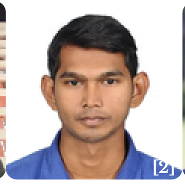
Scanning Tunneling Microscope



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Quantum tunneling is a phenomenon in which particles, such as electrons, tunnel through an insulating barrier in the presence of an electric potential that classical physics deems impossible. In 1981, Gerd Binnig and Heinrich Rohrer at IBM Zürich harnessed this phenomenon to create the Scanning Tunneling Microscope (STM), which allows researchers to visualize and study surfaces at the atomic level. This discovery led them to win the Nobel Prize in 1986


Gerd Binnig and Heinrich Rohrer with 1st STM model

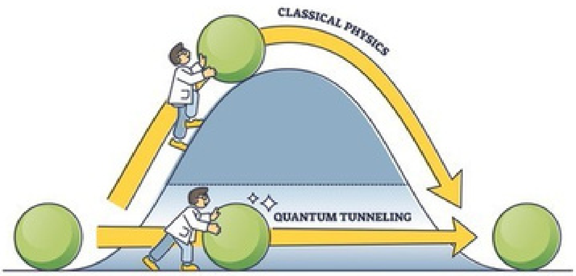

Figure 1. Classical vs Quantum phenomenon

STM operates under high-vacuum conditions (<10^{-5} torr) by bringing a conducting, atomically sharp tip within a few angstroms of a metal or semiconductor sample. When a bias voltage is applied between the tip and the sample, electrons can tunnel through the vacuum gap, generating a tunneling current. By scanning the tip across the sample and maintaining a constant tunneling current through a feedback loop, we can measure the topography and electronic properties of the surface with atomic precision. It also provides information about the local density of states, surface defects, band structure properties, and more. STM is one of the precise imaging techniques available in which we can achieve lateral resolution better than 0.1 nm and vertical resolution as fine as 0.01 nm. As shown in the Figure below, STM measurements were carried out on highly oriented pyrolytic graphite (HOPG) to visualise the unit cell structure. We were able to see the hexagonal unit cell structure, where the unit cell parameter was also observed near the theoretically reported values of 0.26 nm.

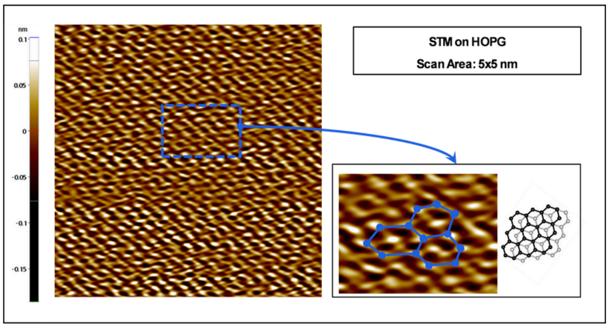

Figure 2. STM image obtained on HOPG

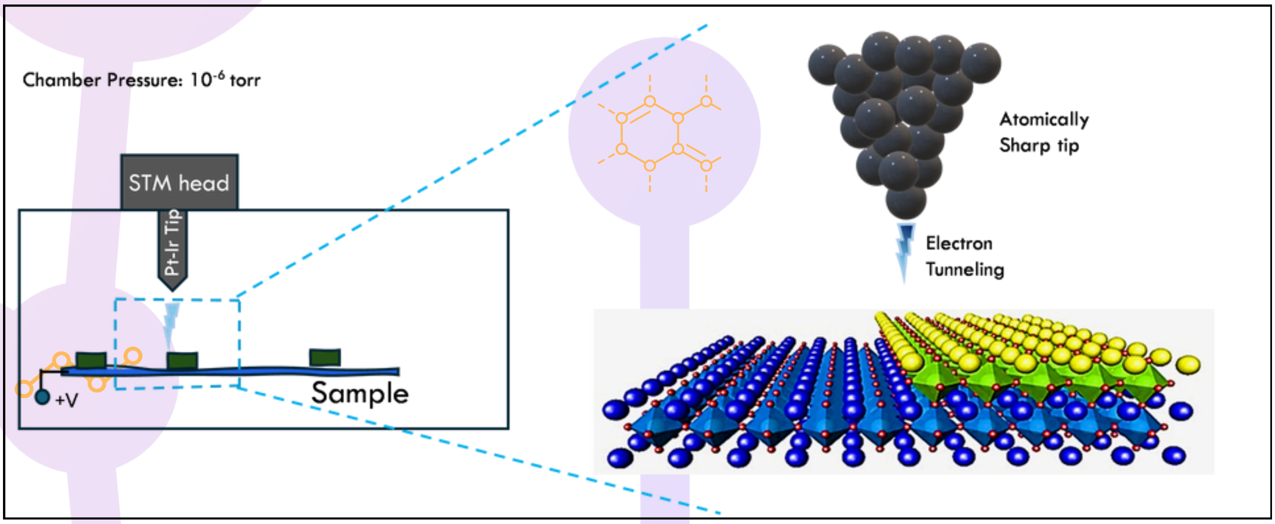

Figure 3. Schematic of how STM works

Figure 4. STM at SATHI CisCoM – IITH

A similar type of measurement (2x2 nm scan) was also conducted on highly oriented platinum (111) – Silicon (100) wafers. We were able to identify atomic planes where the d spacing value is close to the previously reported values. The theoretical value for the d-spacing of single crystal Pt (111) is reported as 0.28 nm, and the values we obtained are comparable, considering that the wafer is not single crystal but highly oriented towards (111) in our case.

These measurements were conducted in the Hi-Vac Scanning Probe Microscope (SPM) system (Available at SATHI – IIT Hyderabad), which can achieve high vacuum levels and is suitable for STM measurements. We use Platinum-Iridium wires, which have atomic sharpness, for the measurements.

The instrument is also capable of measuring currents ranging from 10 mA upto100 fA using current amplifiers like VECA and ULCA.

STM measurement possesses some challenges as it requires extremely clean and stable surfaces, sharp tips, excellent vibration isolation, and sophisticated electronics. Sample selection is also limited to metal or semiconductor, though advanced techniques exist for imaging some non-conductive materials also. Still, Scanning Tunneling Microscopy stands as an advanced tool in modern science, offering deep insights into the atomic and electronic structure of surfaces. Its ability to image and measure properties at the atomic scale continues to drive advances in physics, materials science, and beyond.

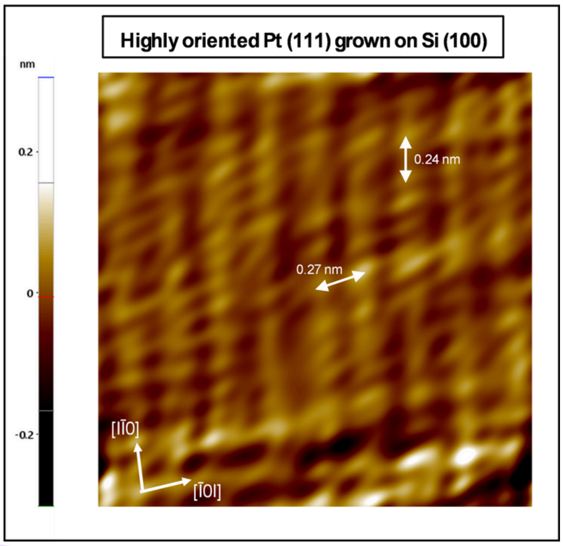

Figure 5. STM image of highly oriented Pt(111)||Si(100)

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