Ultimate Resolution of AFM in Air

The Preservation of Tip and Sample is a Critical Factor

The Ultimate Resolution of Atomic Force Microscope

"What is the ultimate resolution of AFM in air?" As significant as the answer to this question may be, somehow people fail to realize the true intention of this very question. Frequently, the majorities are obsessed with the term 'atomic image' that they strive for the smallest atomic details on their samples. This is partly due to the atomic scale images they have been treated with, such as the one in Figure 1.

A popular misconception is that, the ability to be able to acquire such images projects the performance of an AFM. This is only partially true. It is a widely known fact that 'atomic resolution AFM images' such as that of graphite and mica are images that reflect the average spacing of atoms on the sample surface and not the individual atoms themselves [1, 2]. Such layered materials have atomically flat surfaces, which are characterized by having a uniform atomic lattice. Therefore, it should be noted that the term 'atomic lattice' would be a more accurate portrayal than the term 'atomic resolution'.

And yet, many still believe that an AFM should be able to show atomic structures for all given samples. It is, without a doubt, true that superior AFMs should be able to acquire such atomic lattice images of certain samples; however, the fact of the matter is, the genuine resolution of an AFM ultimately relies on the AFM's ability to preserve its tip condition. The radius of an AFM probe tip is a few nm at best and this radius is that limiting factor in AFM resolution. In the end, 'Ultimate Resolution of AFM' resolves around the subject of probe tip radius and the term 'atomic lattice'.

Atomic Lattice Imaging at the Cost of Ultimate AFM Resolution

One may still 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 on every sample since the mechanical design and signal access of such systems are deliberately engineered for and prohibitively limited to a very small scan range of a specific sample. Note that small range scanners with open loop feedback are required for atomic lattice images, and these scanners have no practical use otherwise. It is no exaggeration that such AFM systems are solely designed for the 1 μm × 1 μm scan of a graphite or mica sample. Consequently, it is not surprising that such AFM systems are fundamentally disadvantaged to image the key features of actual samples other than graphite or mica. Making matters worse, although the ultimate resolution of AFM imaging of a user's sample is influenced by the mechanical design and signal access, it critically depends on the tip and the sample preservation.

How can I achieve Ultimate AFM Resolution?

As mentioned earlier, the radius of the AFM probe tip is a few nm at best, therefore, the ultimate resolution of AFM is critically defined and scaled by the radius of the AFM tip, which is about 2 nm - 5 nm. Unfortunately, the sharpest part of the tip is very fragile. Once the tip touches the sample surface, no matter how soft the contact or gentle the touch, the tip instantly becomes blunt. Therefore, it is not possible to achieve the ultimate resolution with contact or tapping imaging AFM. The ultimate resolution can be achieved only in True Non-Contact mode AFM that preserves both the tip and the sample with a small tip-sample distance [3].

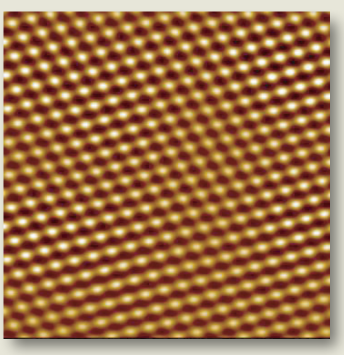

Figure 1.
AFM image of HOPG taken with XE-100 (5 nm scan size). This image shows atomic lattice, not individual atoms.

I thought that the resolution of Non-Contact AFM (NC-AFM) is lower than that of tapping imaging?

Another popular misconception is that NC-AFM has lower resolution than tapping imaging because the tip cannot come close enough to the sample surface. The misconception states that; if the tip did come very close to the sample surface, the tip would occasionally touch the sample surface causing the tip to stick to the sample surface due to the meniscus force. The truth is that most sample surfaces in ambient conditions 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, 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, unlike in contact mode. This is why the tip has to be significantly far from the sample surface in conventional NC-AFM, resulting in poor resolution.

This is so in the case of conventional NC-AFM. It is, no doubt, a technically challenging task to implement proper Non Contact mode with a very small tip-sample distance, hence the initial reason behind tapping imaging: to avoid the difficulty of tip-sample spacing control.4 By concealing its flaws and successfully imitating ultimate resolution, Tapping imaging quickly became popular. However, the fact remains unchanged that the tapping force, even greater than the typical contact force, causes damage to both the striking tip and the sample surface that is being struck; an irony in the name itself.

Ultimate Resolution with True Non-Contact AFM of the XE-series

Once correctly engineered, True Non-Contact AFM of the XE-series provided the ultimate resolution of ambient AFM, far surpassing the capabilities of both Tapping and Contact mode, as shown in Figure 2. A very high performing Z-servo system, a necessity for True Non-Contact, was achievable by abandoning the piezoelectric tube actuators for the stacked piezoelectric actuators. In the end, the advanced engineering of the XE-series, the only series of AFMs capable of True Non-Contact imaging, provides the ultimate resolution of AFM in air.

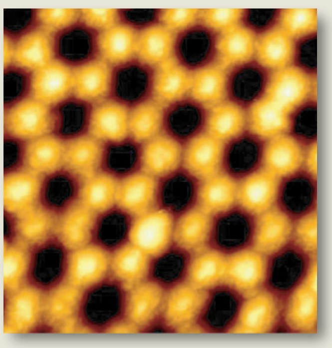

Figure 2.
AFM image of nano structures patterned on aluminum surface taken with XE-100 (500 nm scan size).

Reference

1. H.A. Mizes, Sang-il Park, and W.A. Harrison, Phys. Rev. B 36, 4491 (1987).
2. T.R. Albrecht, H.A. Mizes, J. Nogami, Sangil Park, and C.F. Quate, Appl. Phys. Lett. 52, 362 (1988).
3. Y. Martin, C.C. Williams, H.K. Wickramasinghe, J. Appl. Phys. 61, 4723 (1987).
4. Q. Zhong, D. Innis, K. Kjoller, V.B. Elings, Surf. Sci. Lett. 290, L688 (1993).