Technical Article

by Barbara Foster

Focus on Microscopy: One Button and Two Heads—Mainstreaming AFM

The past decade has seen dramatic growth in scanning probe microscopy (SPM) technology, both in functionality and in broader acceptance. Market research conducted in mid-2007 by **The Microscopy and Imaging Place, Inc.**[1] (McKinney, TX) indicates that approximately 20% of microscopists now use atomic force microscopy (AFM) or scanning tunneling microscopy (STM), with numbers reaching nearly 25% for industrial laboratories. Because of their ability to measure a wide assortment of physical and chemical parameters with nanoscale resolution, AFM and STM have become *the* instruments of choice for nanotechnology.

Interestingly, this technology has taken a dual development path. On one side, these instruments have evolved into ultrahigh-end, exotic AFM/Raman hybrids[2–5] or amalgams of AFM and ultramicrotomy.[6] On the other, they have emerged as very simple instruments for classroom use or limited routine analysis.

Figure 1 *SolverNext dual-head system.*

SolverNext's novel architecture offers AFM and STM under one hood. The sample is placed on the scanning stage, located in the center between the two heads. With the click of a mouse, the head of choice automatically moves into position; the cantilever, laser, and photodiode are automatically aligned; and the image is acquired. Figure 1 shows the AFM head in position. With another click of the mouse, that head automatically retracts and the STM moves into place, ready for a variety of electrical measurements. A third location is available for special heads to image in liquid or for nanoindentation.

The challenge with mainstreaming an instrument as diverse as an SPM is loss of functionality, especially in resolution and choice of imaging mode. As seen in *Figure 1*, the unique dual-head approach of SolverNext (**NT-MDT**, Zelenograd, Russia) meets this challenge, offering a full range of conventional SPM measuring techniques in one sleek, easy-to-use system, making SPM available to the mainstream.

The next-generation SPM

The core of this device is the integrated availability of multiple heads. As explained in the side bar and illustrated in Figure 1, SolverNext is delivered with both AFM and STM, with a third position for easy insertion for specialized heads for imaging in liquid or nanoindentation. *Figure 2a* illustrates imaging in liquid using protein deposited on mica, still in buffer solution (scan size: 320 × 320 nm), an important application for biological and pharmaceutical laboratories. For more industrial situations, Figure 2*b* demonstrates multiple nanoindentations on a sapphire surface, with the accompanying approach curves showing the amplitude and frequency dependencies (Figure 2*c*).

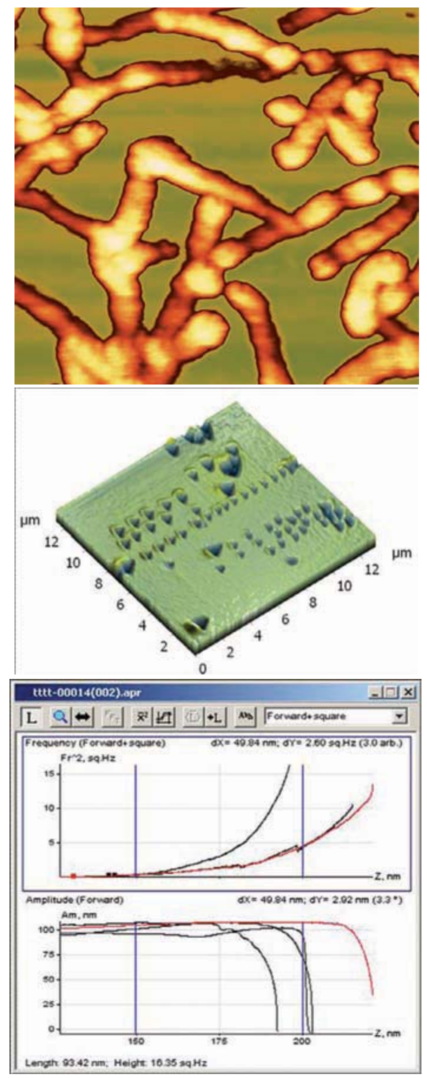

Figure 2 *In SolverNext, AFM and STM heads can be augmented with special heads for a) imaging in liquid, b) nanoindentation, or c) amplitude:frequency dependencies for nanoindentation.*

Unlike most AFM systems, that operate in open air, the SolverNext heads sit within an environmental chamber. Sliding the door down encases the sample in a temperature- and humidity-controlled chamber. The enclosure eliminates the drafts and thermal currents as well as the parasitic electromagnetic fields and electrostatic-free staging that can disturb the cantilever as it scans, causing erroneous images. Temperature within the chamber can be controlled between ambient conditions and 150 °C, and both the chamber temperature and relative humidity can be read directly from an on-board liquid crystal display panel. The door is also deeply tinted, providing additional safety against stray laser reflections. Although extremely versatile, SolverNext uses space wisely, taking up relatively little bench space.

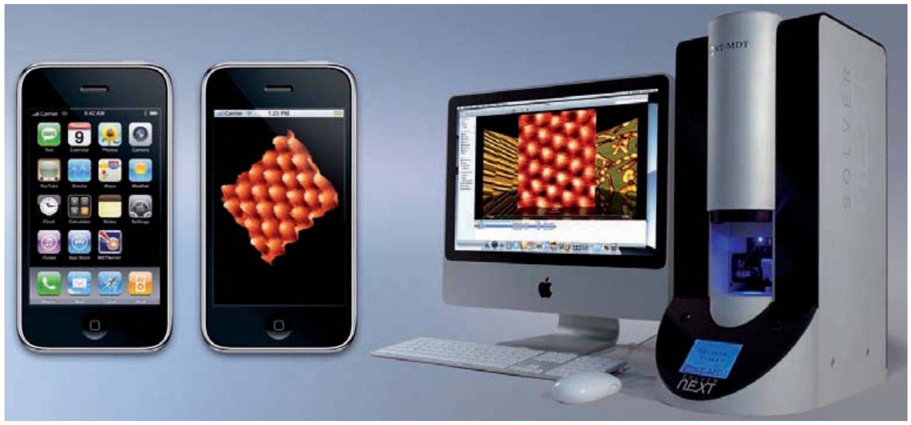

Figure 3 Sleek, flexible, and functional, the SolverNext makes SPM available to the mainstream, even offering a special iPhone applet for simple image analysis and image sharing.

Easy operation boosts accessibility to a broader population

Well-executed alignment is always the first step to good microscopy. However, alignment has been a tedious process in conventional scanning probe microscopy. First, the area to be measured must be found and carefully placed under the scanning area of the cantilever. Next, a laser is centered on the back of the cantilever. Finally, the beam from the laser is centered onto the photodiode, which will record the measurement. Each step requires a delicate touch on precisely machined centration screws.

SolverNext dramatically simplifies the entire alignment process. First, the sample is viewed through an integrated optical microscope. The user sees the image directly and can readily identify the region of interest. A mouse click on that area causes the stage to automatically move that region under the cantilever. Stepper motors, driven by a proprietary **NT-MDT** algorithm, automatically locate the cantilever position, then align the laser to the cantilever, and, finally, center the beam on the photodiode. The whole process is literally click-and-play.

Even scan area can be automatically selected. On conventional research-level systems, one scanner head must be exchanged for another to move from a routine scan size to the smaller areas used for high-resolution imaging. However, SolverNext uses a simple voltage system. High-voltage mode activates a capacitance, closed-loop scanner for 100 × 100 × 10 µm scans. The closed-loop sensors compensate for inherent imperfections in the piezoelectric scanners such as scan nonlinearity, creep, and hysteresis. A click of the mouse activates a low-voltage, open-loop scanner for high-resolution scans over a 3 × 3 × 2 µm area.

MAC + PC: The best of both operating systems

The MAC versus PC war has been raging for decades within the microscopy community. While MACs have been revered for their imaging management and processing capability, they have never enjoyed the breadth of support programming that characterizes the PC world. **NT-MDT** is the first instrument company to capitalize on both operating systems.

Historically, there have been several approaches to coupling the two operating systems. One involves running the MAC operating system (MAC OS) as the primary operating system with Windows (WIN) running in a separate window. The

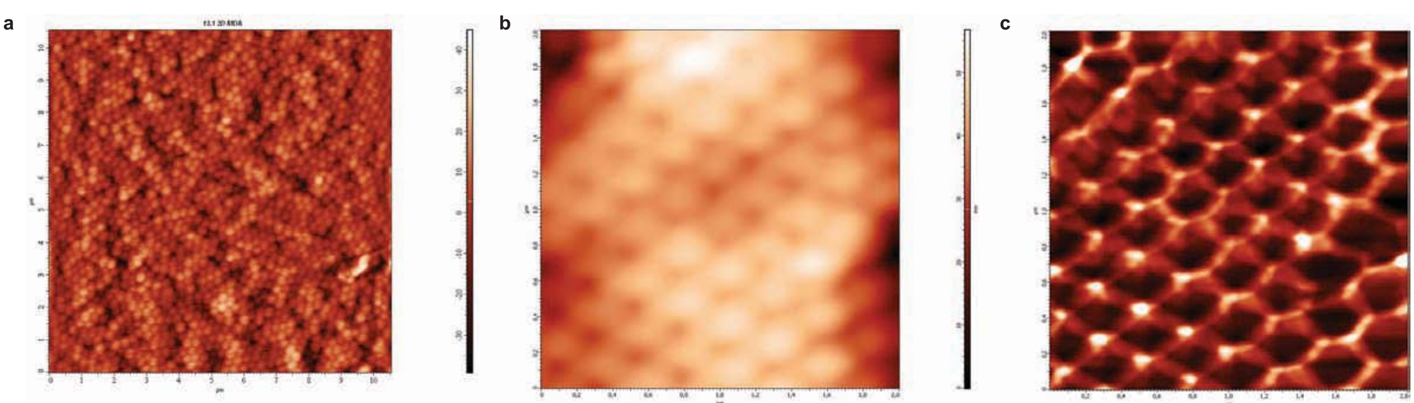

Figure 4 SolverNext delivers a wide range of conventional AFM/STM imaging modes. a) topography of latex: 10 µm × 10 µm scan, b) topography of latex: 2 µm × 2 µm scan, and c) phase image of latex: 2 µm × 2 µm scan.

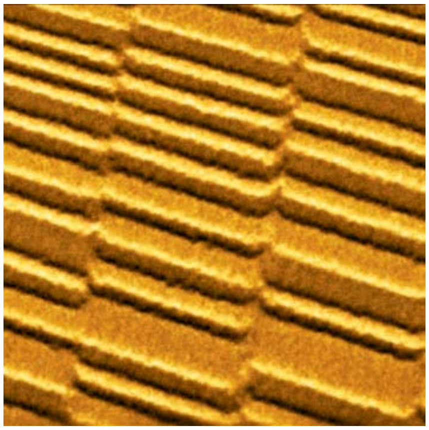

Figure 5 Magnetic force microscopy of a hard disk drive showing the magnetic bits and bytes.

second, more effective alternative is to use the robust MAC hardware to run Windows directly. This was the direction chosen by **NT-MDT**. The result is a flexible, image-friendly operating system well-suited to large-file, 3-D mathematics and manipulation coupled to the expansive libraries of PC programming.

NT-MDT has gone one step further, however, equipping SolverNext with a special applet for exporting images to the iPhone, as seen in *Figure 3*, where they can be viewed dynamically in 2-D or 3-D, and can be easily shared with colleagues or classmates at school or in a technical meeting, or with co-workers in different locations around an industrial facility. The applet also includes more routine image analysis capabilities such as linear and roughness measurements and plane subtraction.

Applications and operating modes

Those new to SPM are often astounded by the alphabet soup used to describe the nearly 40+ different imaging modes that fall under this broad umbrella. *Figures 4* and 5 demonstrate just a few of the many techniques available on this system.

The atomic force head provides both contact and semicontact modes ranging from topography and phase imaging to magnetic force microscopy (MFM); force and frequency modulation; and electrical measurements including spreading resistance imaging (SRI), electromotive force (EMF), scanning Kelvin microscopy (SKM), and scanning capacitance microscopy (SCM). It will even do nanolithography.

Figure 4*a* and *b* show the difference in magnification generated by changing the size of the scan. The 10 μm × 10 μm scan in Figure 4*a* is a much better representation of the hills and valleys generated by the latex microspheres, while the increased magnification of the 2 μm × 2 μm scan in Figure 4*b* is not very useful. Shifting to phase image (Figure 4*c*) uses the delicate hard and soft domains within the surface to generate contrast. For these smaller features, the smaller scan is a better fit.

Figure 5 demonstrates magnetic force imaging. In the case of this computer hard drive disk, the actual surface has no real structure. The three-dimensionality imaged here elucidates the magnetic domains within the surface that comprise the bits and bytes of the stored data.

The scanning tunneling head operates in both constant height and constant current modes and provides insight into electron barrier height, density of states, and current versus height [I(z)] and current versus voltage [I(V)] spectroscopy. For those readers unfamiliar with the power of these diverse techniques or confused by the variety of acronyms, the **NT-MDT** Web site (www.NT-MDT.com) offers not only an extensive glossary, but animated explanations of all of the commonly used techniques.

Is SolverNext for everyone?

The British have a saying about racing that neatly answers this question: "Horses for courses." Just as a sprinter would not sign up to run a marathon, it would be unrealistic for a mainstream, automated microscope to replace the extreme flexibility of a research-level stand. For example, while the resolution is nearly equivalent between SolverNext and its big brother, NTEGRA, NTEGRA's special ThermoHead allows ultrahigh-stability thermal experiments over time, with razor-thin drift readings on the order of nm/hr.

SolverNext scans by sample, while NTEGRA can scan by sample or scan by tip, resulting in a difference of scan size and sample weight: SolverNext is limited to samples that are 20 mm in diameter, 10 mm in height, and 100 g in weight, while NTEGRA's scan by probe system can handle samples up to 100 mm in diameter, 15 mm in height, and 300 g in weight. Furthermore, NTEGRA's dual scan mode extends scan areas up to 150 × 150 mm.

Finally, although SolverNext supplies the user with a very extensive array of AFM and STM solutions, it cannot handle special applications like electrochemistry, nor is it compatible with other investigative techniques. The NTEGRA line does provide accessories for those more exotic applications, and can be set up on an inverted optical microscope or interfaced with a Raman spectrometer or even an ultramicrotome.

The bottom line is: Research is still research and will always require more stringent parameters. However, SolverNext holds its own across a broad spectrum of scanning probe microscopies. It provides a robust, diverse, easy-to-use, and economic solution for classroom, industrial, routine biological, and pharmaceutical laboratories, and makes AFM and STM accessible to a broader audience without the demand for advanced scientific training.

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