## 3- The AFM Cantilever and Tip

Cantilevers and tips are critical components of an AFM system because they determine the ultimate lateral resolution of the system and the force applied to the sample. Integrated tip and cantilever assemblies can be fabricated from silicon or silicon nitride using photolithographic techniques.

### *i- Properties of Cantilevers and Tips*

Atomic force microscopes require not only sharp tips but also cantilevers with "soft" spring constants – lower than the spring constants between atoms in a solid which are on the order of I0 N/m. The spring constant of the cantilever depends on its shape, dimensions and the material from which it is fabricated. As you might think thicker and shorter cantilevers tend to be stiller and have higher resonant frequencies. The spring constants of commercially available cantilevers range over four orders of magnitude from thousandths of a Newton per meter to tens of Newton per meter. Resonant frequencies range from a few kilohertz to hundreds of kilohertz providing high speed response and allowing for non-contact AFM operation.

### *ii- Selecting an Appropriate Cantilever*

The desirable properties for a cantilever depend on the imaging mode and the application. In contact mode soft cantilevers are preferable because they deflect without deforming the surface of the sample. In non-contact mode, still cantilevers with high resonant frequencies give optimal results.

***iii- Tip Shape and Resolution***

The lateral resolution of an AFM image is determined by two factors: the step size of the image (Figure 1) and the minimum radius of the tip.

The sharpest tips available commercially are specified with a minimum radius of about 50 Å. Because the interaction area between tip and sample is a fraction of the tip radius, these tips typically provide a lateral resolution of 10 to 20 Å.

In the microscopy community, two asperities (peaks) are considered resolved if the image satisfies Rayleigh´s criterion. In this application Rayleigh´s criterion requires that the height of the image must dip at least 19% between the asperities (Figure 7). To determine the lateral resolution of an SPM experimentally, we would bring the asperities closer and closer together until the image no longer dips by 19% between peaks. The minimum separation between resolved asperities determines the best lateral resolution of the system. Using this definition, the lateral resolution of an AFM with the sharpest tips commercially available is 10 to 20 Å.

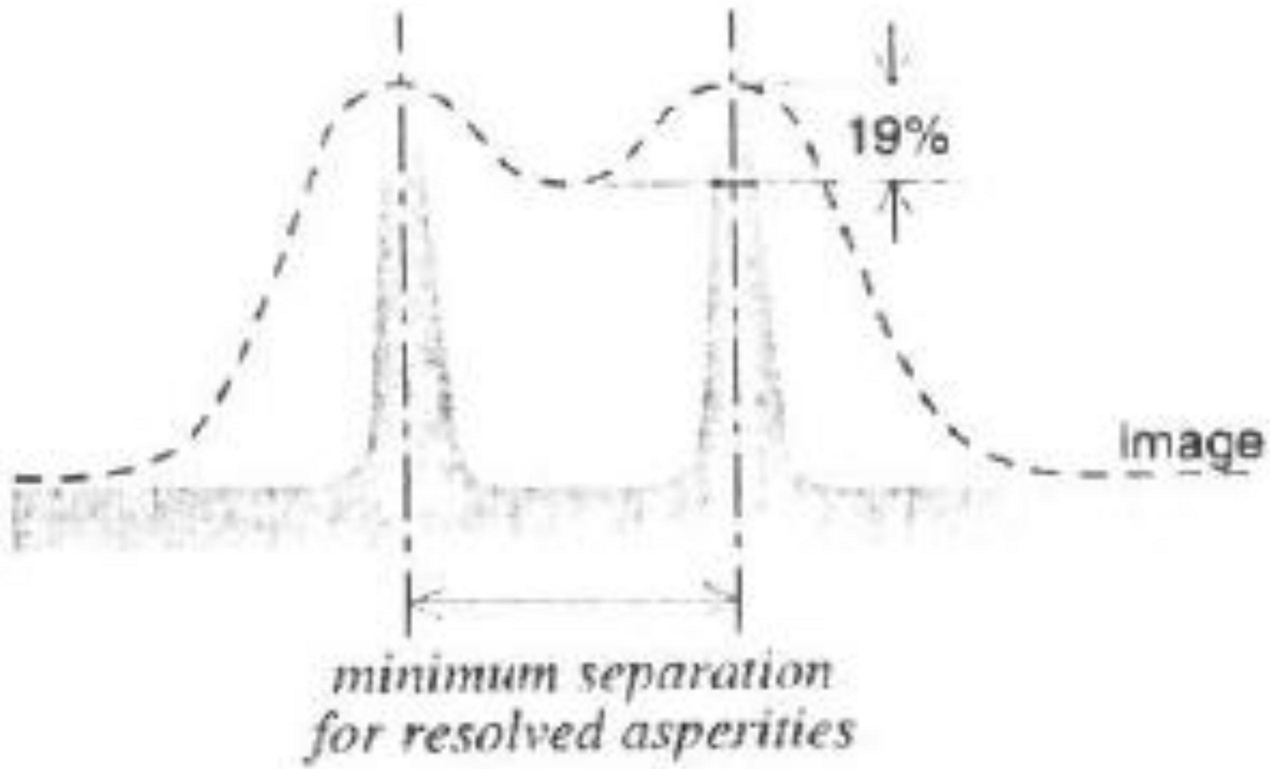



Figure 7- Definition of lateral resolution using Rayleigh's criterion. In this example the two asperities are resolved because the height profile dips 19% between the peaks.

At first glance, the figure of 10 to 20 Å resolution seems to conflict with the ubiquitous images of atomic lattices in AF M brochures. The distinction between imaging atomic-scale features with accurate lattice spacing and symmetry and true atomic resolution bears some comment.

In an AFM the dependence of cantilever deflection on tip-to-sample separation is weaker. The result is that several atoms on the tip interact simultaneously with several atoms on the sample (Figure 8).

In an AFM each atom from the tip that participates in the imaging (each shaded atom in Figure 8) "sees" the sample as a periodic lattice. But because the atoms of the tip are in different lateral positions the lattice that each atom sees is shifted from the lattice seen by its neighbors (Figure 9). Each atom in the tip is also at a different height with respect to the sample. The strength of the signal seen by each lip atom weakens with its distance from the sample. When the contributions from all of the participating atoms in the tip arc combined at each snapshot in time and the result is summed over time as the tip is scanned across the periodic surface, the final image is periodic with the correct symmetry and spacings. However, if one atom were missing the hole left behind would not be detected because the image represents a superposition of many images.

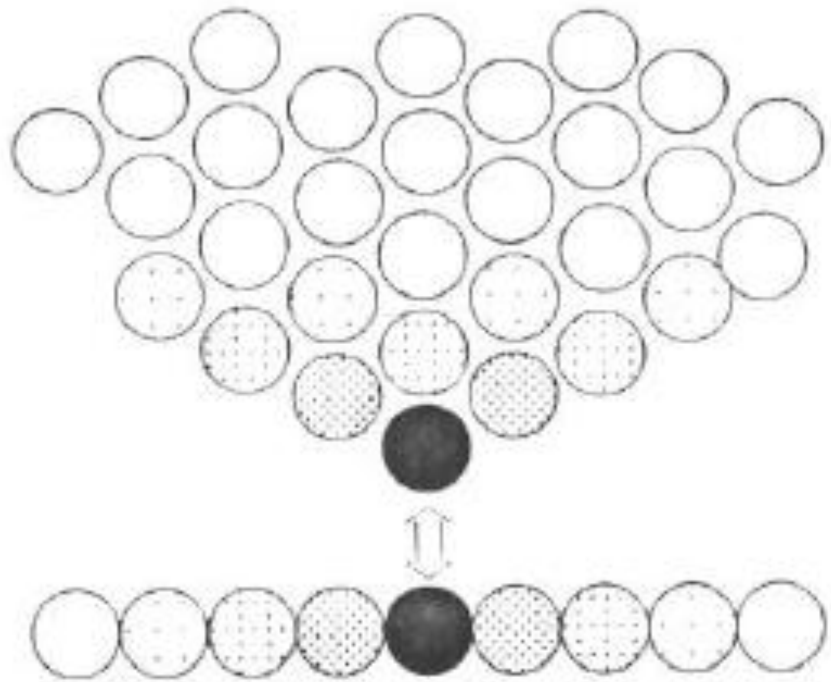
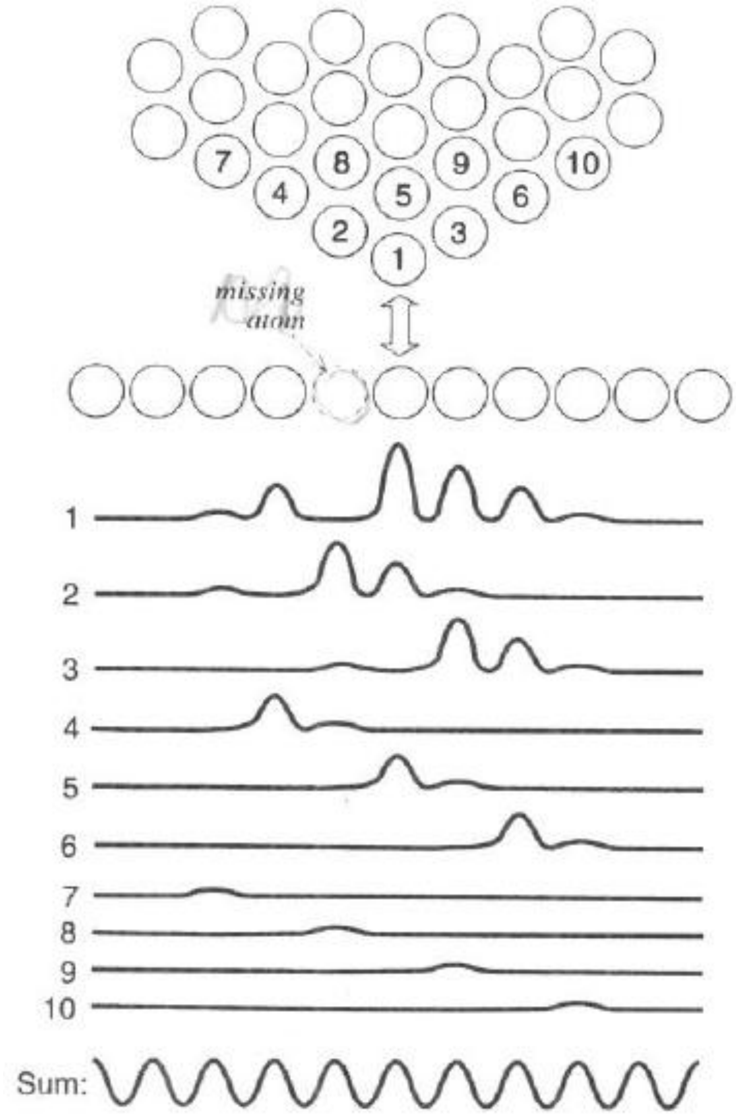


Figure 8- Interatomic interaction in AFM. For AFM, the interaction has weaker distance dependence, so more atoms in the tip and sample are involved. Shading denotes interaction strength.

Figure 9- AFM imaging of an atomic-scale periodic lattice. The profiles below the schematic are numbered to correspond to the image from the associated tip atom, as the sample scans under the tip. The profile labeled sum obtains by summing the contributions from each atom at each instant in time and also summing over time as the sample is scanned under the tip.



## 4- Common Artifacts

### *i- Tip Convolution*

Most imaging artifacts in SPM arise from a phenomenon knows as tip convolution or tip imaging. Every data point in an image represents a spatial convolution (in the general sense, not in sense of Fourier analysis) of the shape of the tip and the shape of the feature imaged. As long as the tip is much sharper than the feature, the true edge profile of the feature is represented. However, when the feature is sharper than the tip, the image will be dominated by the shape of the tip. Figure 10 demonstrates the origin of tip convolution.

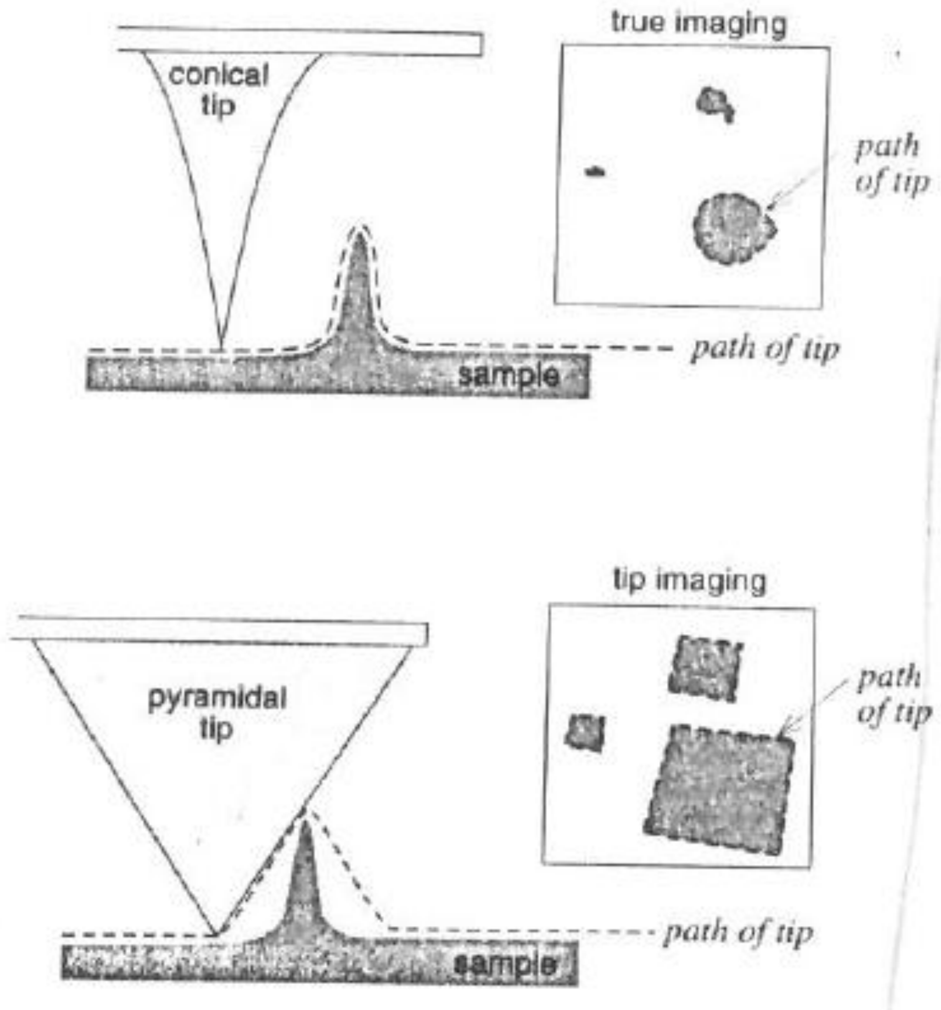



Figure 10- Comparison between true images of feature: imaged by sharp conical tip and tip-dominated image, generated by square-pyramidal tip. Insets show top-down view of 3D SPM image, imaged true and imaged with large, square-pyramidal tip.

***ii- Feedback Artifacts***

If the feedback loop of the SPM is not optimized the SPM image can be affected. When feedback gains are too high the system can oscillate, generating high frequency periodic noise in the image. This may occur throughout the image or be localized to features with steep slopes.

On the other hand when feedback gains are too low the tip cannot track the surface well. In the extreme case, the image will be losing detail, appearing smooth or "fuzzy". A less obvious effect is "ghosting". On sharp slopes, overshoot can appear in the image as the tip travels up the slope, and an undershoot can appear as the tip travels down the slope. This feedback artifact commonly appears on steep features represented as bright ridges on the uphill side and/or dark shadows on the downhill side of the feature.

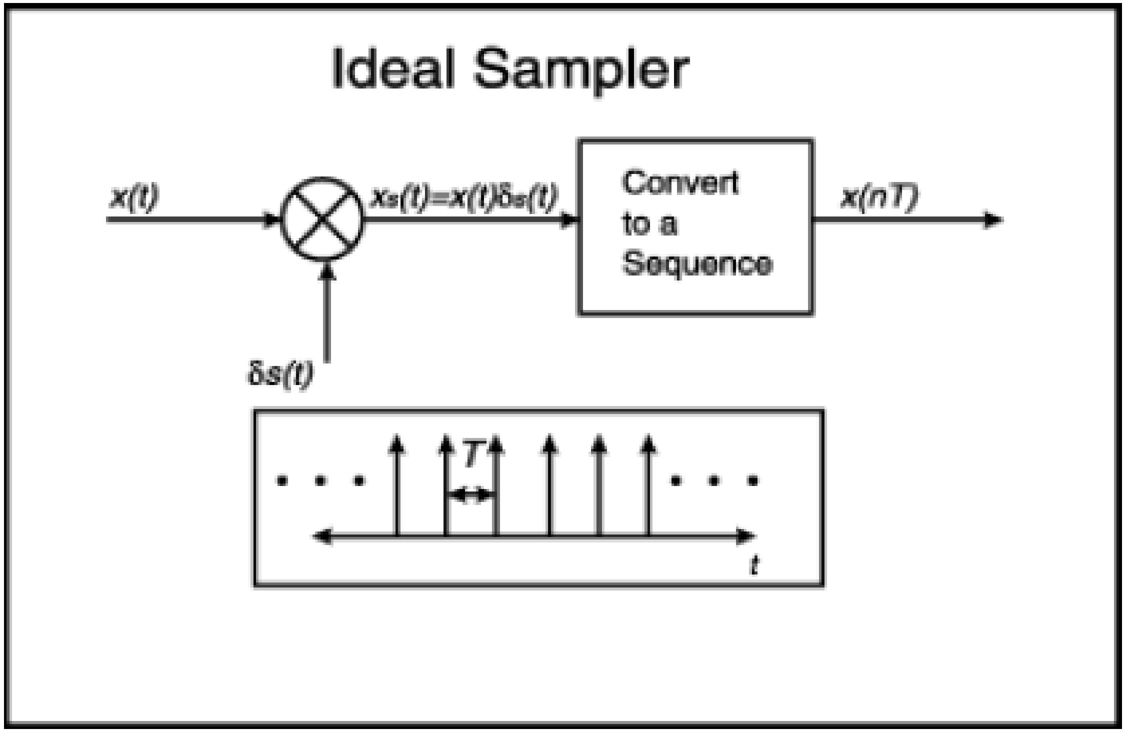



Figure 1- The ideal sampler is a conceptual tool for establishing a link between the continuous-time Fourier Transform (FT) and the Discrete Fourier Transform (DFT). The input to the ideal sampler is *x(t)* and the output consists of the sample values *x(nT).* The "analog" sampled signal, $x_S(t)$, and its FT, $X_S(f)$ are shown in Figure 2.

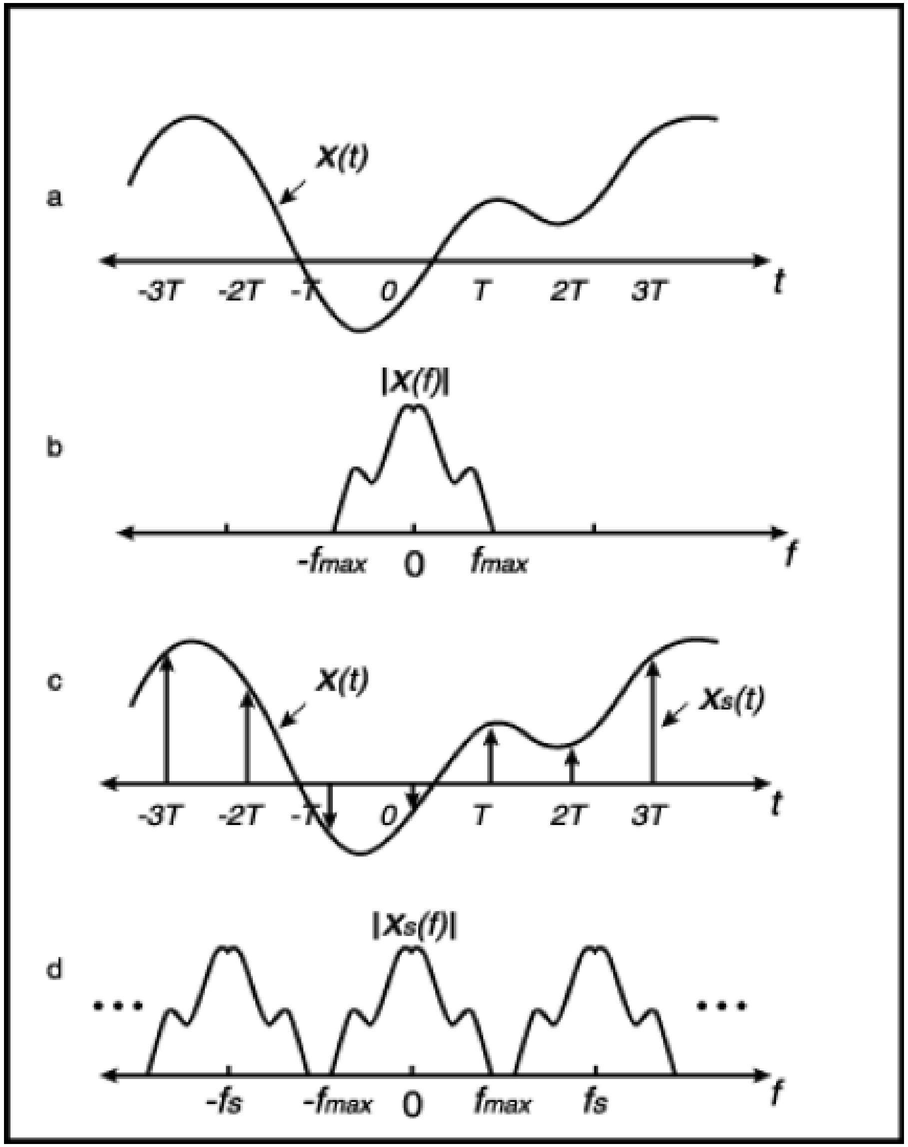



Figure 2-

a) The original continuous-time signal, x(t).

b) The FT of *x(t).*

c) The signal $x_S$(t) (See Fig. 1). This "conceptual" signal consists of an impulse train with each impulse weighted by x(nT) and spaced T seconds apart. Since $x_S$(t) is technically a continuous-time signal, it has a FT $X_S(f)$, (in part d).

d) The FT of $x_S$(t) provides an important conceptual link between the Fourier Transform of the signal of interest x(t) and the DFT of the sampled signal x(nT). Notice that $X_S(f)$ is formed by first multiplying X(*f*) by a constant value 1/T and then replicating X(*f*)/T at intervals spaced $f_S$=1/T apart ($f_S$ is the effective sampling rate). If the sampling rate is not sufficiently large, then $f_S$ will not be large enough to insure that the replicas of X(*f*)/T do not overlap. Aliasing occurs when the replicas of X(*f*)/T overlap.