Ultimate Resolution of AFM in Air

"What is the ultimate resolution of AFM in air?" As significant as the answer to this question may be, it is equally important to clarify and define the meaning of this very question. More often than not, people take the term 'atomic image' at face value and strive to obtain atomic structure on their samples. This is partly due to the atomic scale images they have seen, such as the one in Figure 1.

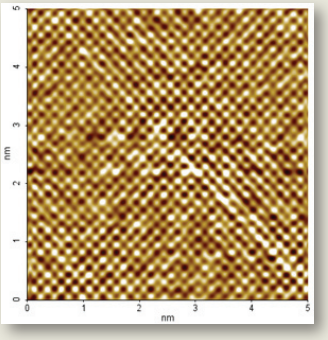

Figure 1. HOPG image taken with XE-100 (5 nm x 5 nm scan size). This image shows atomic lattice, not individual atoms.

A popular misconception is that the ability to acquire such images is a measure of the performance capability of an AFM. It is a widely known fact that images of graphite (HOPG) and mica, as shown in Figure 1, reflect the average spacing of atoms on the sample surface and not the individual atoms themselves.[1, 2] In other words, the image only represents the collective average uniform spacing of the surface, so called atomic lattice. Therefore, the 'atomic lattice' is an inaccurate portrayal of the actual atomic detail in images of graphite (HOPG) and mica.

And yet, many still believe that an AFM should be able to show atomic structures for any given sample. Although it is true that AFMs in ultra high vacuum (UHV) can acquire such atomic resolution images for certain samples, the genuine lateral resolution for ambient AFM is limited by the radius or curvature of the tip. The radius of an AFM probe tip is a few nanometers at best and the ultimate resolution of the technique lies in the AFM's ability to preserve the tip condition.

Tip Preservation is the Critical Factor

One may argue that atomic lattice images are an indicator for the stability of an AFM system; however, they are not an accurate test of the performance for every sample since the mechanical design and signal access of such systems are engineered for and limited to a very small scan range of a specific set of samples, e.g. the 1 μm × 1 μm scan of a graphite or mica sample. Note that small range scanners with open loop feedback are required for atomic lattice images, and these scanners are not practical for all samples.

As mentioned earlier, the ultimate resolution of AFM is critically defined and scaled by the radius of the AFM tip, which is about 2 nm - 5 nm. The sharp end of an AFM tip is so brittle that once it touches a sample, it becomes instantly blunt and limits the resolution of an AFM; this reduces the quality of the image. Consequently, preserving tip integrity is the prerequisite for the consistent and ultimate resolution in AFM.

Ultimate Resolution of Ambient AFM with Non-Contact Mode AFM

Another popular misconception is that Non-Contact AFM (NC-AFM)[3] has poor resolution because the tip does not contact the sample surface and needs to maintain a large tip to sample spacing. Most ambient AFM vendors in the market, due to slow Z-servo feedback, elect to operate NC-AFM significantly far from the sample surface, resulting in poor resolution. If the Z-servo feedback is slow and limited by the bandwidth of a Z-scanner, the tip occasionally touches the sample surface when the tip closely approaches the sample surface. In ambient conditions, most sample surfaces are, in fact, covered with a liquid layer. When a probe tip comes in contact with the sample, the tip may become stuck in this layer due to meniscus forces, in which case the cantilever oscillation will stop. Therefore, when NC-AFM is operated with a very small tip-sample distance, even a slight deviation of tip-sample interaction force from the set point can be fatal if the system lacks accurate control to stay in the attractive force regime for NC-AFM.

It is a technically challenging task to implement proper Non Contact mode imaging with a very small tip-sample distance, hence the initial reason behind the development of tapping imaging: to avoid the difficulty of tip-sample spacing control.[4] Park Systems' crosstalk eliminated (XE) AFM successfully overcomes the aforementioned challenge with its high force Z scanner actuated by patented multiple stacked piezos. With a typical resonance frequency of 10 kHz, the Z scanner, in this flexure-based AFM design, is decoupled from the XY scanner; this provides the XE-series an additional degree of freedom to implement a high force actuator thereby improving its Z-scan bandwidth. This design allows the XE series to operate with a very small tip-sample distance of a few nanometers thereby realizing a very reliable and stable operation of Non-Contact AFM in ambient atmosphere. Hence, the True Non-Contact Mode of the XE-series allows AFM users to easily and routinely obtain Non-Contact AFM images of any sample with the ultimate resolution of an ambient AFM. (See Figure 2).

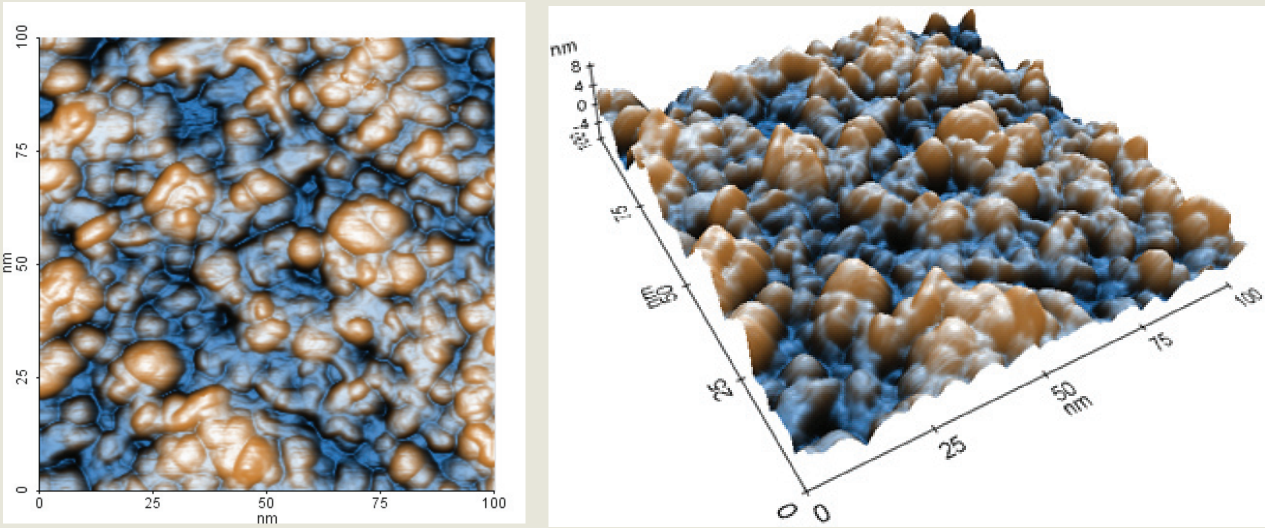

Figure 2. High resolution (100 nm x 100 nm) image of a gold surface, acquired by True Non-Contact Mode of the XE-100 AFM.

Reference

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