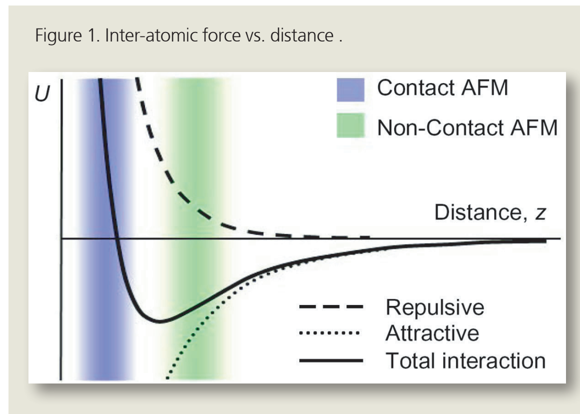
Non-Contact Mode AFM vs. Tapping Mode AFM

Non-Contact Mode AFM

The first Non-Contact AFM (NC-AFM) was developed by Martin et al in 1987.[1] NC-AFM measures surface topography by utilizing the attractive inter-atomic force between the tip and a sample surface (see Figure 1). NC-AFM, the attractive deflections are often too small for traditional direct current (DC) methods to resolve a surface topography. One solution is to use a piezoelectric modulator to vibrate the cantilever near its resonant frequency (Figure 2) as it passes over a surface, and correlate changes in the cantilever's vibrations to topographical features.

Figure 1. Inter-atomic force vs. distance .



As the tip approaches a sample, the van der Waals attractive force between the tip and the sample causes changes in both the amplitude and the phase of the cantilever vibration (see Figure 3). These changes are monitored by a Z-servo system feedback loop to control the tip sample distance (see Figure 4).

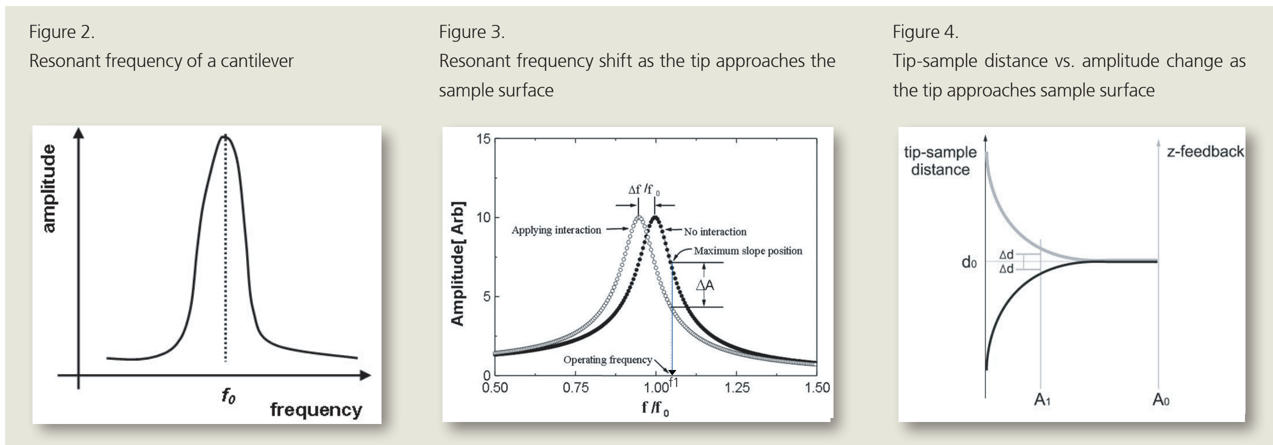


Figure 2.
Resonant frequency of a cantilever

Figure 3.
Resonant frequency shift as the tip approaches the sample surface

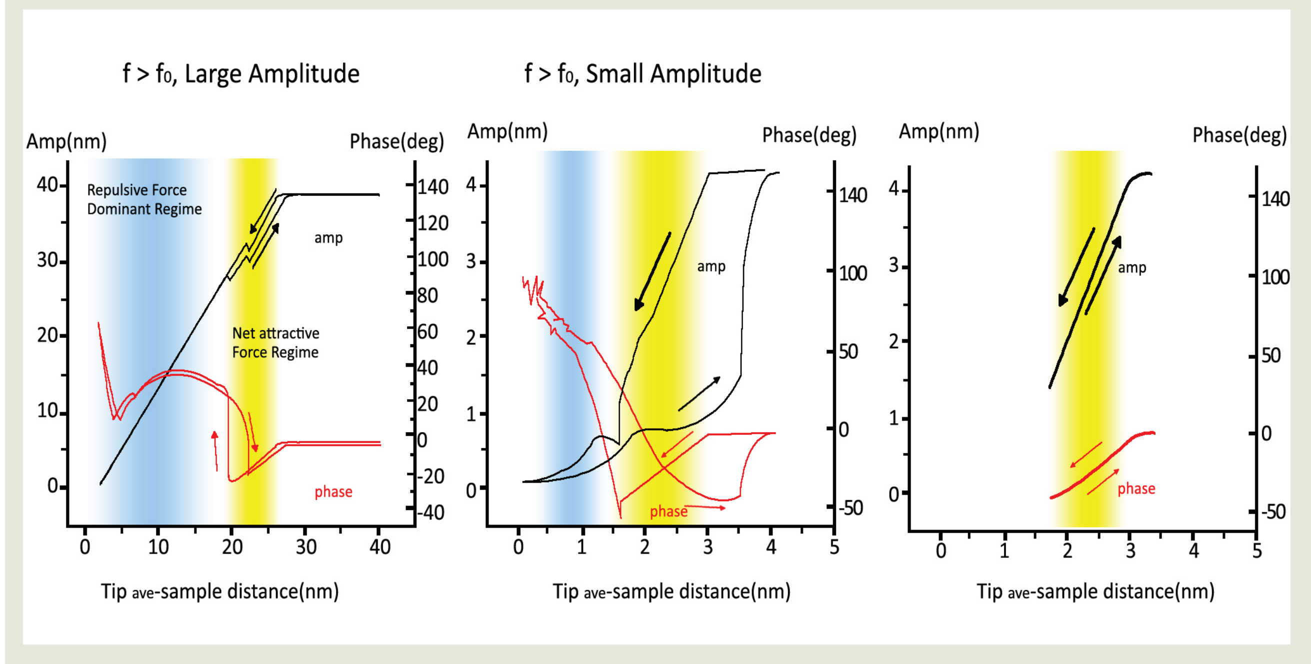
Figure 4.
Tip-sample distance vs. amplitude change as the tip approaches sample surface

In order to realize NC-AFM in an ambient atmosphere, it is critical to maintain the tip-sample distance at a certain constant value and to prevent the tip from contacting the sample surface. Once the tip makes accidental contact with the sample, the tip can stick to the sample surface and stop its vibration due to the meniscus force of the liquid layer on the sample surface.

Figure 5. Amplitude vs. distance plot of a tip oscillating with large free air amplitude

Figure 6. Amplitude vs. distance plot of a tip oscillating with small free air amplitude

Figure 7. Amplitude vs. distance plot under the net attractive force regime



From the amplitude vs. distance plot shown in Figure 5, at large free air amplitudes, the range of the net attractive force regime (yellow) is small in comparison to the movement of the cantilever oscillation. Hence, under such conditions, maintaining the tip in the attractive regime is challenging. With smaller free air amplitudes, less than 4 nm, a larger portion of the curve falls under the attractive interaction regime but it is limited to a very small scan range of 1 nm or so (Figure 6 and 7).

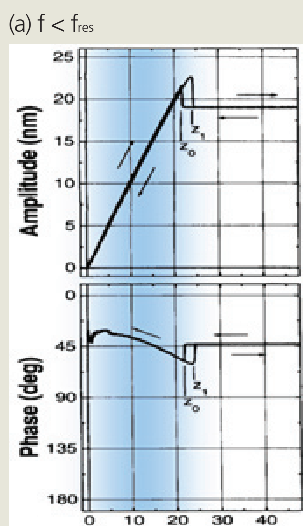
Therefore, a very high performing Z-servo feedback is required for NC-AFM in an ambient atmosphere. The mechanical response of the Z-scanner must be very fast to track the changes due to tip-sample interaction and prevent the tip from contacting the sample surface.

Tapping Imaging

If the Z-servo performance is not sufficiently high, the tip will regularly stick to a sample due to meniscus forces. In such cases, the Z-scanner must pull the cantilever tip away from the sample surface, a process that frequently generates glitches on AFM images. One quick remedy is to increase the tip-sample distance, however this results in a significant loss of lateral resolution. To overcome this loss, Zhong et al.[2] introduced a deliberate 'tapping' mode, in which the tip strikes against the surface and detaches from the sample surface on each oscillation cycle by using a large vibration amplitude (Figure 8). Although tapping may eliminate the lateral frictional force, the tip-sample impact force can be larger than the force in typical contact mode AFM and dull the tips quickly.

Figure 8. Principle of Tapping Imaging

(a) $f < f_{res}$



(b)

"The motivation for this tapping mode AFM is to overcome the difficulty of operating the non-contact mode AFM...
The oscillation amplitude, and therefore, the energy associated with the oscillation, is made to be sufficient to overcome the stickiness of the surface."

Q. Zhong, D. Innis, K., Kjoller, V.B. Elings, Surface Science Letters 290, L688 (1993)

Lacking accurate control to stay in the attractive force regime, due to the slow feedback speed of Z scan actuators, most ambient AFM vendors in the market elect to operate their systems in the repulsive force regime, i.e. tapping mode AFM, allowing the tip to periodically come into contact with sample surface.

Non-Contact Mode AFM

Park Systems' crosstalk eliminated (XE) AFM successfully meets the feedback requirements for True Non-Contact AFM. To improve feedback speed, the XE-series Non-Contact utilizes a stacked piezo actuator rather than a piezoelectric tube scanner whose typical resonant frequency is less than 500 Hz. The patented multiple stacked piezos used in the high force Z scanner have a typical resonant frequency of 10 kHz; this allows extremely precise control as well as fast feedback response to keep a constant tip-sample distance without damaging the tip or sample. In addition, the XE series employs a phase detection feedback instead of amplitude detection feedback utilized in other AC imaging modes. The advantage of phase feedback over amplitude feedback is improved feedback sensitivity. 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/f0.

Figure 9 shows an example in which True Non-Contact AFM of the XE-series successfully traces the steep contour of a polymer sphere that has a diameter of about 6 µm.

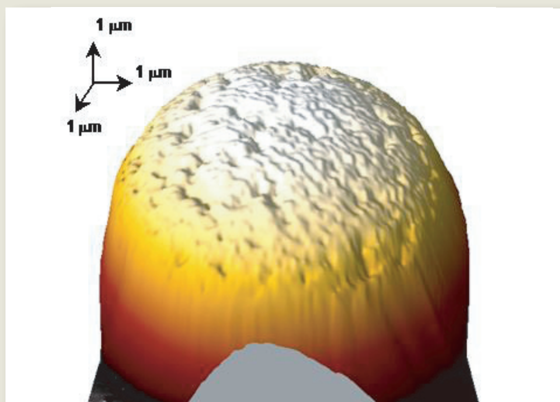


Figure 9. True Non-Contact AFM image of a polymer sphere taken with an XE-100 (6 µm scan size).

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).