Automated Nanoscale Quality Control For Reliable, Artifact-free Atomic Force Microscopy

Author: Dr James Vicary, Managing Director, NuNano, Bristol, UK

Atomic Force Microscope (AFM) users need to acquire the best high-resolution images and the most reliable and consistent data possible. To do this, they need highly accurate and precise AFM probes. Any defect to the probe's nanoscale tip will result in imaging artifacts and inconsistent data – and there is a chance the AFM researcher won't even realise it, resulting in lost time and resources.

Full inspection of every AFM tip at the nanoscale is a critical, yet impossible task to do manually. NuNano has customised a TESCAN Field-emission Scanning Electron Microscope (FE-SEM) to automate this process. This article discusses the importance of high-quality control of AFM probes and reviews the different types of tips and their applications.

Introduction

AFM is an important method for topography imaging and measuring material properties such as friction, mechanical, electrical, magnetic forces and more. AFM users need to acquire the best high-resolution images and the most reliable and consistent data possible. To do this, they need highly accurate and precise AFM probes.

AFM images will appear blurry if the probe has a blunt tip, or worse, features can appear duplicated if the probe as a double tip (two discrete sharpened points on one tip). The probe could be blunt in one direction or the other. If the tip is blunt, say by even 5nm, the imaging data will be inaccurate and there is a chance that the AFM user won't even realise it. In which case, precious time and resources have been wasted.

UK-based NuNano understands the need for high-quality AFM probes. The NuNano team has over 30 years of AFM experience, and now specialises in the design and manufacture of probes for AFM and cantilever-based sensor devices. NuNano's proprietary microfabrication processes enable them to manufacture AFM probes with the tightest dimensional tolerances in the market at present. They also ensure a high level of quality control, allowing them to confidently provide their customers with AFM tips that offer extremely accurate imaging and the most reliable measurement data.

Manual inspection of AFM probes, specifically the almost atomically sharp tip, using a scanning electron microscope (SEM) is one approach to maintaining such a high level of quality control at the nanoscale. However, for NuNano, this manual approach was not keeping pace with demand. They needed to scale volume while also maintaining the highest quality control.

Automating the SEM for 100% Inspection

Quality control at the nanoscale is a very demanding and often impossible task. Yet having experienced the variability of AFM probes first-hand during three decades of AFM-based academic research, the NuNano team was determined to make the task viable. To do this, NuNano selected the TESCAN MIRA FE-SEM. Key features were the system's large chamber size and the stage motion that could tilt and handle the whole wafer of probes. Another key component was the flexibility of TESCAN's Shark SEM software that could accommodate customisation. Finally, TESCAN was supportive of NuNano as a start-up and provided a true partnership in helping to meet their needs.

NuNano has customised the TESCAN FE-SEM software for their highly automated imaging requirement. In collaboration with the Visual Information Laboratory at the University of Bristol, NuNano created software using machine learning algorithms that allow them to automate control of the FE-SEM and acquire high resolution images of the tip apex for every probe on a wafer - that's 400 probes per wafer - to achieve 100% tip inspection. NuNano can identify a tip and capture an image of the apex in as little as 30 seconds, which would be impossible to do manually. This level of automation and throughput also minimises the chance of contamination of the tip.

This high level of quality control enables NuNano to confidently provide its customers with AFM probes that offer extremely accurate imaging and the most reliable measurement data. However, not all AFM probe tips are alike.

AFM Probe Tips

A conventional AFM probe consists of an almost atomically sharp tip at the end of a microcantilever, which is raster scanned over a sample surface. By measuring the deflection of the cantilever in response to the forces arising between the tip apex and the sample, an image of the surface can be built up.

It's likely that tip sharpness is the first characteristic that enters a researcher's head when they think about AFM probes. Both the sharpness of the tip apex and the aspect ratio of the tip (microscale sharpness) are important considerations in surface imaging because they determine image resolution. The aspect ratio of the tip is determined by its microscale shape, whereas the sharpness of the tip apex should be independent of it, if suitable sharpening processes have been applied during fabrication.

Naturally, to resolve a surface feature, the tip apex should be sharper than the size of the feature being imaged. When a surface is imaged using the tip, each point imaged is a spatial convolution of the shape of the tip and the imaged feature. If the microscale sharpness of the tip is large, steep edges will appear broadened because each point imaged becomes dominated by the shape of the tip. Furthermore, the uniformity of the tip shape will impact on whether there is imaging consistency in different scan directions. If the sidewalls of the tip are not the same, symmetrical images will not be obtained.

The three most common shapes of AFM tips are conical, pyramidal, and tetrahedral. The aspect ratio of pyramidal and tetrahedral tips is limited by their

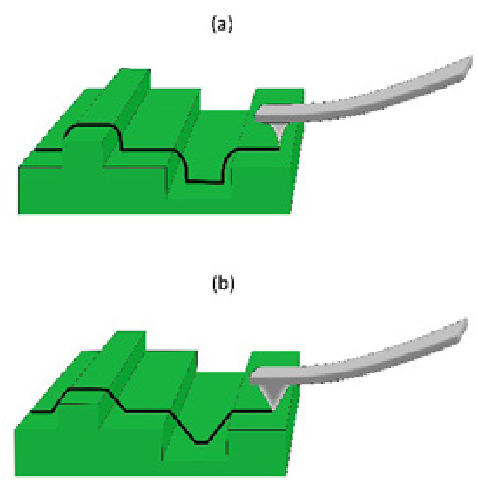

Figure 1. Schematic showing the trace (black line) of an AFM probe with (a) a conical tip and (b) a pyramidal tip as it moves along a sample surface.

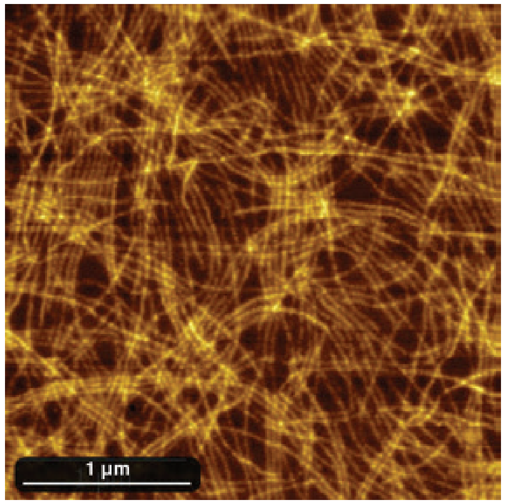

Figure 2. Poly (3-hexyl thiophene) semiconducting nanofibers deposited by spin coating on silicon. Imaged using a SCOUT 350 AFM probe in AC mode with a Bruker Dimension 3100 AFM. (z-scale: 20 nm). Image courtesy of Dr Piotr Wolanin, Prof. Charl Faul & Prof. Ian Manners, University of Bristol, UK.

fabrication process, which requires etching along the crystallographic planes of silicon.

The Superiority of Conical Tips

Conical tips are superior to pyramidal and tetrahedral types in many ways. Firstly, they can be fabricated with higher aspect ratio because etching along a particular crystal orientation is not required

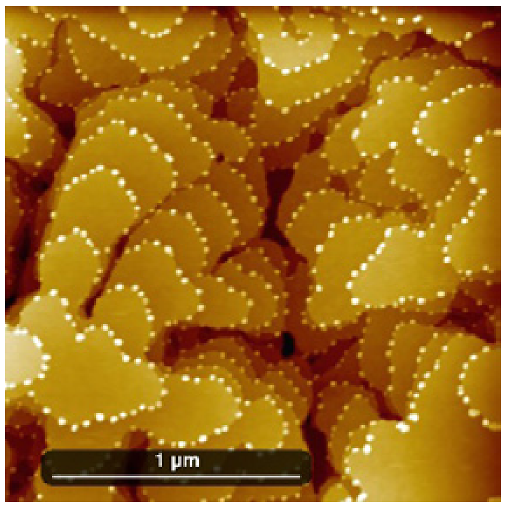

Figure 3. C60 nanostructures clustered on the step edges of a pentacene layer. Imaged using SCOUT 350 RAI probes in tapping mode with an Agilent SPM 5500 system. (Image size: 2 x 2 µm, z-scale: 1.5 µm). Image courtesy of Ms. Andrea Huttner, Dr. Tobias Breuer, and Prof. Dr. Gregor Witte, University of Marburg, Germany.

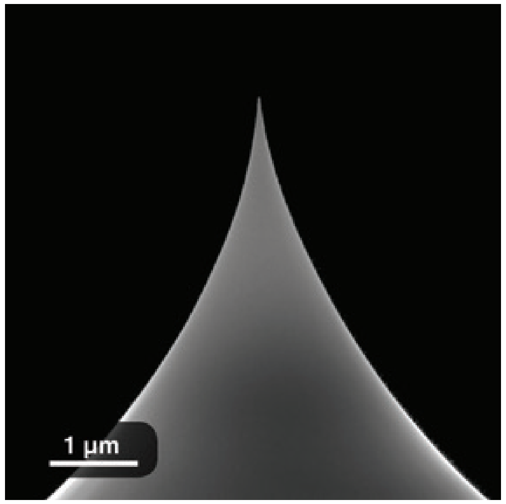

Figure 4. Scout standard tip.

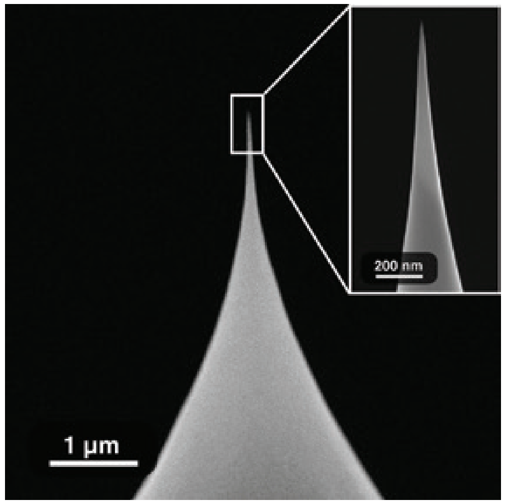

Figure 5. Scout HAR tip.

for their fabrication. The trace of a conical tip over a surface with steep-edged features is shown in figure 1. It is evident that the conical tip more closely resolves the real' profile of such a surface. Secondly, they are manufactured using dry etching, which allows for geometrical uniformity. This means that with conical tips, the image will look identical regardless of scan direction.

NuNano probes with conical tips provide advantages over probes fabricated with pyramidal or tetrahedral tips. They have allowed for high resolution imaging of, for example, semiconducting nanofibers on silicon (figure 2) and C60 nanostructures on pentacene steps (figure 3).

NuNano Probe Tips

The standard tip on NuNano's Scout range of silicon AFM probes is a 7µm high conical tip with a nominal radius of curvature at the apex of 5nm (figure 4).

NuNano's high aspect ratio (HAR) tip has a more tapered profile, with a cone angle over the last 1 µm of the tip of less than 15°. This is ideal for imaging highly three-dimensional samples, for example microfabricated trenches forming gratings or waveguides (figure 5).

Conclusion

There are many different types of AFM probe tips: conical, pyramidal, and tetrahedral, however conical tips are superior in many ways. Regardless of their superiority, all may introduce artifacts if they are not inspected prior to being shipped to the customer. NuNano has developed a methodology to inspect 100% of its probes using a customised TESCAN FE-SEM, guaranteeing the highest quality control for its customers.

About the author

James is Managing Director of NuNano, a UK-based company specialising in the design and manufacture of probes for atomic force microscopy (AFM) and cantilever-based sensor devices. He started out in the field of atomic force microscopy during his PhD in the Scanning Probe Microscopy group in the School of Physics at the University of Bristol, under the supervision of Prof. Mervyn Miles. His work focused on the use of high-speed AFM for nanofabrication. During his postdoc, also at Bristol, he transitioned from using AFM to designing and fabricating unique AFM probes for new AFM instrumentation being developed by his colleagues. This led to James and his co-founders forming NuNano to bring new probe designs to the wider AFM community.