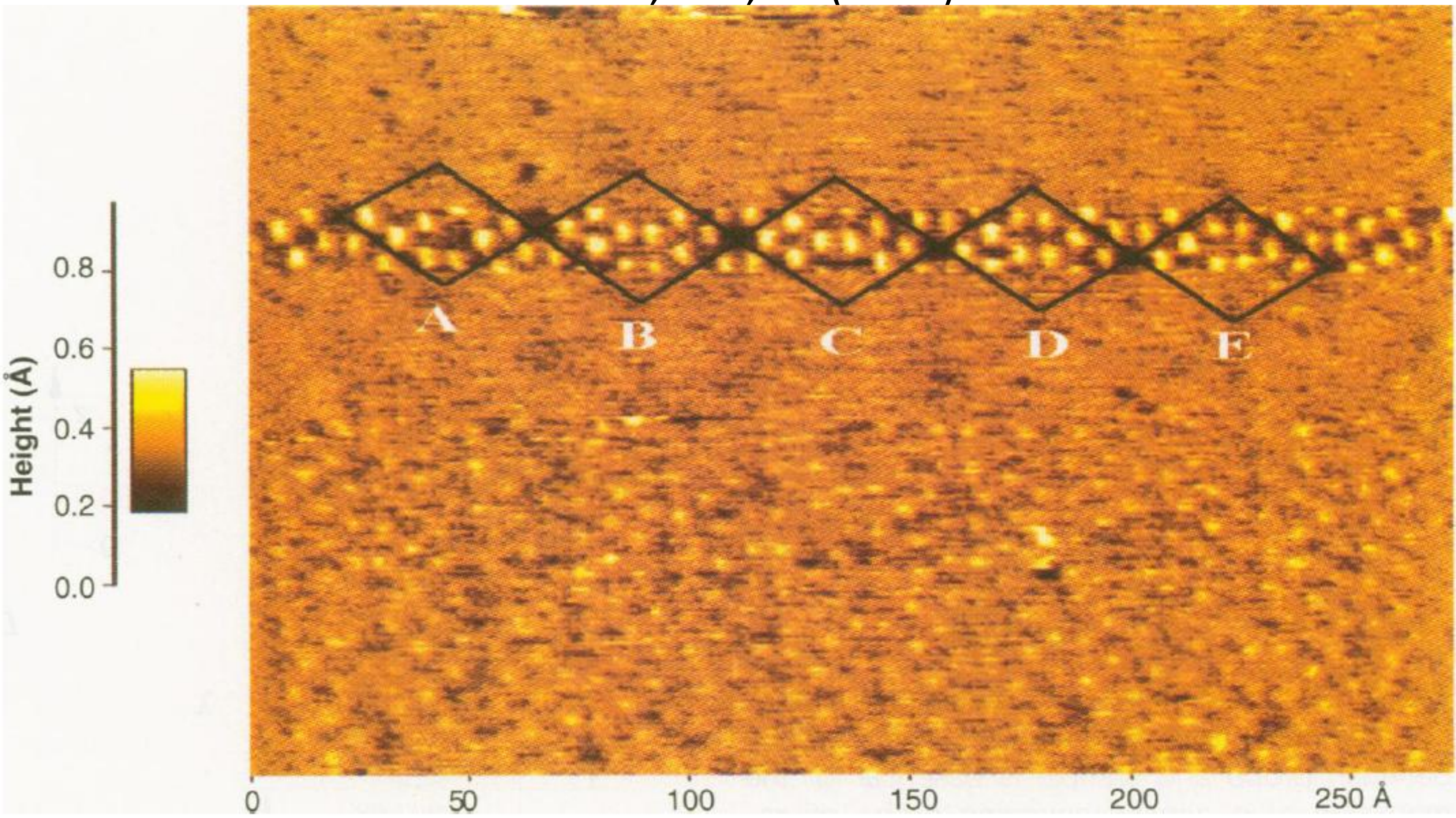
Atomic Force Microscopy (AFM) / Scanning Force Microscopy (SFM)



Atomic Resolution of the Silicon (111)-(7×7) Surface by Atomic Force Microscopy

Franz J. Giessibl

Science, 267, 68 (1995)



The Force Needed to Move an Atom on a Surface

Markus Ternes,[1]† Christopher P. Lutz,[1] Cyrus F. Hirjibehedin,[1]*
Franz J. Giessibl,[2] Andreas J. Heinrich[1]

Science, 319, 1066 (2008)

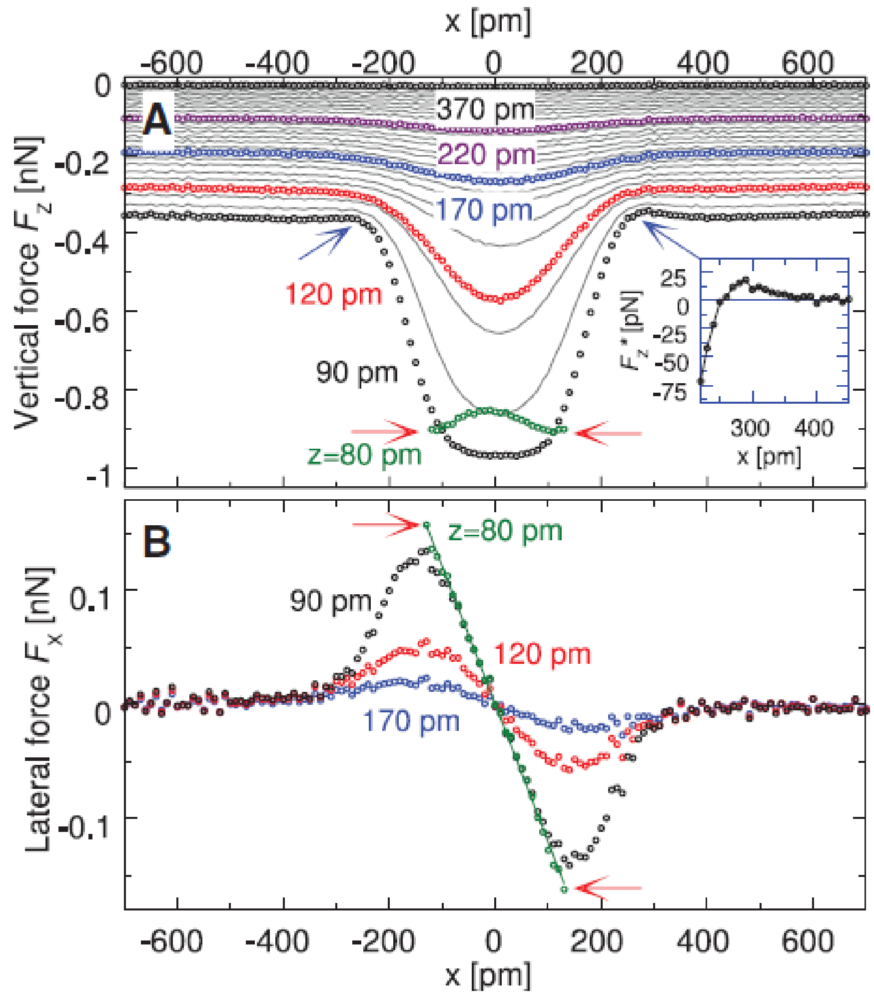
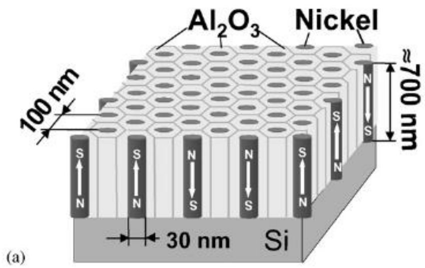
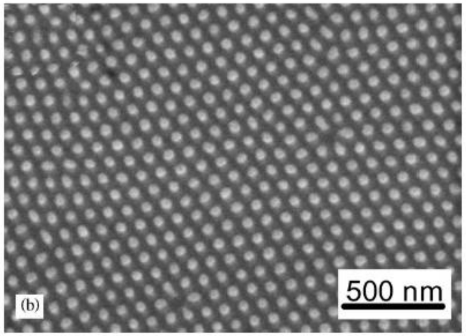


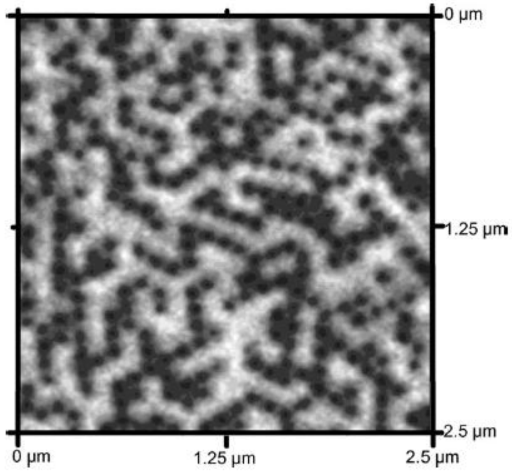
Fig. 3. Vertical and lateral forces for manipulating CO on Cu(111). Vertical (**A**) and lateral (**B**) force components when moving the tip over a CO molecule on Cu(111) for different tip heights *z*. The *x* direction corresponds to the easiest adsorbate motion from an on-top binding site to an adjacent one via a bridge site. The blue arrows mark a repulsive force $F_z^* = F_z - F_B$ of up to 20 pN between tip and molecule (see inset). At $z = 80$ pm, the molecule hopped between neighboring binding sites (red arrows). The green line in (B) is a linear fit to the lateral force with a slope of 1.2 N/m.

Magnetic Force Microscopy





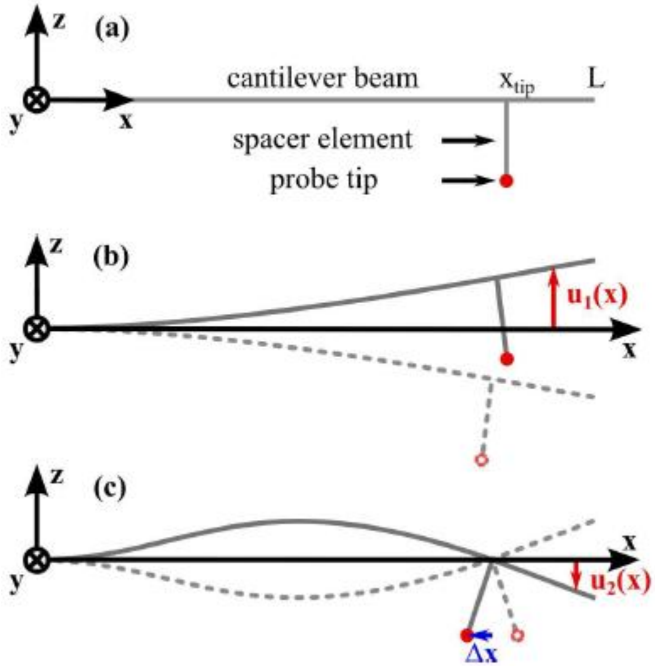
SEM

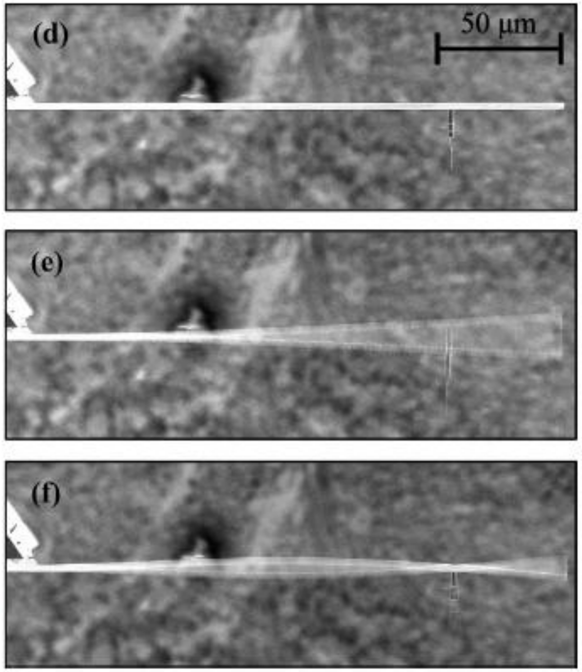


MFM

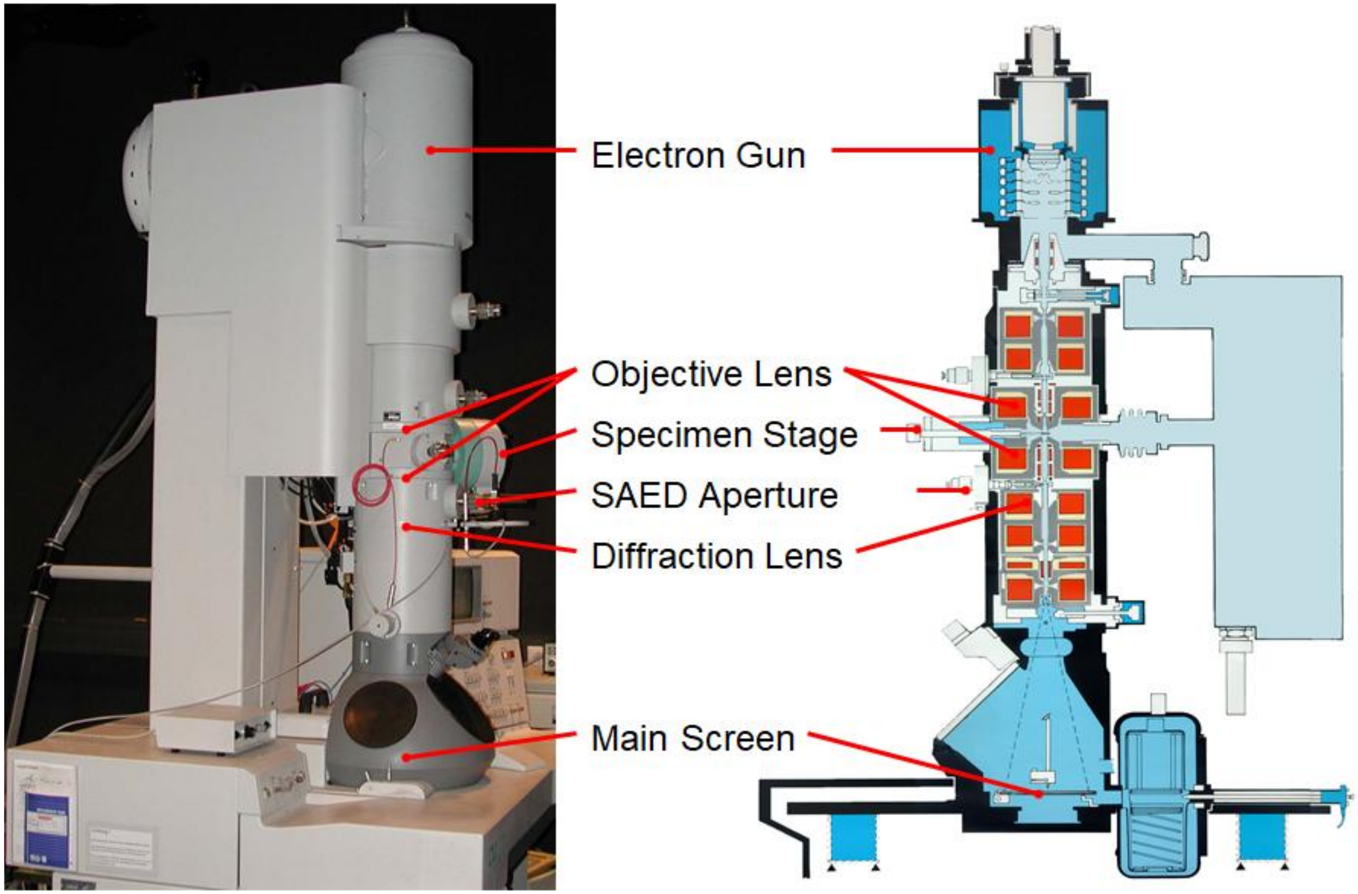
Source: Nielsch et al., JMMM **249**, 234 (2002)

New types of MFM sensors

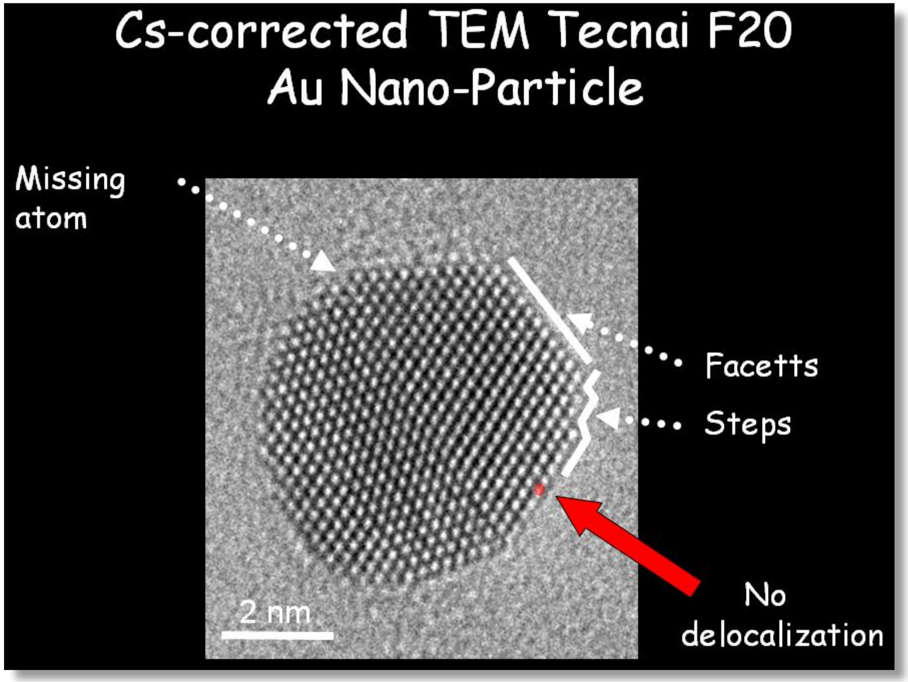




Source:
Reiche, Mühl et al.
New J. Phys. (2015)



TEM setup (source: FEI company and Dr. Axel Lubk / IFW Dresden)



Example: TEM of Au nano-particle (Thanks to Dr. Axel Lubk).

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Please note, I did not show many slides. I used the blackboard. Therefore, the slides just provide some supporting information.

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