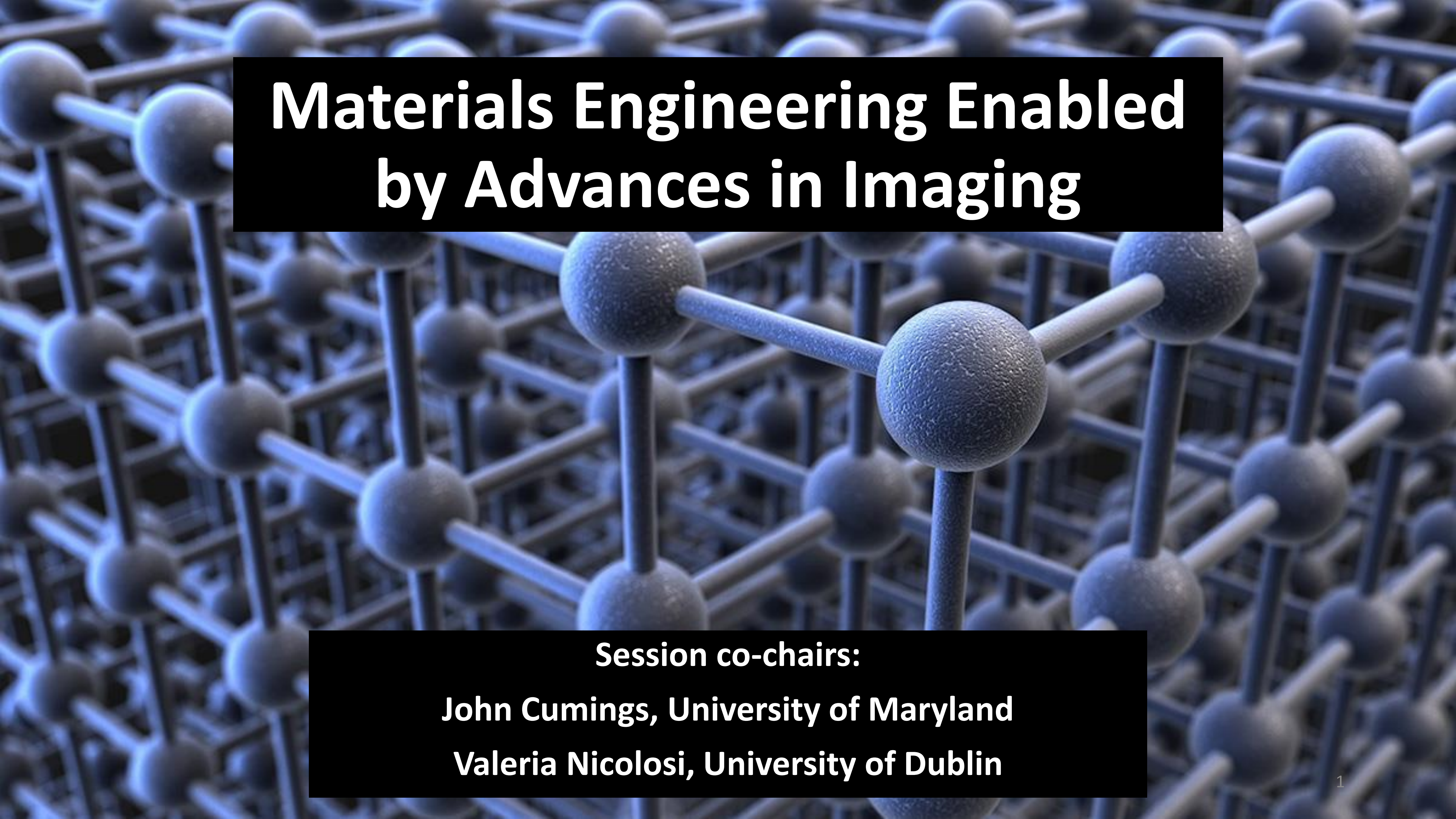


Materials Engineering Enabled by Advances in Imaging

Session co-chairs:

John Cumings, University of Maryland

Valeria Nicolosi, University of Dublin

The Nobel Prize in Physics 1986 was divided, one half awarded to Ernst Ruska "for his fundamental work in electron optics, and for the design of the first electron microscope", the other half jointly to Gerd Binnig and Heinrich Rohrer "for their design of the scanning tunneling microscope."

The techniques: Where are they now?

The Nobel Prize in Physics 1986

Photo from the Nobel Foundation archive.

Ernst Ruska

Prize share: 1/2

Photo from the Nobel Foundation archive.

Gerd Binnig

Prize share: 1/4

Photo from the Nobel Foundation archive.

Heinrich Rohrer

Prize share: 1/4

Q: What is Engineering?

A: An Engineer harnesses the forces of nature for the good of humankind.
(Tredgold 1828)

Q: What are the forces of nature?

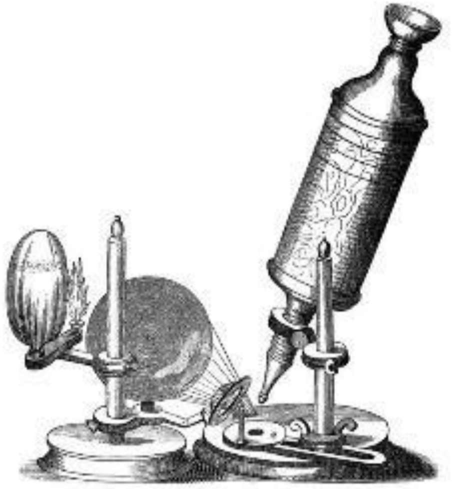
A: Wind, rain, solar, geothermal. (Civil Engineering)

A: Covalent and ionic bonding. Yield shear stress. Tensile strength.
(Materials Engineering)

First Microscopes: 1590's – 1610's Janssen and Galileo

Leeuwenhoek: 1670's

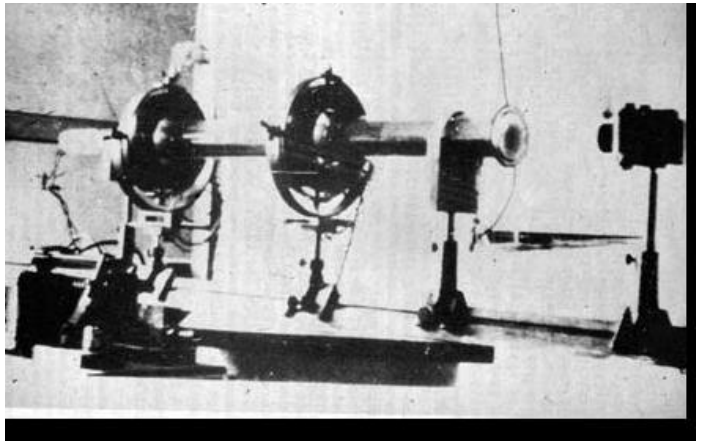
Robert Hooke: 1670's



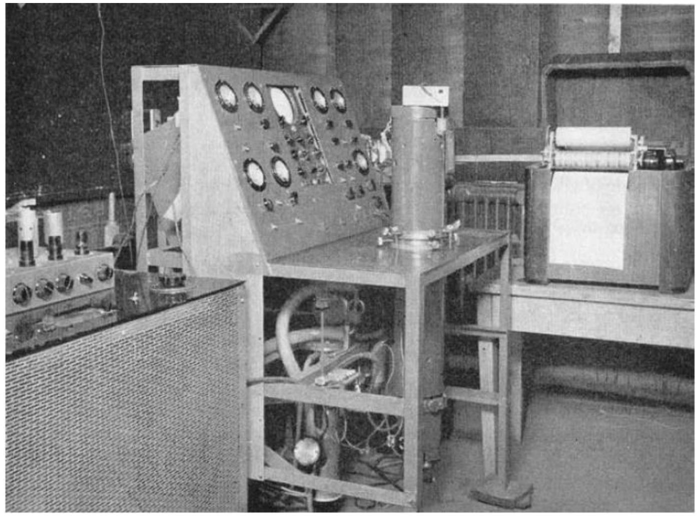
1857: Zeiss' first compound microscope:

Electron Microscopes

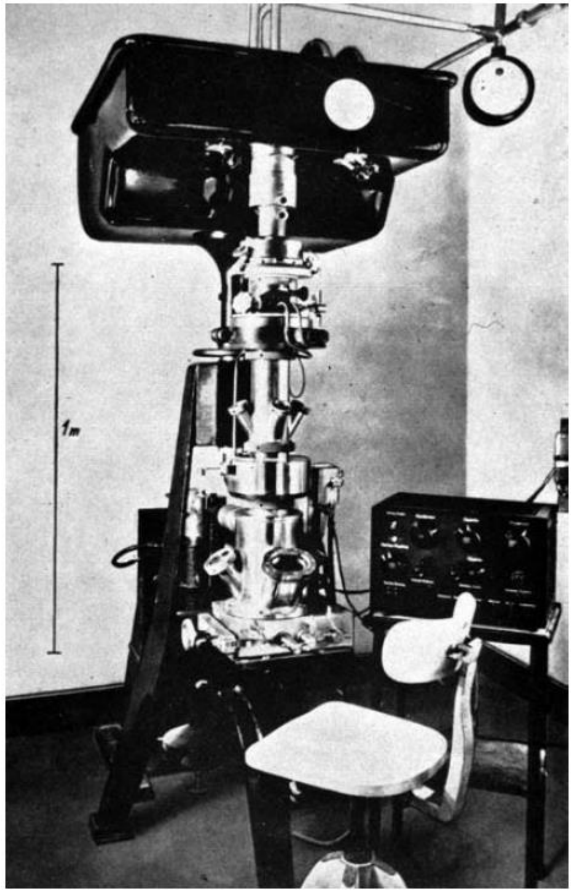
TEM: Transmission Electron Microscope
Ruska & Knoll 1931-1933



SEM: Scanning Electron Microscope
RCA (US) 1942

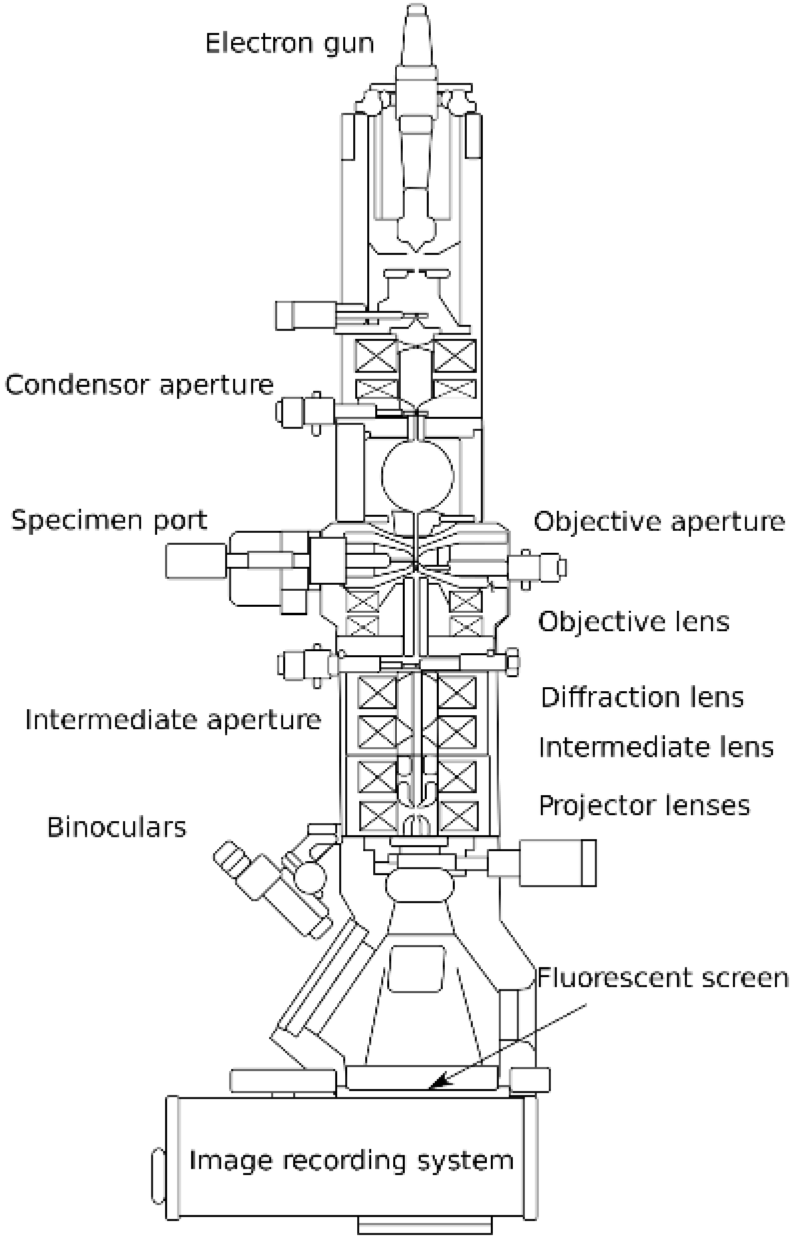


Commercial: Siemens 1938



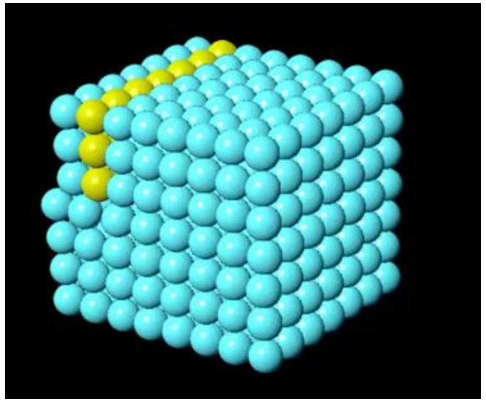
(Also modified for scanning)

The Modern
Transmission Electron Microscope
Circa 1950's



Credit: David Eccles

Atomic Defects in Materials

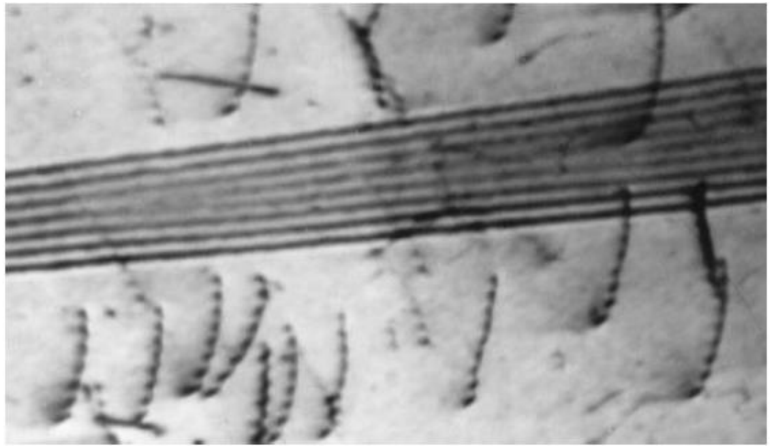


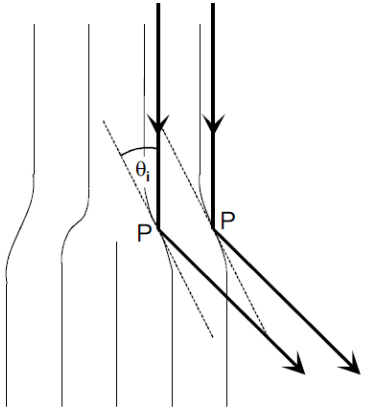
1934: Orowan, Polanyi, and Taylor– Plasticity in metals is due to motion of *dislocations*.

1953-4: Cottrell & Read publish detailed theories, which are accepted, despite *no experimental observation of dislocations.*

Read: *"it became the fashion to invent a dislocation theory of almost every experimental result in plastic deformation. Finally, it became apparent that dislocations could explain not only any actual result but virtually any conceivable result, usually in several different ways."*

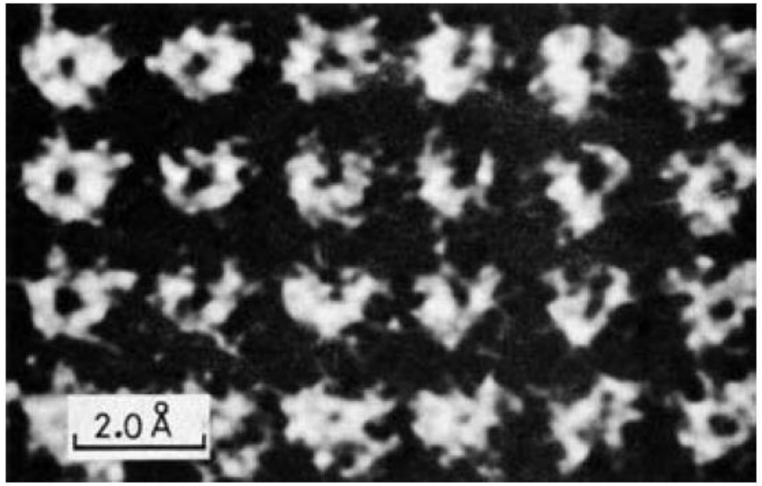
1956: P.B. Hirsch, R.W. Horne and M.J. Whelan observe dislocation motion by TEM diffraction contrast, including 15 figures of evidence.





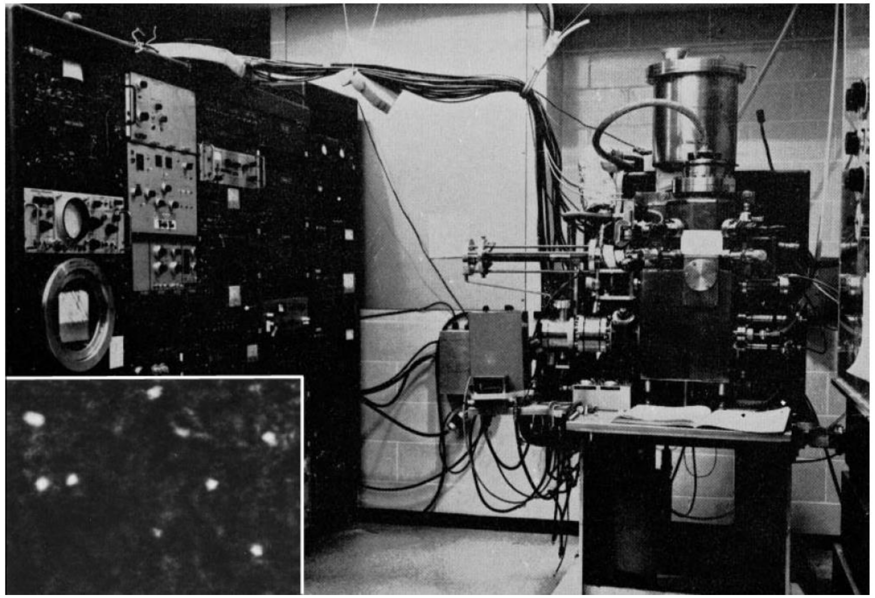
Atomic Resolution

High-Voltage TEM 600+ kV: True atomic resolution (1977-1980)



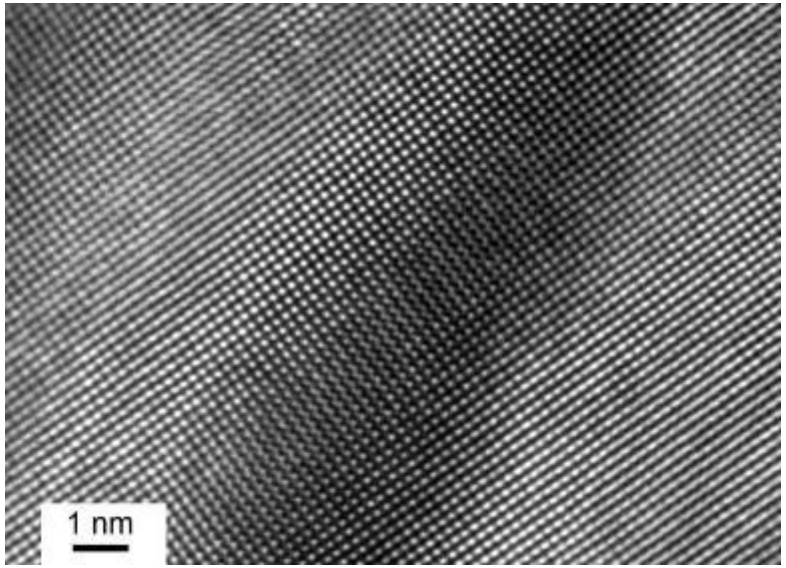
Hashimoto 1977

Dedicated STEM: Sees atoms (1965)



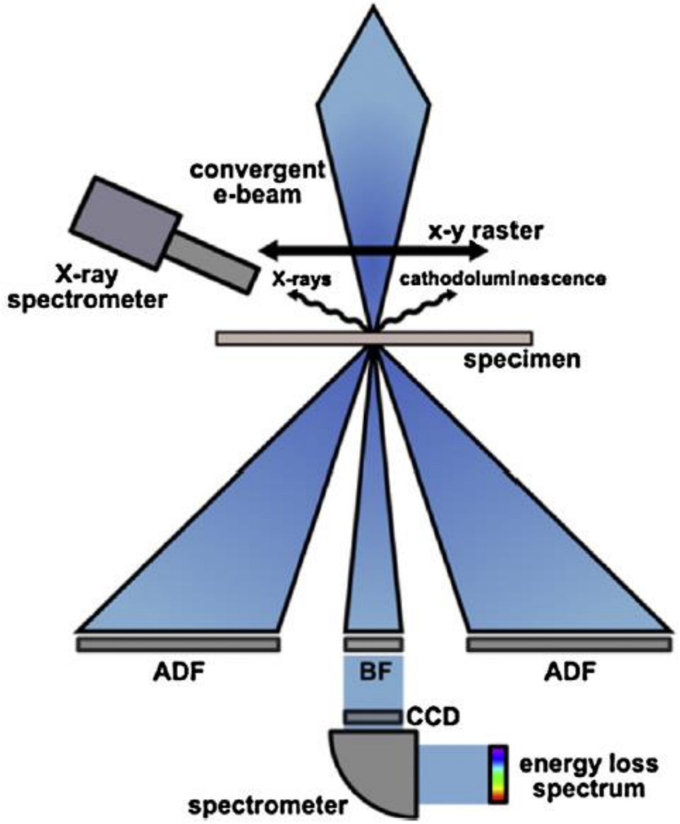
Crewe U. Chicago

(also at 200 kV, 1980’s)

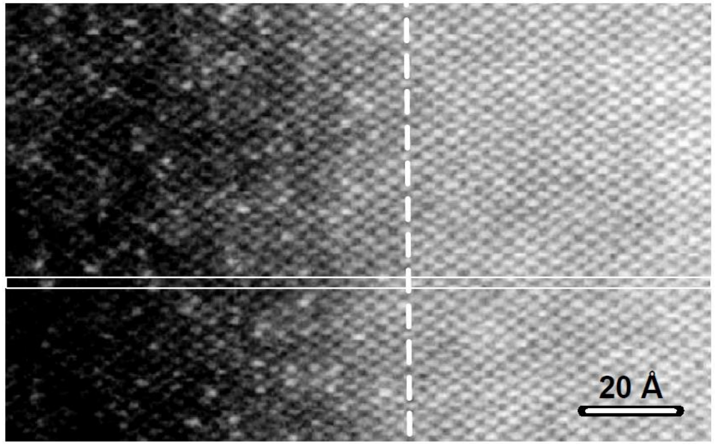


I T Bae Binghamton

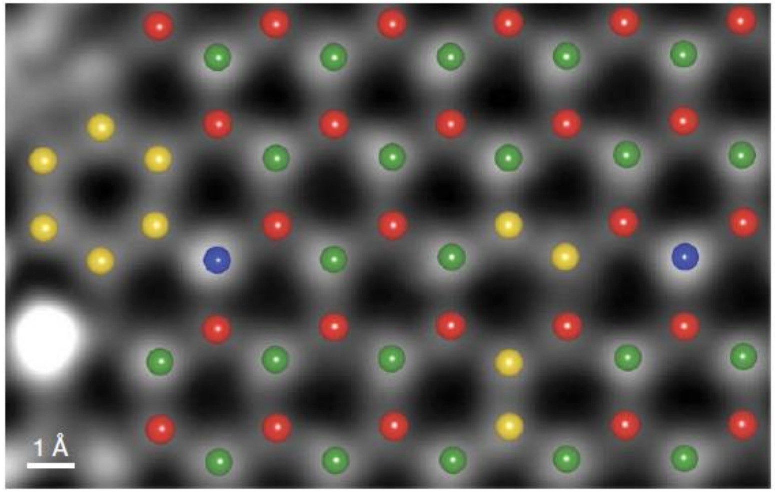
Modern STEM



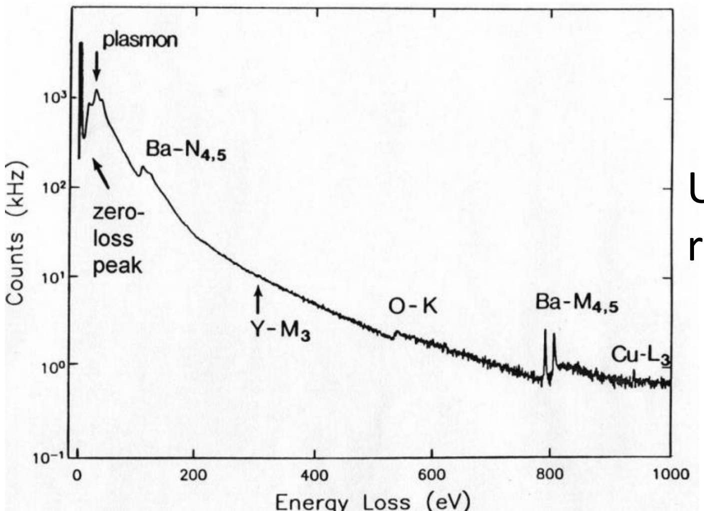
Atomic Resolution STEM Voyles et al Lucent Bell Labs 2003



Atom element identification (Krivanek et al Nature 2010)

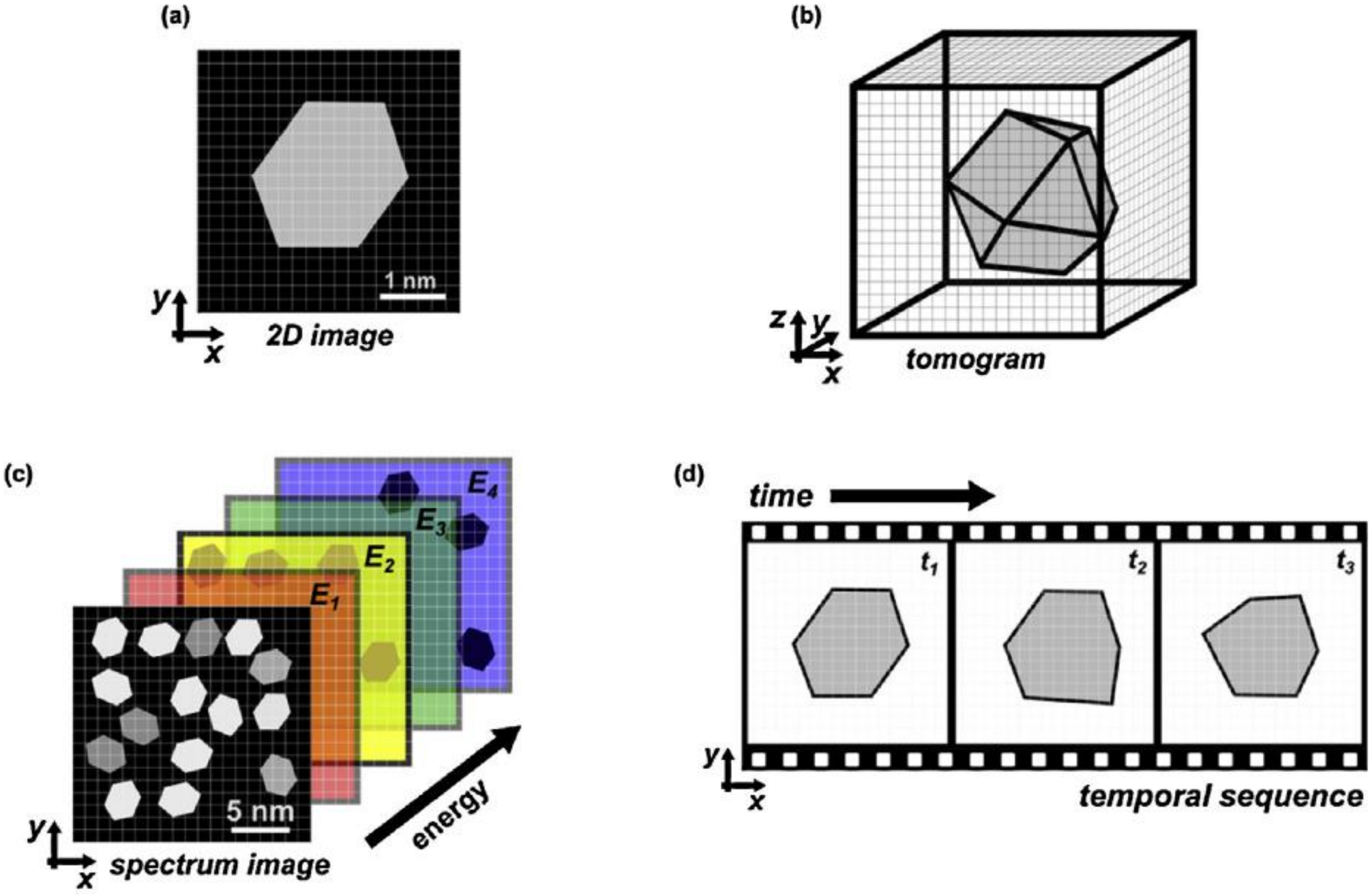


Thomas et al Chem Phys Lett 2015



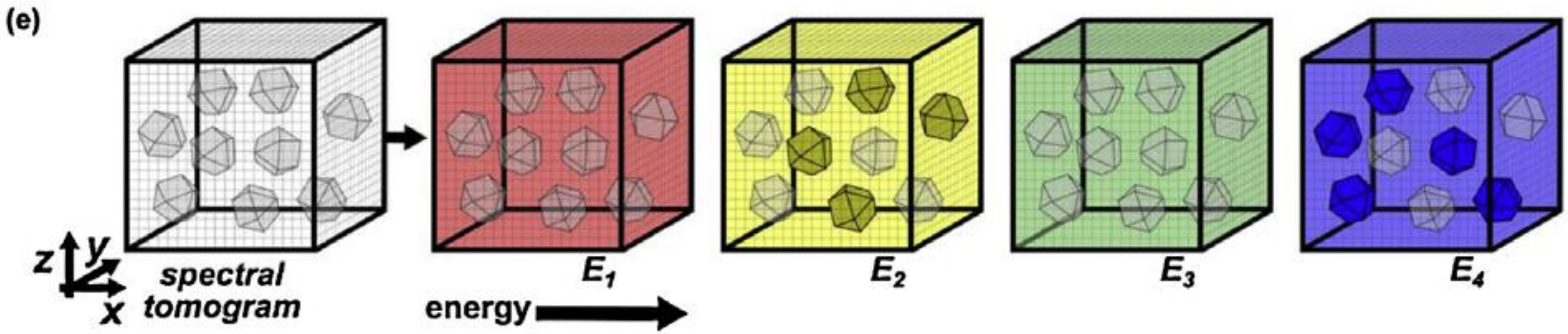
Ultimate energy resolution: 0.010 eV

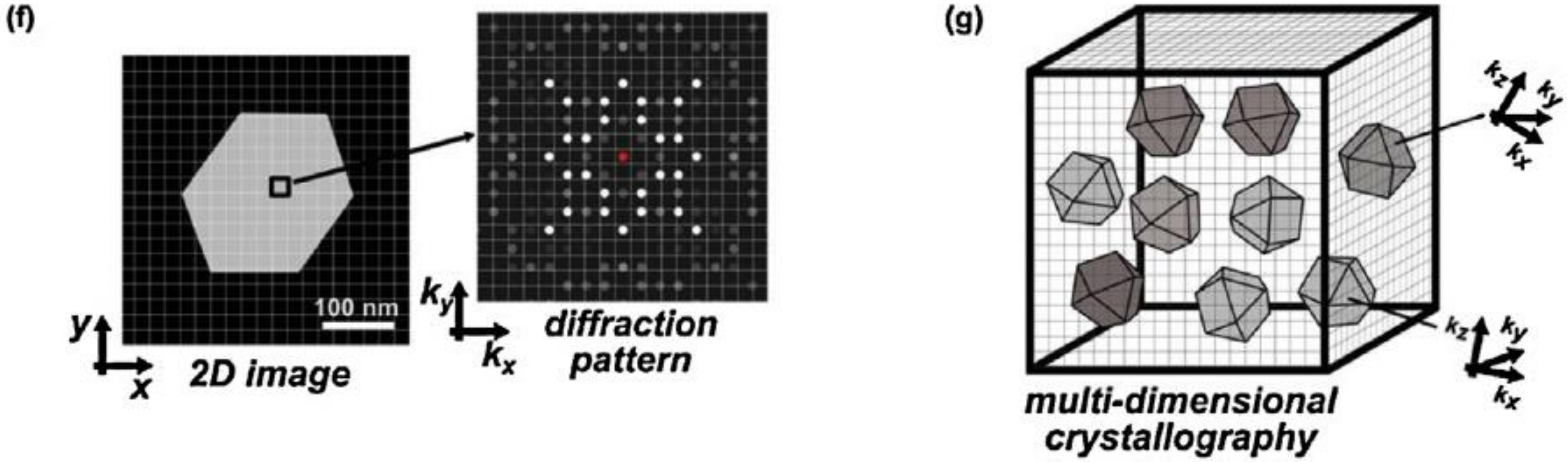
Multi Dimensional Data



Thomas et al Chem Phys Lett 2015

Multi Dimensional Data



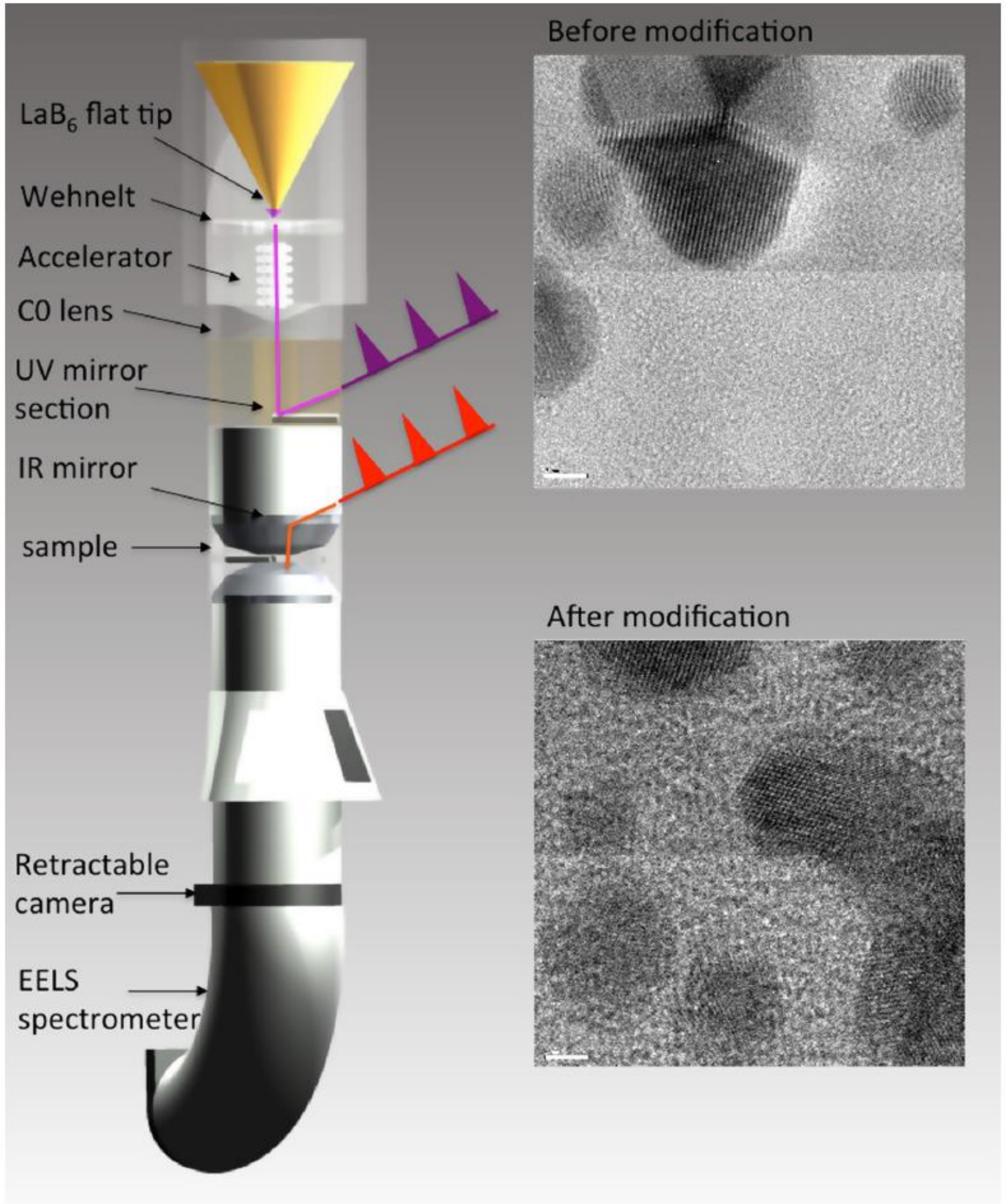


Thomas et al Chem Phys Lett 2015

Ultrafast TEM

Laser Based
e.g. Flannigan UMN,
Lagrange Reed & Campbell LLNL

Not always atomic resolution,
But approaching nsec time resolution



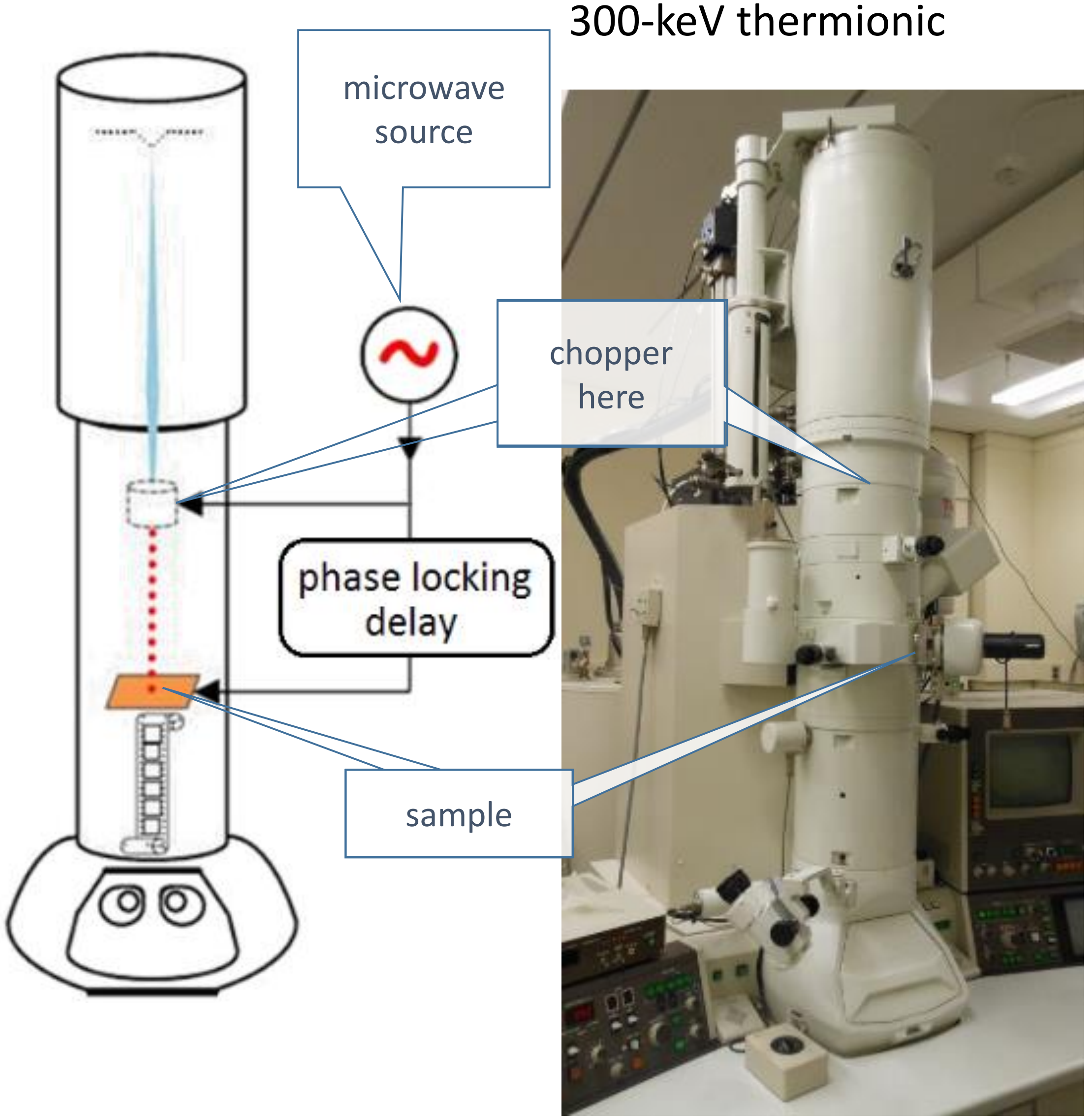
Piazza et al Chem Phys 2013

Ultrafast TEM

Microwave Chopper Based
e.g. June Lau NIST
Yimei Zhu Brookhaven

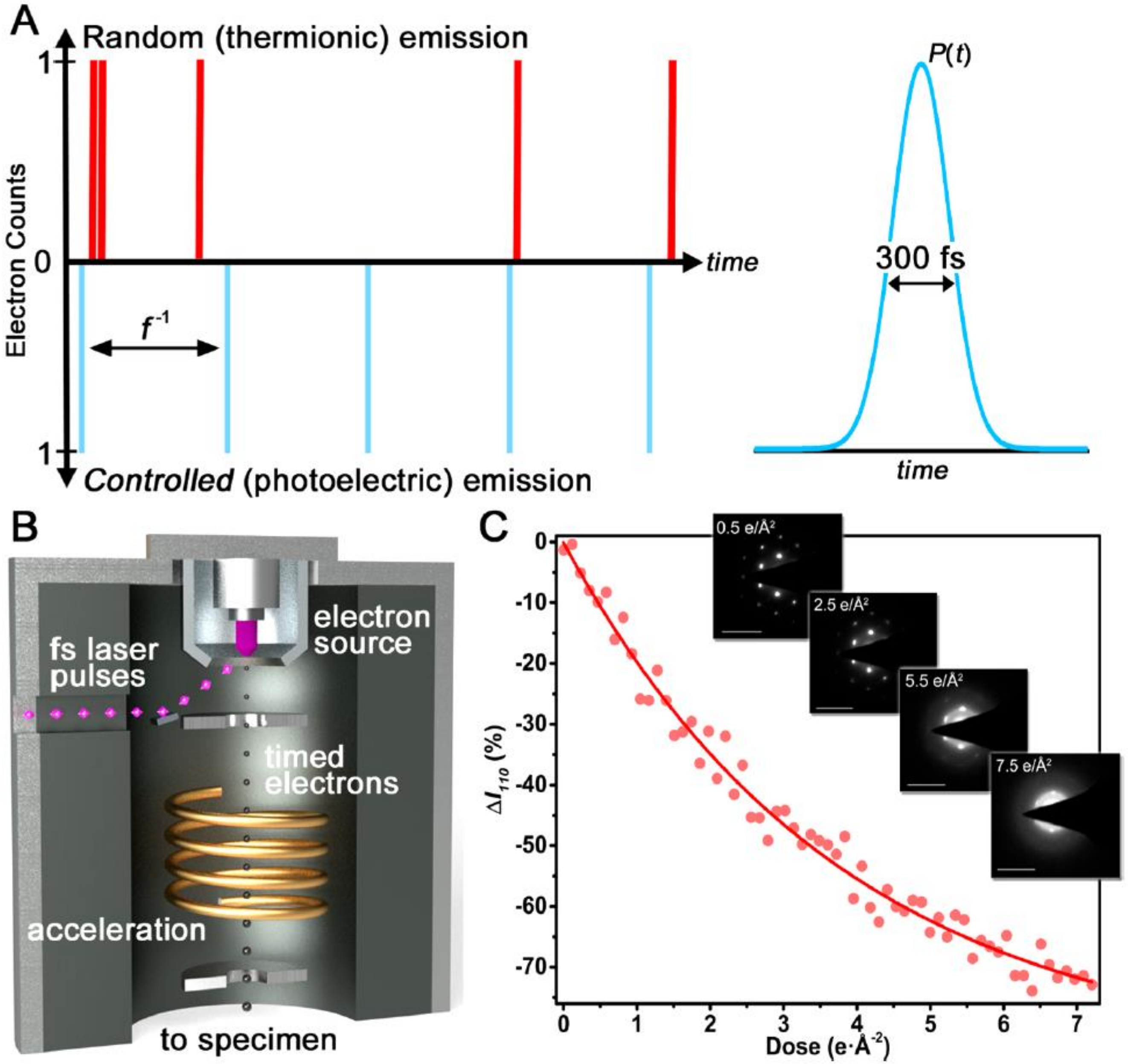
< nsec time resolution
up to 10% duty cycle

Jing et al. Ultramicroscopy 2019



Pre-modified JEM3010 TEM at NIST

<u>Ultrafast TEM</u>:
Reducing Beam Damage

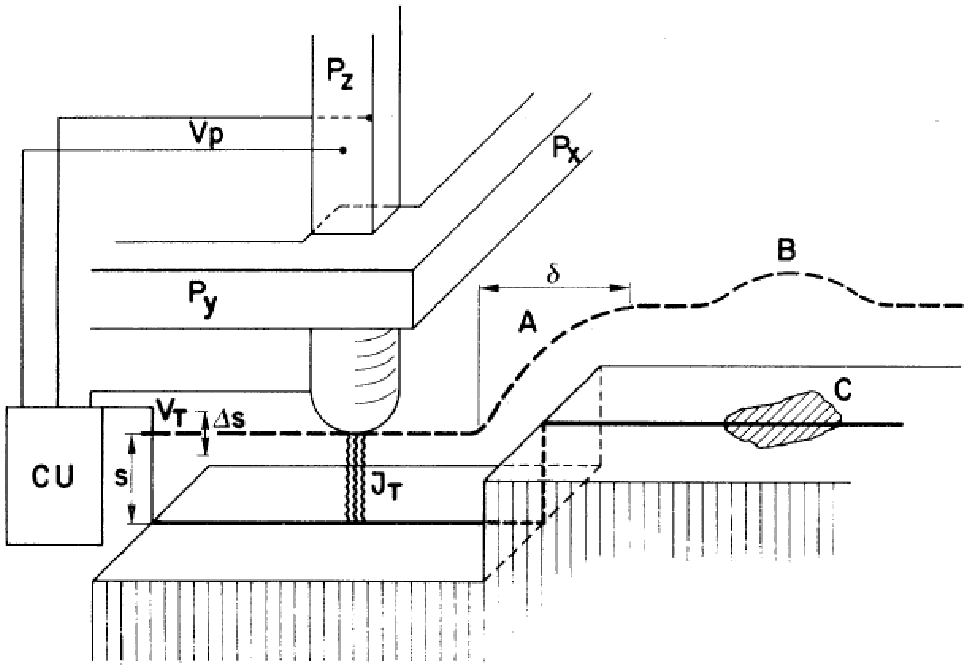


D. Flannigan UMN (2019)

VOLUME 49, NUMBER 1 PHYSICAL REVIEW LETTERS 5 JULY 1982

Surface Studies by Scanning Tunneling Microscopy

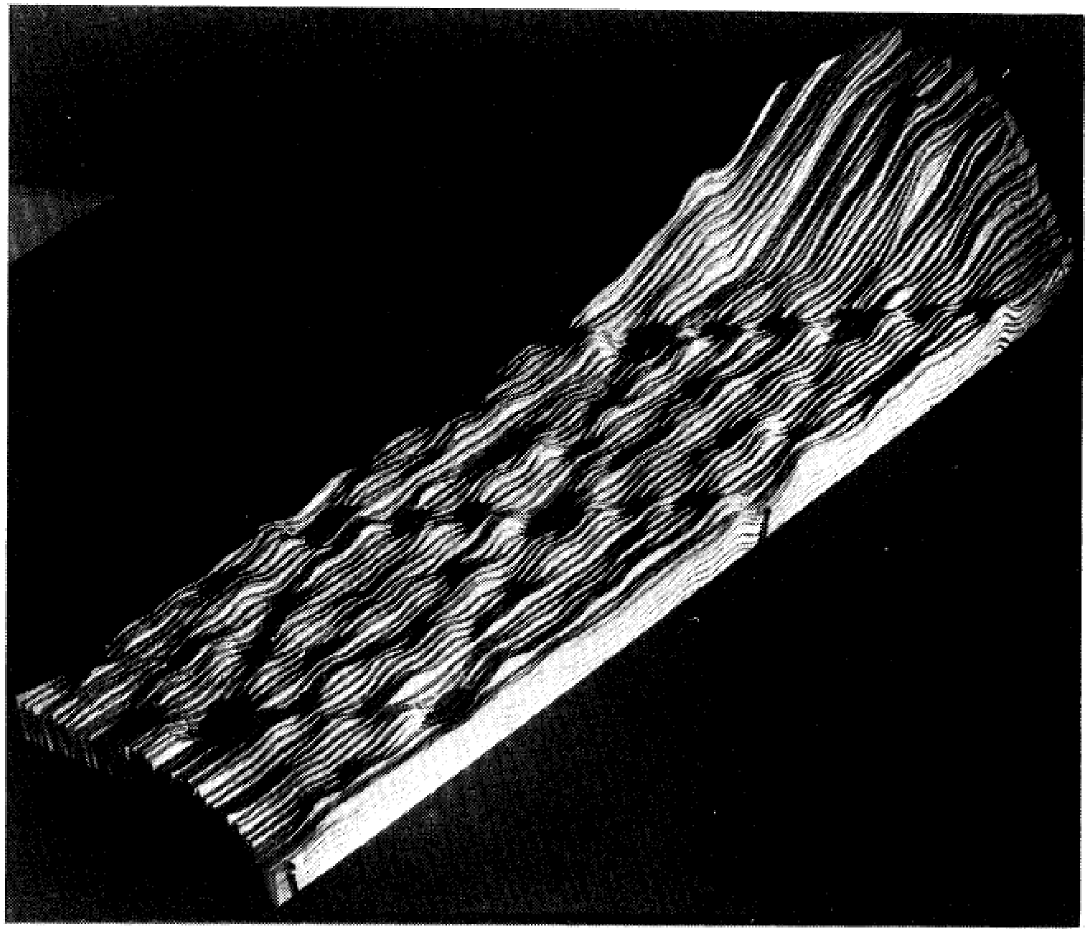
G. Binning, H. Rohrer, Ch. Gerber, and E. Weibel
IBM Zurich Research Laboratory, 8803 Rüschlikon-ZH, Switzerland
(Received 30 April 1982)

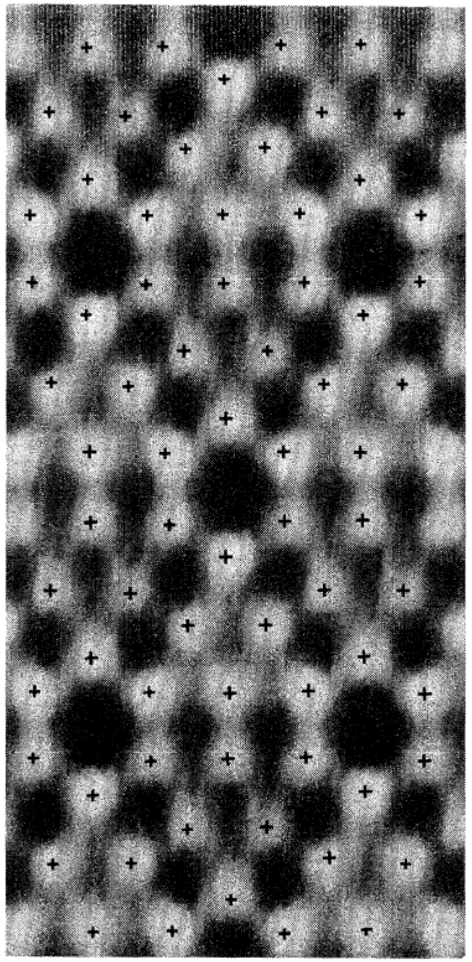


7 × 7 Reconstruction on Si(111) Resolved in Real Space

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

(Received 17 November 1982)





Atomic Force Microscope

G. Binnig[a] and C. F. Quate[b]
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

and

Ch. Gerber[c]
IBM San Jose Research Laboratory, San Jose, California 95193
(Received 5 December 1985)

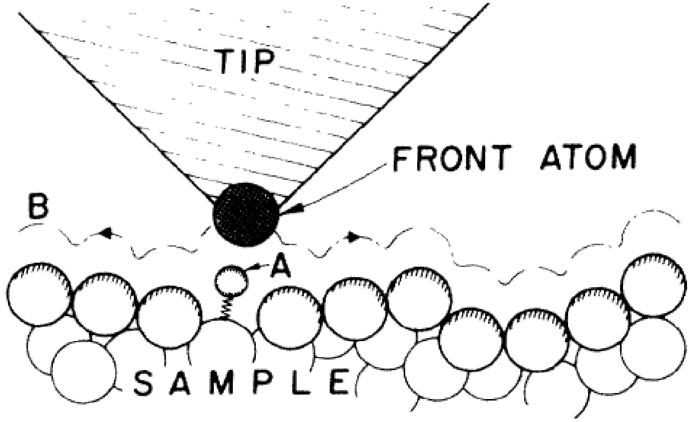


FIG. 1. Description of the principle operation of an STM as well as that of an AFM. The tip follows contour *B*, in one case to keep the tunneling current constant (STM) and in the other to maintain constant force between tip and sample (AFM, sample, and tip either insulating or conducting). The STM itself may probe forces when a periodic force on the adatom *A* varies its position in the gap and modulates the tunneling current in the STM. The force can come from an ac voltage on the tip, or from an externally applied magnetic field for adatoms with a magnetic moment.

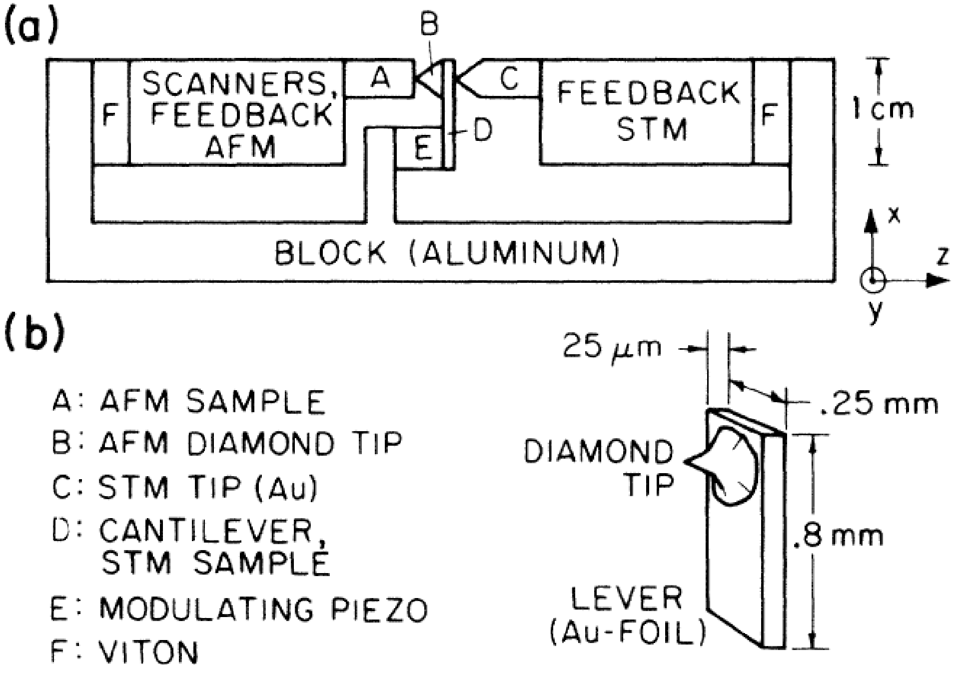


FIG. 2. Experimental setup. The lever is not to scale in (a). Its dimensions are given in (b). The STM and AFM piezoelectric drives are facing each other, sandwiching the diamond tip that is glued to the lever.

1. Imaging Materials at the Space-Energy-Time Limit
David Flannigan, University of Minnesota

2. Imaging and Spectroscopy of Molecular Nanostructures
Peter Nirmalraj, EMPA

3. Through Graphene and Beyond
Sarah Haigh, University of Manchester

4. The Universe is My Nano-fab: Scanning Transmission Electron Microscopy of Nanomaterials from Space
Rhonda Stroud, Naval Research Laboratory