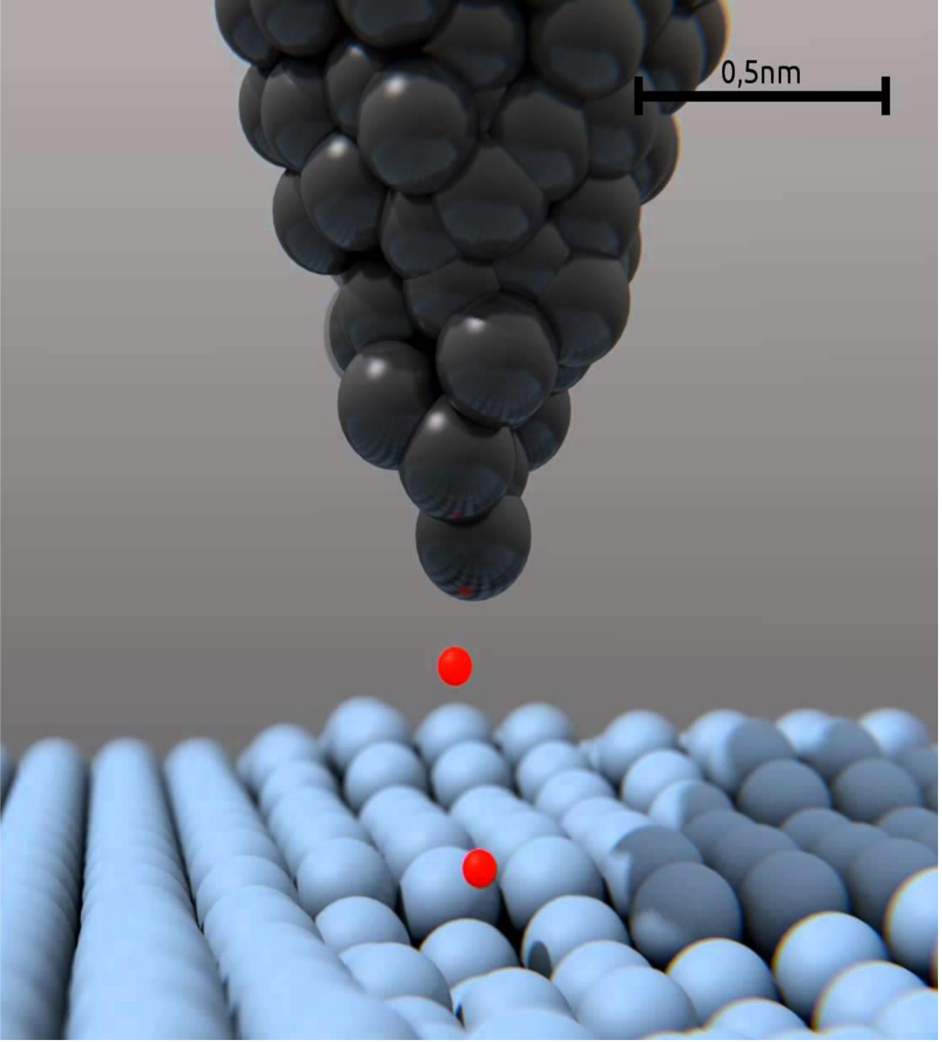


Cover picture taken from the video: https://www.youtube.com/watch?v=EXcQxuWR1pI

Surface Studies by Scanning Tunneling Microscopy

G. Binnig, H. Rohrer, Ch. Gerber, and E. Weibel
IBM Zurich Research Laboratory, 8803 Ruschlikon-ZH, Switzerland

(Received by Phys. Rev. Lett. on 30th April, 1982)
DOI: https://doi.org/10.1103/PhysRevLett.49.57

Presented by Tyler Salners, Preetha Sarkar, Devyn Shafer, and Jiayu Shen
Physics 596
December 1st, 2017
University of Illinois at Urbana-Champaign

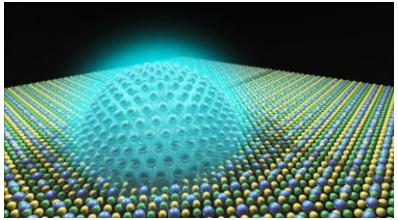
Significance of Surface Science

- Characterization of surface structures is essential for the development of new materials
- Surface characteristics are typically different from bulk characteristics
- A few applications:

Solar Panels: Surface properties are paramount to optimizing efficiency

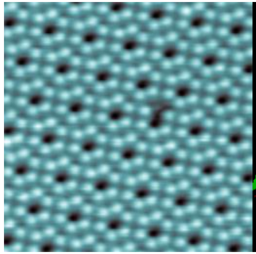
https://www.sciencedaily.com/releases/2016/09/160928151119.htm

Quantum dots: Applications in solar energy, transistors, LEDs, medical imaging

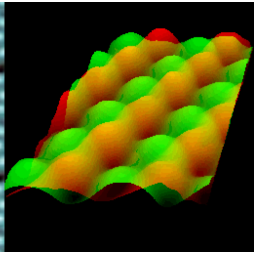


http://jqi.umd.edu/news/quantum-bit/2014/01/20/quantum-dots-nanocrystals-packed-potential

Semiconductors: As electronic components get smaller, it becomes more important to understand nanoscale characteristics



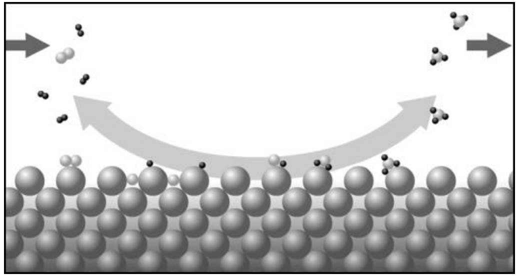
Scanning tunneling microscope (STM) image of Si(111)5x5 reconstructed surface



STM image of the GaAs(110) surface.

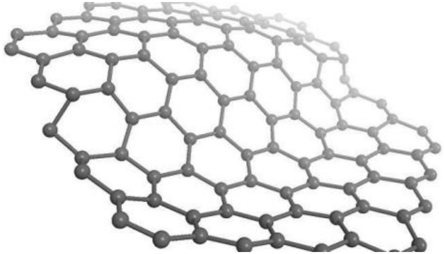
http://www.andrew.cmu.edu/user/feenstra/stm/

Catalysis: Determining how and why catalytic reactions occur and designing surfaces for specific outcomes



http://www.spaceflight.esa.int/impress/text/education/Catalysis/Commercial.html

Graphene: Strong, light, flexible, transparent, and conductive; possible applications in electronics, energy, and medicine



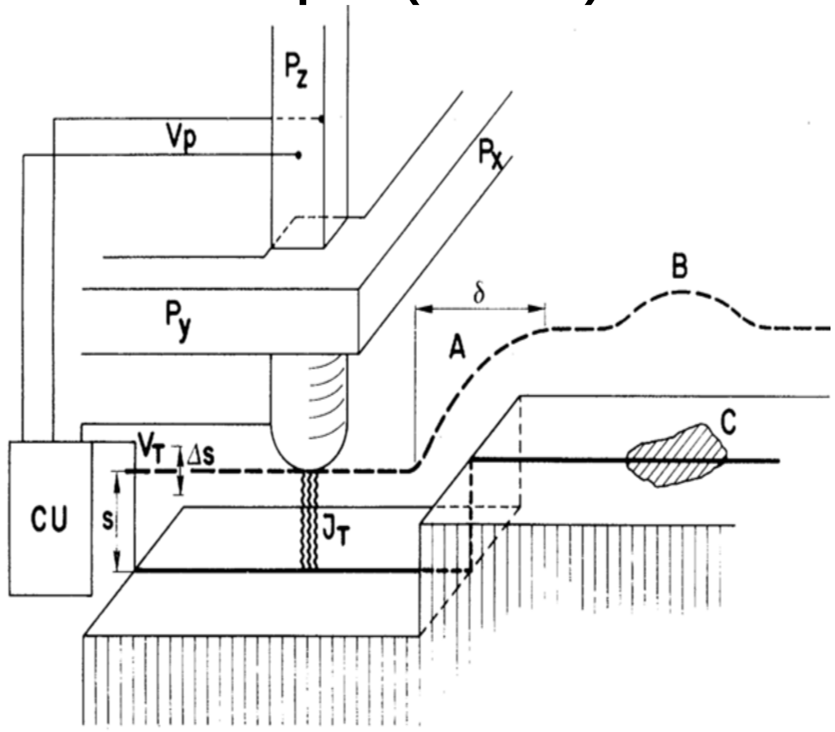
https://phys.org/news/2016-10-scientists-graphene-high-resistance-ozonation.html

Surface Characterization Techniques, 1920s-1970s

Technique	Year	Features
Auger Electron Spectroscopy	1922	Composition
Low-Energy Electron Diffraction (LEED)	1927	Surface lattice structure and its level of regularity/perfection
Transmission Electron Microscopy	1931	Requires an ultrathin section of the material
Field Emission Microscopy	1936	Requires a needle-shaped sample
X-Ray Photoemission Spectroscopy	1954	Composition
Scanning Probe Microscopy (Topografiner)	1972	Surface features with vertical resolution of ~30Å and horizontal resolution of ~4000Å

Invented in 1982, Scanning Tunneling Microscopy offered scanned images of atoms on the surface of a sample at unprecedented levels of resolution (~2Å horizontal and ~0.1Å vertical) with an instrument much less susceptible to vibrational noise than its predecessor, the Topografiner. Binning and Rohrer won the Nobel Prize for STM in 1986.

Principle of Operation of a Scanning Tunneling Microscope (STM)



- Metal tip scanning the surface at a constant tunnel current $J_T \propto \exp(-A\varphi^{1/2}s)$
  $A=(4\pi/h)(2m)^{½}=1.025Å^{-1}eV^{-½}$

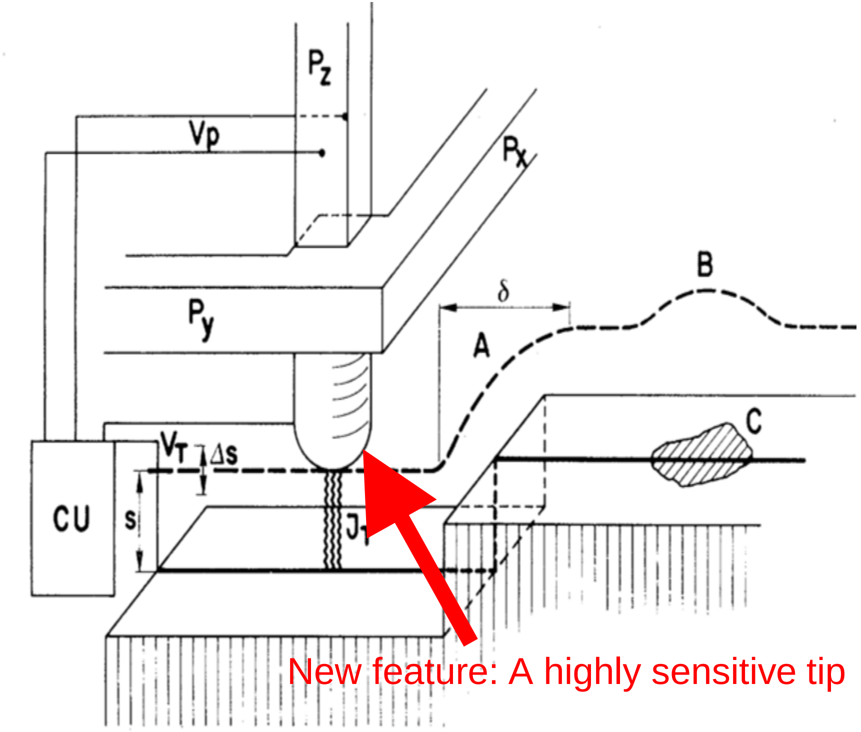
  φ: average barrier height (work function)

  s: width of barrier (z-distance)

- Voltages applied to piezo elements P_x,P_y and P_z map the surface topography directly

R. H. Fowler and L. Nordheim, Proc. Roy. Soc. London, Ser. A 119,173 (1928); J. Frenkel, Phys. Rev. 36, 1604 (1930)

Principle of Operation of a Scanning Tunneling Microscope



- Theoretically, lateral resolution < 100Å require tip radius ~100Å
- Solid metal rods of 1mm diameter and ground 90º tips. Overall tip radii ~1000Å-1μm
- Minitips and ‘mini-spot-welding’ increase lateral resolution to up to 10Å
- Separation of true structures and work function mimicked structures, although can be done in principle, was not studied in detail

Resolution Capability of STM: $CaIrSn_4$ (110) Surfaces

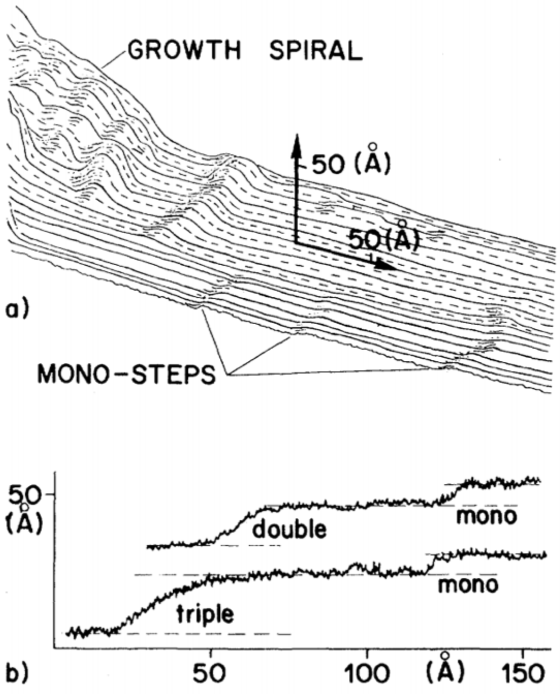
The Ir layers are very inert after solvent etching: good for the STM at moderate vacuum

Data of its crystal structure were available in literature

Weak and homogeneous contamination

Height of steps: a few atoms

Average spacing 6.7Å: consistent with crystallography (Mater. Res. Bull. 15, 799)



Phys. Rev. Lett. 49, 57

Resolution Capability of STM: Au (110) Surfaces

Reconstruction of Au (110) surfaces was of interest

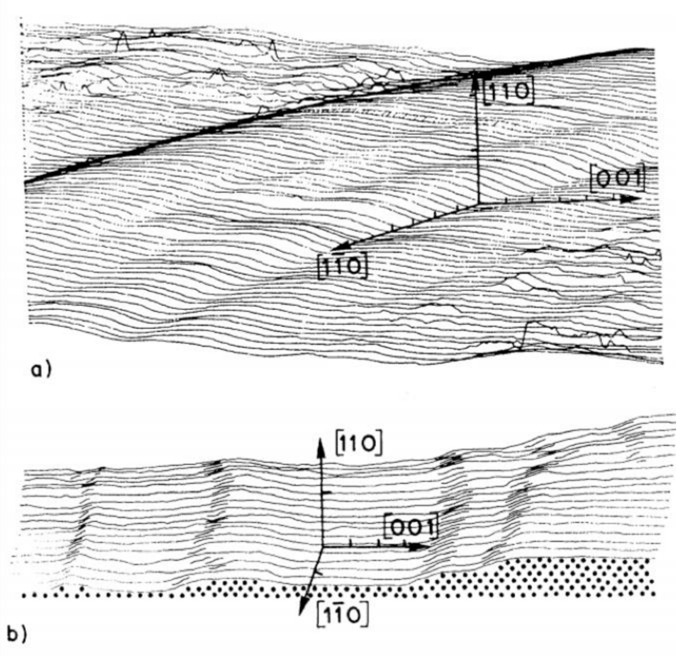
Scanned at room temperature and 300℃, both after annealing at 600℃

a) Room temperature: smooth corrugation
b) 300℃: more abundant steps

Reconstruction of Au (110) was controversial

- 2×1 reconstruction: favored by LEED (Surf. Sci. 77, 265, 283), but NOT observed by STM
- Distorted hexagonal topmost layer model? (Verh. Dtsch. Phys. Ges. 1, 278)

Future study: combination of LEED and STM



Phys. Rev. Lett. 49, 57

Early Implications of Scanning Tunneling Microscopy

- The STM technique developed in this paper has orders of magnitude better resolution than previous scanning techniques (e.g., scanning electron microscopy).
- The method is non-destructive.
- The method has potential use in any field that uses microscopy.
- STM technique can, in principle, separate true structural features from “work function-mimicked” features. Work function profiles, however, weren’t studied in detail, and rather were used to get an overall picture of the surface condition.

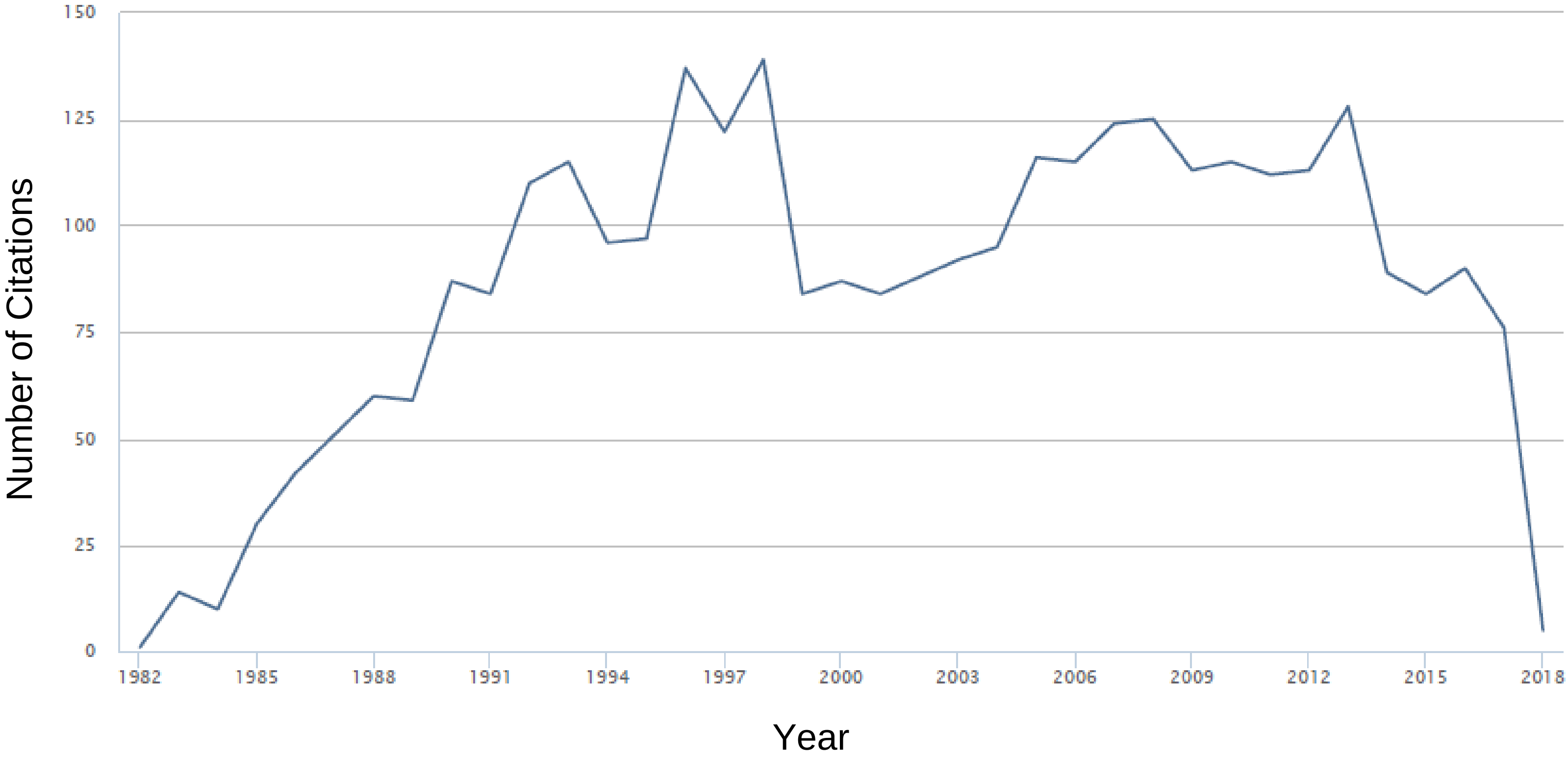
Critiques: Scientific Validity

- Developed better-suited tip to suppress vibrations
- Recognized possibility of work-function-mimicked structures and took measures to attenuate them
- Used smooth-surfaced materials for tests where results confirmed previous measurements (Ir(110) plane spacing and SEM-located growth spirals) and also demonstrated the ability to rule out theories of surface reconstruction in Au
- Did not really explain the details of modulating signals to rule out the variation in work function

Critiques: Importance

- This was the first paper with surface topography using STM.
- The authors verified that tunnel current depends strongly on barrier width.
  - It was possible to see monoatomic step resolution.
  - Precise measurement of corrugation resulted in better understanding of surface reconstructions.
- Broad impacts: the technique enables
  - Detailed understanding of the microscopy of adsorbed molecules,
  - Study of crystal growth,
  - Confirmation of the fundamental aspects of tunneling, and
  - Space-resolved tunneling spectroscopy.

3189 Citations



Critiques: Accessibility

- Although it was probably necessary, the paper heavily referenced other literature, which at times made it a difficult read.
- The paper did not explicitly include some technical details, but it was in general easy even for non-experts to read to get a big picture of STM.
- Some terms were used without a clear definition or reference: “work-function-mimicked”, “work function profile”, etc.
- The reasons why Au was used were not explained in detail by the paper.

Summary

- The paper reports the first experimental results on surface topography in high resolution using STM, a technique that revolutionized the field of surface science, particularly with respect to the study of surface reconstruction.
- The introduction of a new type of scanning tip
  - improved the resolution by several orders of magnitude,
  - reduced vibrational impacts, and
  - presented a non-destructive method of surface determination.
- The STM technique can, in principle, be used to separate true surface structures from those introduced by changes in work function.
- Topographies of $CaIrSn_4$ (110) surfaces and Au (110) surfaces were shown to demonstrate the capabilities of STM.