

Emerging Nanotechnology Products

Nanorevelations by the Indigenous nanoREV 4.0 Air STM

The nanoREV 4.0 is an Air STM (Scanning Tunneling Microscope) (Fig. 1) which has emerged out of a very successful collaboration between IIT Kanpur, Inter University Accelerator Centre (IUAC) New Delhi and Quazar Technologies, a Delhi-based hi-tech instrumentation firm. It is indigenous, in that we have designed and machined every mechanical component, designed and soldered every electronic card, designed and coded every software routine, with our own hands. It is commercial, in that it can be ordered over the net from www.quazartech.com and will be supplied with the usual warranties, excellent

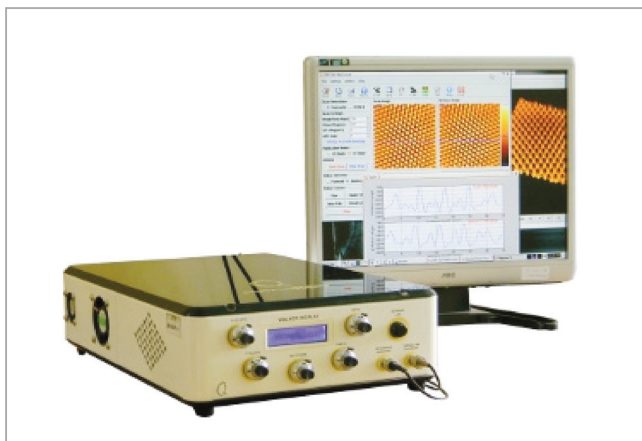


Fig. 1: The nanoREV 4.0 Setup

instrumentation and application support and at a price, universally acclaimed to be “interesting”. Indeed, we are committed to extending the benefit of this indigenous development to the far reaches of our academic spectrum. The process has, in fact, begun: The NanoRev 4.0 is already generating data in a number of our leading labs.

The end-game began with a simple but thrilling phone call: “I think that what I’m seeing on the monitor are atoms on the surface of HOPG”. The excitement at both ends of the line was

palpable. “We’ll be right over” and we were. We have preserved the images we took that night for the sake of historicity (Fig. 2).

Please note that the same structure recurs on different scales. This recurrence convinced us that we were dealing here with a genuine signal, not with mere noise. Although we had crossed this essential hurdle, we quickly realized that we were far from done: Our piezoelectric scanner lay out of reach inside an aluminum shield, the vibration isolation was provided by a heavy slab placed on an inflated tire, our electronics was scattered over several modules connected to one another through a hairy mess of wires, ‘our’ power supplies were not ours at all, they were borrowed, the software was functional but basic. Two years of evolution, lots of sweat, some blood and we arrived at nanoREV 4.0, sleek, compact, self-contained, portable, internationally competitive, aesthetic, user-friendly and greatly enhanced feature-wise.

To fully appreciate the design of the nanoREV 4.0, it is useful to recall how an STM basically works: A Scanning Tunneling Microscope uses a sharp probe (usually made of W or PtIr) brought to within a few angstroms of the (necessarily conducting or semi-conducting) surface being scanned. A bias voltage (ranging for the nanoREV 4.0 from -10V to +10V) applied between probe and surface causes conduction electrons of one, to tunnel quantum mechanically into the conduction band of the other, thereby establishing a small current between them. As the surface is scanned in 256x256 steps of user-specified (variable) size, the tunneling current is measured point-by-point and recorded. This matrix of current values is then

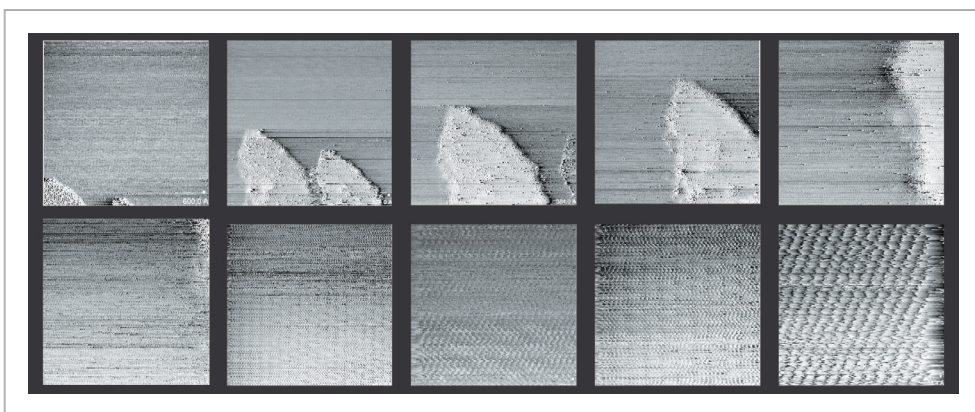


Fig. 2: We zoom in on the atoms of HOPG for the first time

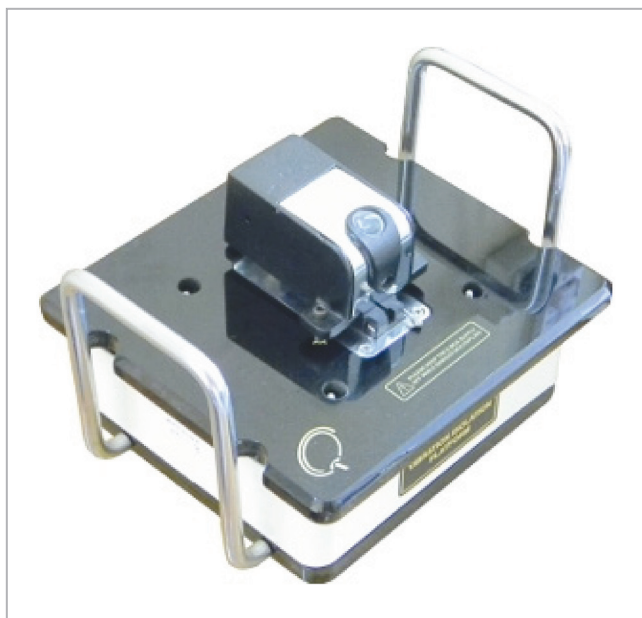


Fig. 3: (a) Schematic showing the preparation method for super-hydrophobic $\text{Fe}_2\text{O}_3 @ \text{C}$ nanoparticles and (b) technique for the removal of oil from water surface through $\text{Fe}_2\text{O}_3 @ \text{C}$ nanoparticles under the action of an external magnetic field (Reprinted with permission from American Chemical Society, Zu et. al., ACS Appl. Mater. Interfaces, 2 (2010) 3141–3146]

converted, by a suitable image-processing package, into a visual representation of the surface.

When using an STM, it helps to keep in mind that (a) getting good images with it is very much like taking good photographs with a camera and (b) the imaging here is more tactile than visual: We are mapping the surface through feelers (probes) rather than eyes. While photography is without question an art, it is definitely aided by a camera, with excellent control of aperture, zoom, exposure time etc. This is the sense in which the features of the nanoREV 4.0 will help you to not only get excellent images but to interpret them as well.

Before we start discussing these features, it is important to note that the height of the probe above the surface is varied by means of a voltage applied to a piezoelectric element carrying the latter. To calibrate an STM, we basically have to determine the voltage we need to apply to the piezoelectric actuator in order to make the tip move by say a nanometer parallel (for X/Y-Calibration) or perpendicular (for Z-Calibration) to the surface. This is done with the help of a God-given calibrator, namely, highly oriented pyrolytic graphite (HOPG), a layered material,

with a lattice constant of 2.456 angstroms and an inter-layer separation of 3.354 angstroms (Fig. 4). Once the atoms on the surface of HOPG have been resolved, the calibration can be straight-forwardly carried out. Every nanoREV 4.0 is of course properly calibrated before it is supplied.

The nanoREV 4.0 uses this calibration to put at our disposal, a very handy distance-measuring tool: we need merely select points A and B on any image we have taken and the nanoREV 4.0 will, if prompted, read out the distance between them in appropriate units of length. It will also incidentally give us the line scan if asked, that is, the values of the tunneling current, along AB.

Turning to its imaging features, we begin by noting that the nanoREV 4.0 gives us the option of scanning the surface in either the Constant Height (CH) or Constant Current (CC) mode. In the CH-mode, the voltage applied to the piezoelectric actuator controlling the

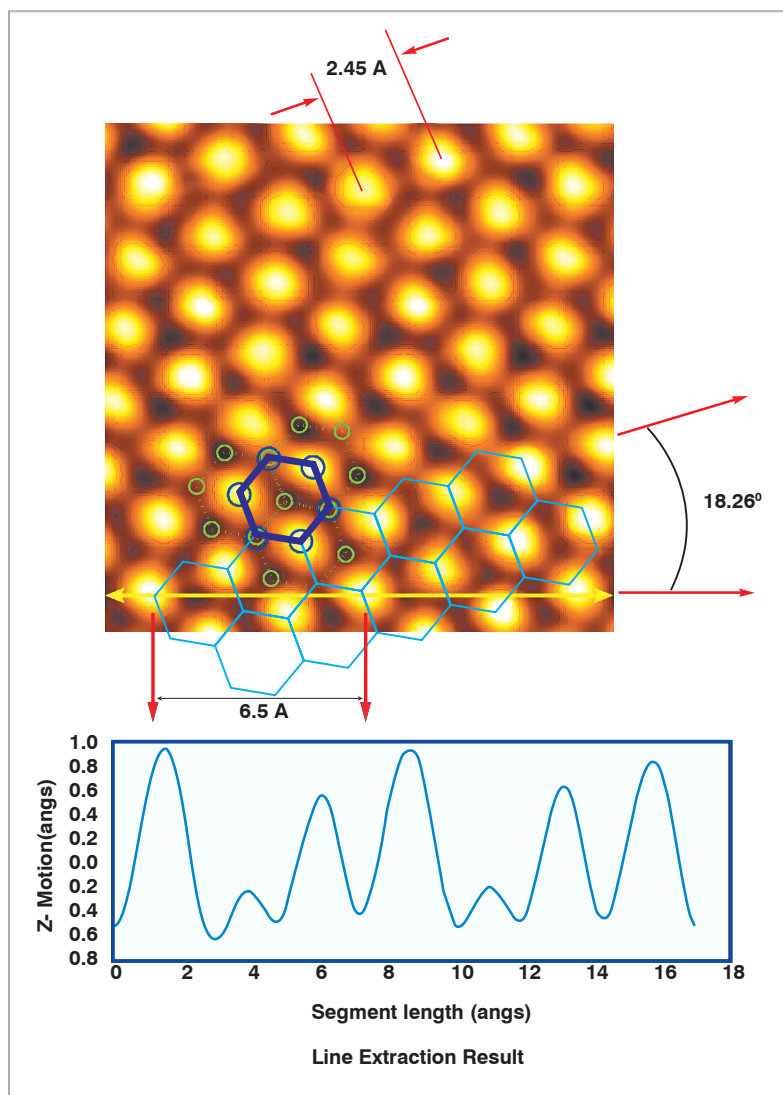


Fig. 4: The nanoREV 4.0 in action: Atomic resolution on HOPG and the tunneling current profile along the yellow line

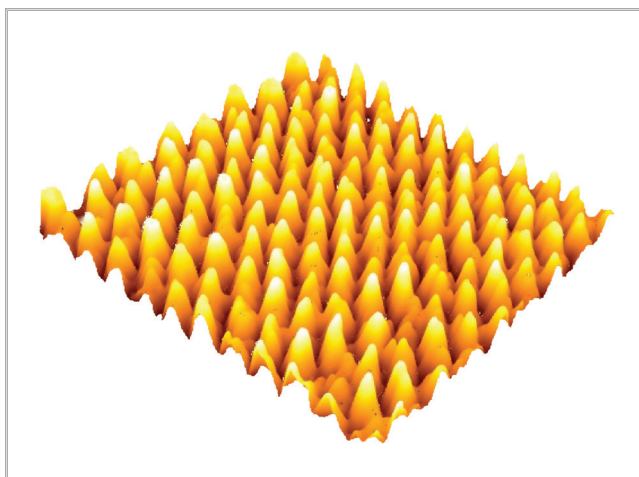


Fig. 5: 3D rendering of nanoREV images

probe's z-motion is kept fixed and the tunneling current is the signal, while in the CC-mode, the error signal fed back to the piezoelectric actuator, in order to keep the tunneling current fixed (by an in-built feedback circuit) is the signal. The CC-mode should be adopted for large area scans, because here we move the probe in large steps over the surface, and hence risk crashing it into some unanticipated structure or other. The CH-mode, on the other hand, is useful for resolving atoms, since atoms become visible only when we graze small atomically flat sections of the surface. In this case, the electronic feedback is more of a disturbance than a help.

The choice of tunneling current in the CC-mode decides how close we are to the surface. The nanoREV 4.0 allows us to choose any current between $\pm 5\text{ nA}$ and $\pm 50\text{ pA}$. While it is possible to go below 50 pA , we run the risk of losing the tunneling current every now and then.

The probe of the nanoREV 4.0 undergoes a raster motion: It samples, in the case of horizontal scans, all points from A to B, moving left to right, and then retraces its motion going this time from B to A, before moving one step down to C, and continuing the same routine. The motion for vertical scans is similar. The nanoREV 4.0 is thus able to produce two renderings of every image: The 'scan' image uses signals obtained when the probe moves horizontally from left to right, and the 'retrace' image uses those obtained while moving from right to left. For vertical scans, the images correspond to motion from top to bottom and bottom to top. It is imperative that both the scan and retrace images be identical. If they are not, we are almost certainly picking up noise.

If an acquired image is darker on say the left than the right, indicative of a consistently smaller amount of tunneling on that side, this is almost certainly because the sample is sloping markedly to the left. The nanoREV 4.0 provides, on its front panel, knobs for compensating the slopes along both the x- and

y-axes. To facilitate slope-compensation, it further has an in-built software oscilloscope, on which the slope, if present, can be straight-forwardly seen and corrected.

The nanoREV 4.0 makes available an array of filters and image-processing tools. These include spatial and Fourier low-pass filtering, background subtraction and histogram equalization. Among image interpretation aids, we should list 3D-renderings and 2D-Fast-Fourier transformations (Fig. 5). By skillful use of these tools, we can improve contrast, remove clearly identified sources of noise, and view the image at different scales and in different (pseudo-) colors. (The coloring of all SPM images is, incidentally, completely arbitrary).

The nanoREV's field of view, that is, the limit of its scan range, $2.6\text{ }\mu\text{m} \times 2.6\text{ }\mu\text{m}$ is interesting: We are talking here of one four-hundredth of a millimeter, the edge of a sharp razor, crossed with that of another one. The point of intersection is our window of perception. But as we magnify and zoom over 4 to 5 orders of magnitude to well-below 0.1 nm , we see an entire universe opening out, reminiscent of Krishna's revelation to Arjuna of the entire Universe in his mouth.

nanoREV 4.0 also provides some very useful exploration tools for the scan area within its field of view. We can zoom any section of the image that we mark out with the help of a mouse or hot-keys. But remember that the sample which we mount for scanning can typically have dimensions of up to 10 mm in diameter. What if we wish to explore several areas each equal to nanoREV's field of view? The answer lies in the fact that all our data comes from the tip-sample junction. Since what happens away from the tip is irrelevant, we can simply bend the probe so as to make the tip reach any point of the sample. The upshot is that the sample can only be explored within points but the points can be chosen at will.

The nanoREV 4.0 can additionally be used to obtain local IV- and dI/dV -curves for all the samples

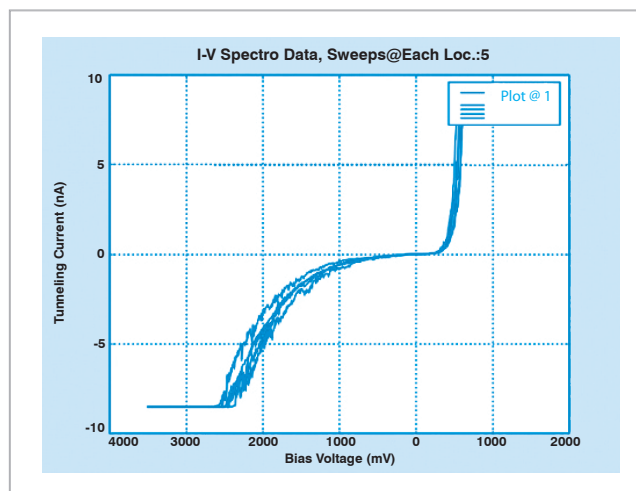


Fig. 6: IV spectroscopy using nanoREV 4.0

being scanned (Fig. 6). The scanning tunneling spectroscopy support built into it makes the nanoREV 4.0 ideal for the measurement of band-gaps, doping polarities and Fermi-levels of doped semiconductors.

The nanoREV 4.0 is perfect for scanning layered solids. These include HOPG, the rare earth chalcogenides (tantalum disulphide, molybdenum diselenide, bismuth telluride etc). All the bonds of these materials lie within the layer to which they belong. Since no bonds are left dangling, these materials do not contaminate even in air. By contrast, materials with dangling bonds like Si(111), contaminate so fast that they can be scanned only under UHV conditions.

Figure 4 and 7 show nanoREV 4.0 images of some layered structures. Note that our atomic images of HOPG show clear evidence of the van der Waals force acting between atoms of different layers, while charge density waves are clearly visible in our images of tantalum disulphide.

nanoREV 4.0 can be further used to scan conducting and semi-conducting films deposited epitaxially through thermal evaporation (followed by annealing), RF sputtering or laser ablation, i.e. onto substrates with commensurate lattice structures. It can be used to explore formations with sizes ranging typically from 1-2 microns to 1-2 nm even on non-conducting surfaces with roughness on the scale of a few nanometers, provided one deposits a thin (5-10 nm) layer of gold over the former.

Lastly, the nanoREV 4.0 has support for the application of controlled voltage pulses to its probe, a technique which often allows us to both reconstitute the tip as

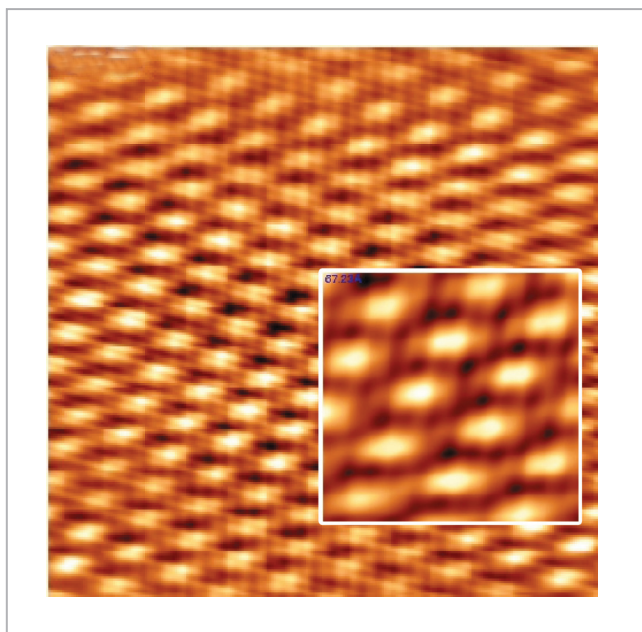


Fig. 7: A nanoREV image of charge density waves on tantalum disulphide

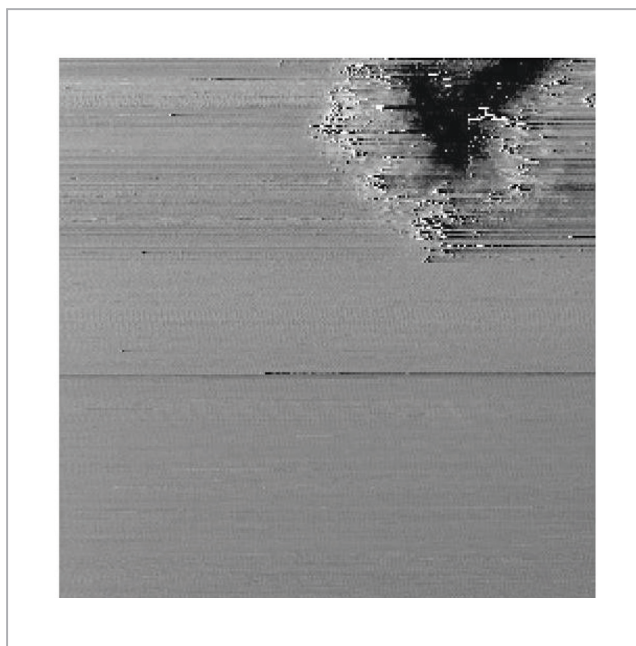


Fig. 8: A crater punctured on HOPG by sharp pulses using the lithography feature of nanoREV 4.0

also to do a certain amount of lithography (Fig. 8).

Apart from its utility as a research instrument, the nanoREV 4.0 is an excellent teaching and training tool. Indeed, it can be used to give all post-graduate students of Nanoscience a uniquely practical introduction to the nano-world.

In recognition to the fact the utility of an affordable hi-tech instrument is vastly increased if the expertise to use it creatively also becomes available locally, QuazarTech provides free training to nominated PhD scholars from all academic institutions acquiring the nanoREV 4.0. It does this through ten well-designed and insightful experiments in Nanoscience. The trained PhD students can, of course, be further used as teaching assistants for an experimental course on Nanotech, based on the nanoREV 4.0.

Those interested in exploring further the remarkable opportunity opened up by the nanoREV 4.0 should visit www.quazartech.com where they will find many more images from the nano-world and videos of the nanoREV 4.0 in action.

Dr. D. Sahdev
Professor
Dept of Physics
IIT Kanpur, India
Email: ds@iit.ac.in

Joshua Mathew
Quazar Technologies Pvt Ltd
New Delhi, India