

STM AT HIGH TEMPERATURE: What you see is what you see . . . usually

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There remains two basic axioms of all microscopists: the first...if you look, you're bound to see something, and the second...not everything you will see is artifact. These axioms apply particularly well to scanning probe microscopy at the molecular and atomic level. Fortunately, coarser resolution images share comforting similarities with images from other established scanning methods. Holes in optical discs look like holes when probed with AFM tips, and these holes look very much like SEM images, a subject with which we have some familiarity. At the molecular and atomic level, however, the scanning probe instruments may or may not be "seeing" the sample, though they are clearly seeing something.

Comparison of surface structure observed with indirect surface structural measurements, for example by LEED (Low Energy Electron Diffraction) or RHEED (Reflection High Energy Electron Diffraction) usually under ultra-high vacuum conditions can lead, by inference, to an understanding of the real bulk or average surface structure. With these indirect methods, spatial resolution is not usually very good, though microscopes with electron diffraction capability can see structure at very high resolution indeed. Direct comparisons with transmission electron images (either planar or reflection) have helped to establish that, in many cases, the actual atomic surface structure does bear resemblance to that observed by scanning probe methods. As more and more understanding of the actual imaging mechanisms improves, our understanding of the correlation of the observed images with the actual structure will also improve.

The surface of Si has been well characterized by a variety of the above mentioned methods. Structural transitions occur at a variety of temperatures depending on the original orientation of the surface. (For those unfamiliar with crystal nomenclature and crystal structure, the best lay description is in Kurt Vonnegut's "Cat's Cradle"...imagine piles of canon balls...For those unfamiliar with "Cat's Cradle", there are a depressingly large number of excellent technical references). Paraphrasing, the arrangement of atoms on the surface can (does) change when the temperature of the bulk material is changed. The arrangement of atoms in the bulk does not necessarily change. Thus, only the top atomic layers change their structure. The STM can see this, usually after it has happened (the high temperature structure is preserved at lower temperature by rapidly lowering the temperature).

To see it while it happens, it should be possible to change the temperature during observation. Direct observation during the temperature change would allow the observer to see these changes directly within some limiting observational time resolution. For the STM observations to be discussed subsequently, this time resolution is typically about 15 seconds, though it may be less. (This is the time between one full image and the next). Direct observation has another major advantage. Conventional before and after pictures usually do not register the same area. Under direct observation, the same features can be monitored over time and local changes can be followed spatially.

Changes in microstructural physical phenomena require energy. (Reading this article takes energy...some would say work). Features within structures tend to be of higher or lower energy than their surroundings. A tree in a cornfield is more likely to be hit by lightning than the corn. Sites of high energy in crystal surfaces are then likely locations where things can and do begin to happen. These sites can be edges, defects (areas of the crystal that defy normal arrangements of atoms), and other phases (material different from the base material) to name a few. By observing the structural changes directly, we can see what effect these defects have on the initiation of structural reactions and rearrangements.

Using a high temperature stage capable of heating specimens up to 1500° K (1200° C), structural rearrangements of the Si surface have been studied in great detail. The two images shown in Figure 1, recorded 16 seconds apart while the sample was being cooled from 880° C through 860°

C, demonstrated that the nucleation (initiation) of the ordered arrangement of the Si surface takes place at step edges (the dark bands in the images). The microscope scan electronics allow images to be acquired at one scan rate and displayed at another, usually TV rate, thus permitting video taping during otherwise digital acquisition. These two figures were recorded on video tape.

The stability of this high temperature stage at temperature is excellent. Note the registration between the two images. It is also possible to change the temperature slowly and still retain the positional stability necessary to observe

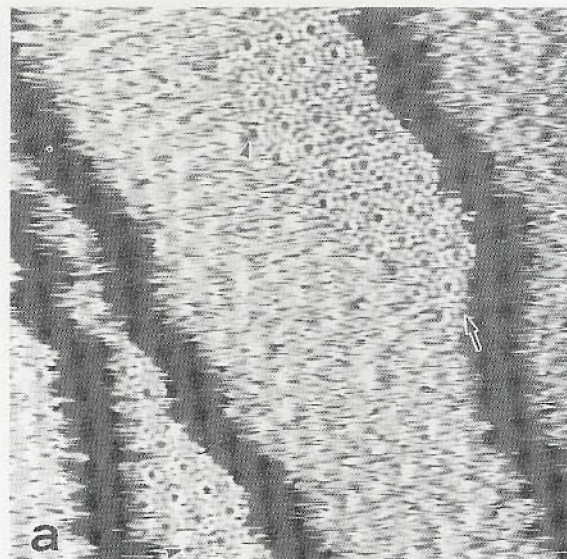


Figure 1A: Si Surface at 860° C.

The Eyes Have it . . .

Percival Lowell, the Yankee astronomer, convinced himself that Mars was "inhabited by beings of some sort or other" although the "existence of extraterrestrial life does not involve 'real life in trousers' or any other particular form of it with which we may be locally conversant", because he believed that, as described by Schiaparelli before him, the red planet was criss-crossed by canals, obviously artificial structures built by an advanced civilization. Said Lowell "Schiaparelli's discoveries were due solely to the genius of the man - his insight, not his eyesight, for at a telescope" and here we would add, at a microscope as well, "eyes differ surprisingly little, brains surprisingly much." The eyes have it.

-- Jean-Paul Revel

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