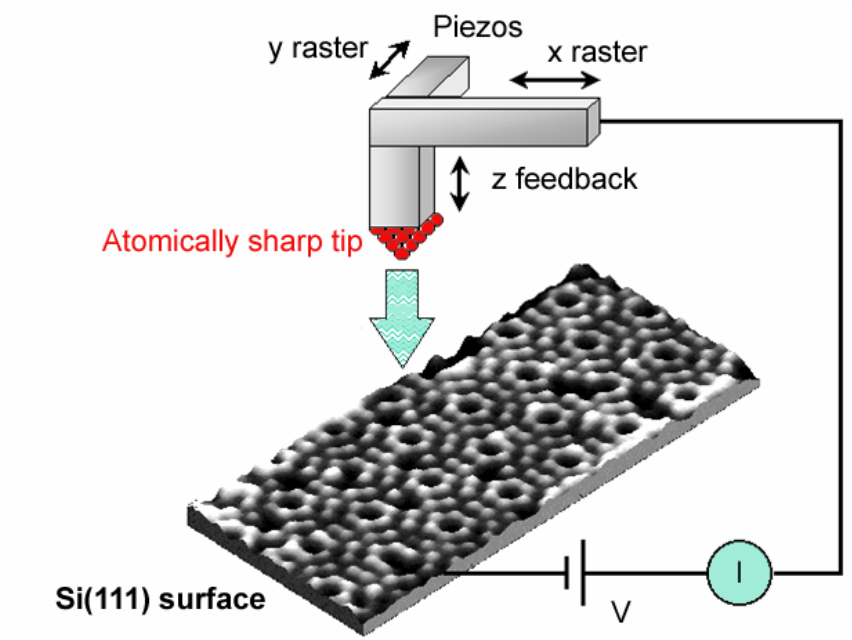
A few slides on STM from a lecture given at the Institute of Physics 'Experimental Techniques of Semiconductor Research' course

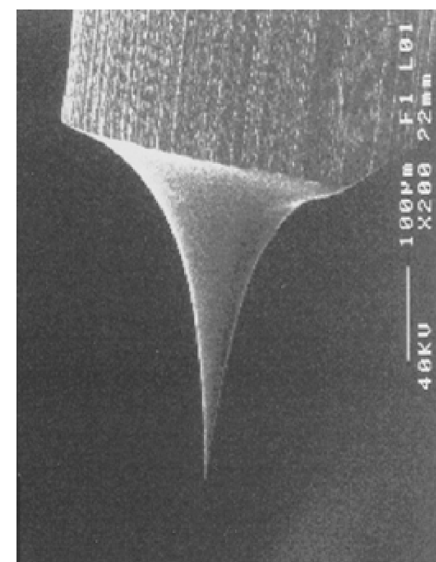
Gavin Bell

STM: Basic Operation



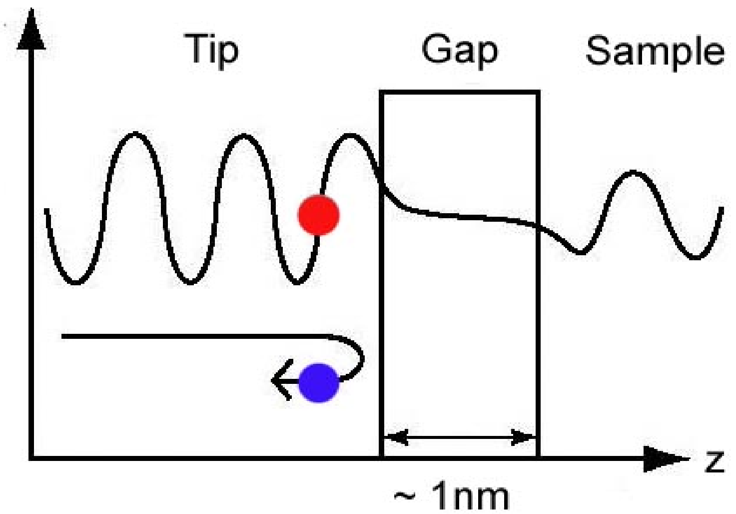
Can readily achieve *atomic resolution*: need a good tip (bit of a black art), clean and flat surface, low vibrations and low electrical noise.

Etched tungsten tip:



Constant current mode: keep tunnelling current constant by adjusting z with feedback system as x and y are rastered → image made up of (x,y,z) coordinates, contrast via topography and LDOS.

STM: Tunnelling Current



Tunnelling Current (10 pA to 10 nA)

Bring tip close (~ 1nm) to conducting sample. Bias tip relative to surface (a couple of volts for semiconductors).

Electrons can tunnel from tip to surface or vice-versa. Classically forbidden.

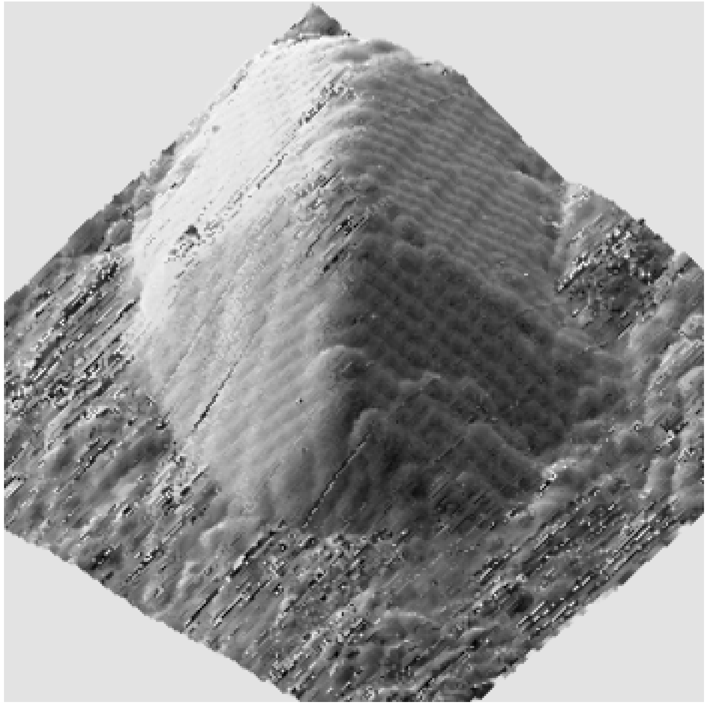
Wavefunction overlap, and hence tunnelling current, *exponentially decreases* with tip-sample gap.

STM images always mix electronic and topographic contrast.

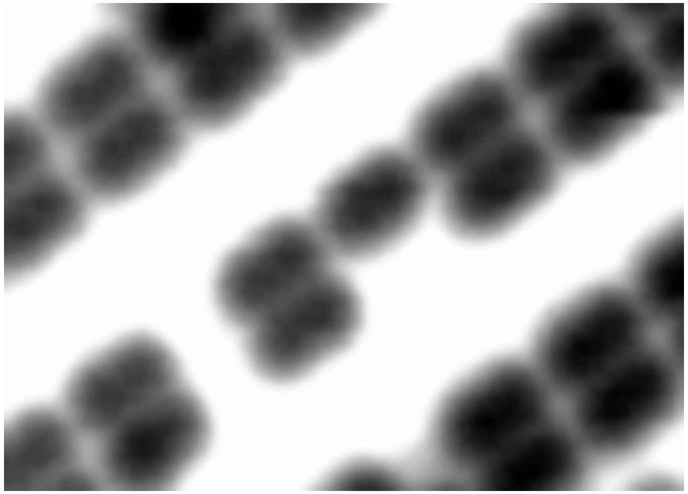
The tunnelling matrix element contains the local density of electronic states (LDOS) in the surface at the appropriate energy level.

$$I_t \propto \left| M_T \right|^2 e^{-2K\Delta z}$$

STM: Atoms!



3D rendering of STM image of single InAs quantum dot on GaAs(001), showing atomic resolution on the dot sides. SPM techniques give a true 3D topography – e.g. one can integrate to get the volume.

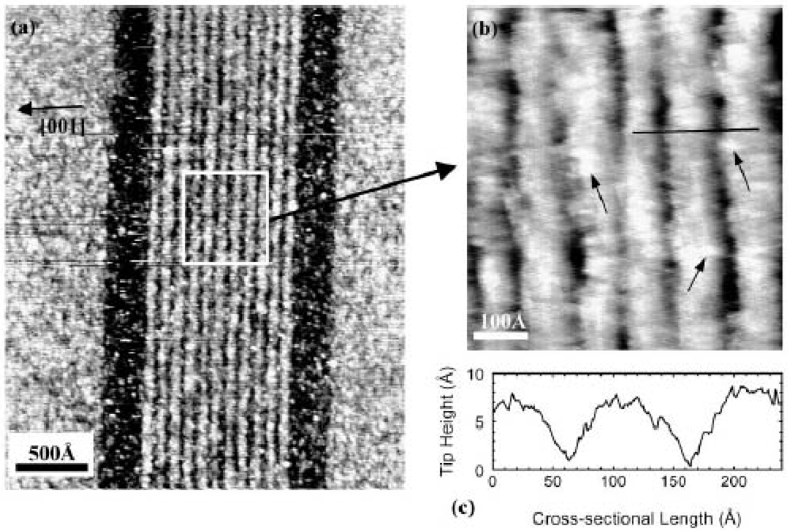


Atomic resolution STM of InAs(001)-(2x4) showing arsenic dimer-pair-rows, missing dimer defect and unit mesh registry defect. Image ~ 4.5 by 3 nm. As dimers have high LDOS at negative sample bias… 'filled states' image.

STM is great at highlighting surface defects (unlike diffraction)…

XSTM: cross sectional STM

- Cleave III-V heterostructure along {110} plane in vacuum.
- A ‘good’ cleave gives atomically flat plane, so should see primarily electronic contrast.
- But be aware of atomic steps on cleaved surface as well as topographic ‘bulge’ in strained structures.
- XSTM applied to III-V quantum wells, quantum dots, laser structures, etc.
- Atomic resolution easily possible.



From K.S. Teng et al. (2002): XSTM of (Al,Ga)InP multi quantum barrier.

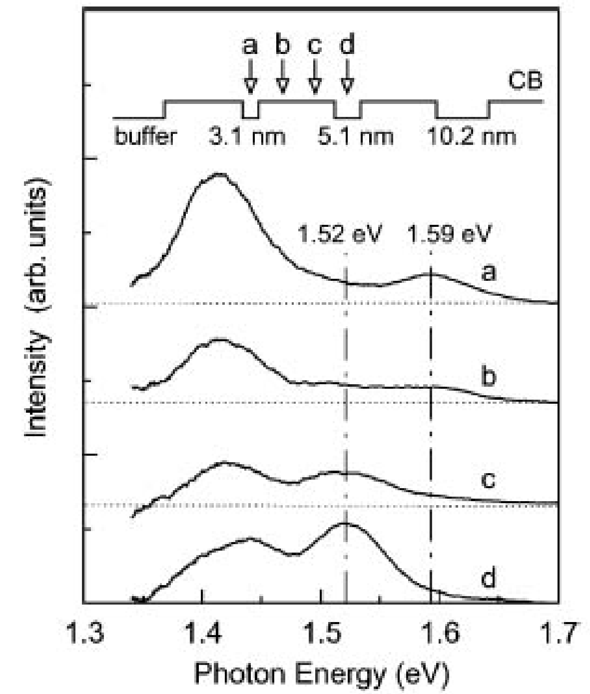
Contrast mechanism: electronic, not topographic. Higher band gap material appears dark in this empty state image (positive sample bias).

STM: Electronic Structure

- **Scanning Tunnelling Luminescence (STL)**
- Local injection of electrons using STM tip.
- Measure luminescence spectra as a function of tip position.
- Low intensity due to nA injected current!

Example: identify emission peaks from 2 different wells and measure intensity as a function of tip position to get diffusion length of hot electrons.

Tsuruoka et al. Appl. Surf. Sci. 190 (2002) 275.



- **Scanning Tunnelling Spectroscopy (STS)**
- Use STM to measure I-V curve with feedback off (constant height)
- LDOS given by (dI/dV) / (I/V)