True Non-Contact Mode vs. Tapping Imaging

Tapping Imaging is Merely a Compromise Between Contact and NC-AFM

The Non-Contact Mode AFM

The first Non-Contact mode AFM (NC-AFM) was developed by Martin et al in 1987,1. In NC-AFM, a cantilever is deliberately vibrated by a piezoelectric modulator with very small amplitude at a fixed frequency near the intrinsic resonance of the cantilever. As the tip approaches a sample, the van der Waals attractive force between the tip and the sample acts upon the cantilever and causes changes in both the amplitude and the phase of the cantilever vibration. These changes are monitored by a Z-servo system feedback loop to control the tip-sample distance.

Difficulties in Non-Contact AFM

It is important to maintain the tip-sample distance at a certain constant value (typically a few nm) and to prevent the tip from contacting the sample surface. Once the tip makes an accidental contact with the sample, the tip can stick to the sample surface and stop vibrating due to the meniscus force of the liquid layer on the sample surface. Therefore, a very high performing Z-servo system is required for NC-AFM. The mechanical response of the Z-scanner must be very fast. For this reason, a stacked piezo actuator provides much better performance than a piezoelectric tube scanner. It is also advantageous to use phase detection, as apposed to amplitude detection, because the change in amplitude of the cantilever vibration is less sensitive and does not occur instantaneously with a change in the tip-sample interaction, but on a timescale of t » $2Q/f_0$.

If the Z-servo performance is not sufficiently high, the tip will regularly stick to a sample due to meniscus forces. This stops the Non-Contact oscillation. In such cases, a Z-scanner must retract the cantilever far enough to detach the tip from the sample surface. This process generates glitches on AFM images. One quick remedy is to increase the tip sample spacing, but this will result in a significant loss of lateral resolution. In order to solve this problem, Zhong et al.2 introduced a 'tapping' imaging in which a tip strikes against the surface on each oscillation cycle and detaches from the sample surface by using a large vibration amplitude. The resolution of tapping imaging, however, is not as high as that of NC-AFM since the very sharp end of a tip is extremely fragile and becomes blunt instantaneously as it makes aggressive contact with the sample.

It must be noted that the tip-sample impact force in tapping imaging is so great that it has the tendency to be destructive to both the tip and the sample. Tapping imaging may eliminate the lateral frictional force, but the tip-sample impact force is even greater than in typical Contact mode AFM. This force results in significant tip wear, which is bound to limit spatial resolution, and even worse, the sample can be irreparably damaged. This is even more so a problem in the case of imaging soft materials. On the other hand, a constant tip-sample distance is maintained in NC-AFM without damaging the tip or sample. With proper Z-servo performance, the ultimate resolution of AFM can be achieved in True Non-Contact mode, as in the XE-series the tip-sample distance is successfully kept at a few nanometers. Figure 2 demonstrates the comparison of movements of the probe tip relative to the sample surface for images being acquired between True Non-Contact AFM of the XE-series and tapping imaging AFM.

Figure 1. Inter-atomic force vs. distance .

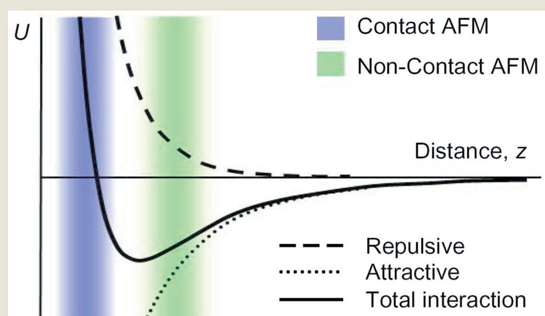

Figure 2. Tapping Imaging vs. True Non-Contact mode.

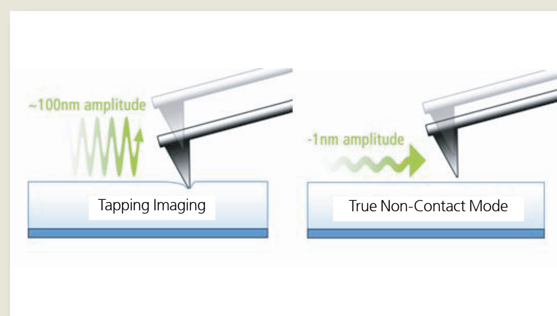

Figure 3 shows a comparison between a True Non-Contact AFM image and a tapping AFM image. Figure 3(a) was taken with an XE-100 which utilizes a stacked piezo actuator for Z-scanning and a lock-in amplifier for phase detection. Figure 3(b) was taken with a Digital Instrument Multimode AFM that uses a piezoelectric tube for z-scanning and a rms-to-DC converter for amplitude detection. Ultimately, the resolution of tapping imaging is not as high as that of NC-AFM since the very sharp end of the tip is extremely fragile and is instantaneously blunted as it makes contact with the sample.

Figure 4 shows another example in which only True Non-Contact AFM of the XE-series can successfully trace the steep contour of a polymer sphere that has a diameter of about 5 µm.

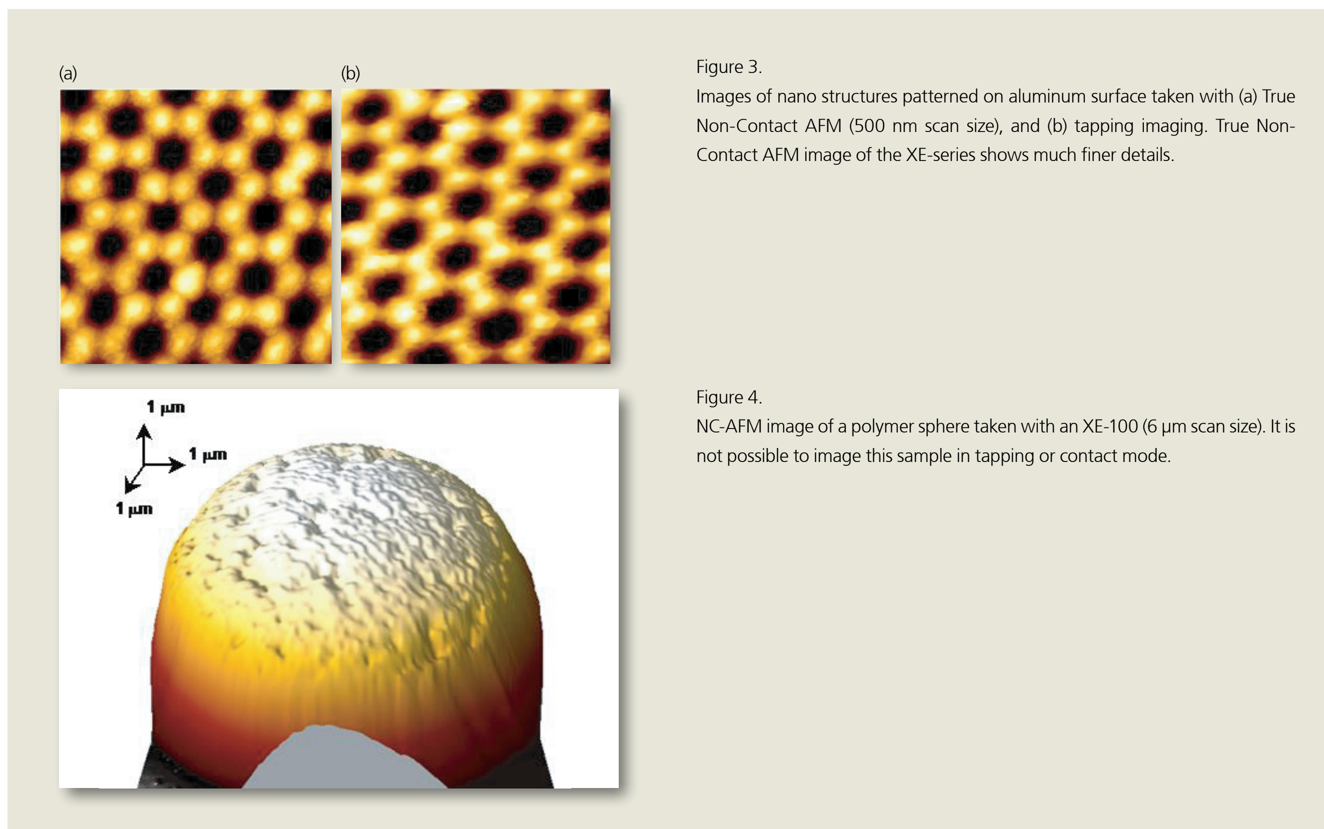

Figure 3.
Images of nano structures patterned on aluminum surface taken with (a) True Non-Contact AFM (500 nm scan size), and (b) tapping imaging. True Non-Contact AFM image of the XE-series shows much finer details.

Figure 4.
NC-AFM image of a polymer sphere taken with an XE-100 (6 µm scan size). It is not possible to image this sample in tapping or contact mode.

Reference

1. Y. Martin, C.C. Williams, H.K. Wickramasinghe, J. Appl. Phys. 61, 4723 (1987).
2. Q. Zhong, D. Innis, K. Kjoller, V.B. Elings, Surf. Sci. Lett. 290, L688 (1993).