How to Evaluate an AFM

What is a Good AFM?

When it comes time to purchase an AFM, there are many features that may be important based on the final system application. These features will create a long list of questions that will be unique to the user when they proceed to evaluate an AFM system. Questions that may be important to individual users include: Is the system designed for industrial or research applications? Is the system going to be installed in a multi-user facility? Will the system support all of the available options that I require? Is the system easy to use for low-level users? Is the AFM flexible for high-end users? These and many other questions are common when a customer first begins to gather information about available AFM systems.

Once these questions have been answered, and a list of viable systems has been compiled, the user needs to make a fundamental comparison of the systems that best meet their overall requirements. With this goal in mind, Park Systems has compiled what we believe to be a comprehensive overview of "What is a Good AFM"

The Basics

Historically, while AFMs have proven to be a reliable instrument for determining relative sample dimensions, they have struggled to provide accurate absolute dimensions of surface features. As the dimensions found in research and industrial applications become smaller and smaller, it is now more important than ever for AFMs to measure the absolute dimensions of surface features with accuracy and repeatability,.

For taking nanoscale measurements, the accuracy and reliability of measurements and the flexibility of available modes and options are just as important as resolution. When it comes time to purchase or upgrade an AFM, regardless of your diverse application needs, AFM performance will be influenced by the. seven attributes listed and described below,:

- Noise Floor
- XY Scan Flatness
- XY Scan Linearity
- Tip Life
- Thermal Drift
- Available SPM Modes
- Option Compatibility

Noise Floor

Even the smallest environmental vibrations can add noise to AFM results, making it a challenge to image the smallest details and characterize the flattest surfaces. To measure the baseline noise, or noise floor, the user brings the cantilever to the sample surface and obtains the system response to a "zero scan" (See Figure 1). A good AFM should be isolated from vibrations to achieve a noise floor below 0.5Å

- 0 x 0 nm scan, staying in one point
- 0.5 gain, in contact mode
- 256 x 256 pixels

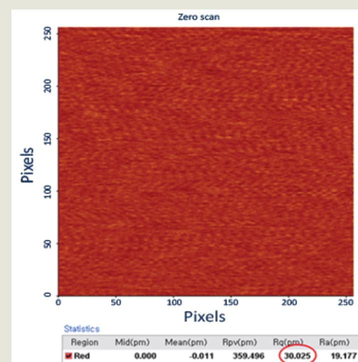


Figure 1. The noise floor is measured by taking a "zero scan," in which the tip is brought to the sample surface, and a 0 x 0 nm, 256 x 256 pixel scan with 0.5 gain is performed. The signal for this scan of just one point corresponds to the noise floor of the instrument.

XY Scan Flatness

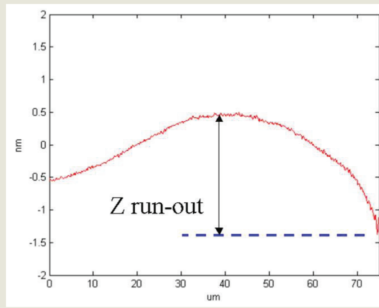


Figure 2. The Z run-out, or out-of-plane motion, is the peak to valley height of scan profiles without any software correction except for the sample tilt correction (no higher than 1st order plane fitting). The sample can either be an optical flat (reference mirror) or a flat portion on an AFM calibration standard.

The AFM scanner is the most important component of any AFM, as the scanner performance determines the accuracy of the imaging results an AFM can provide. Therefore, it is very important to evaluate the presence and amount of any scanner artifacts, such as high-order and non-linear background motions, to avoid distorting the resulting AFM image (see Figure 2).

Hence, a customer must look for a scanner design which minimizes out-of-plane motion when imaging a flat surface. A good AFM scanner must keep the Z out-of plane motion within a few nanometers over the entire scan range, independent of scan rate (see Figure 3), scan size, and scanner offset (see Figure 4).

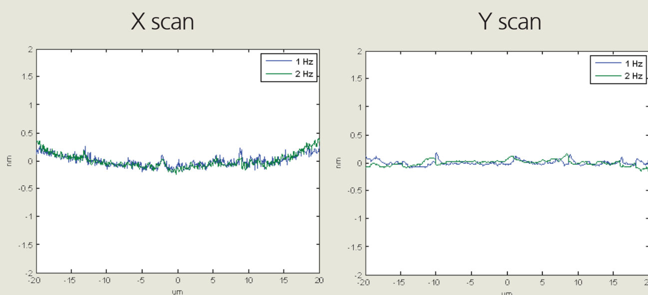


Figure 3. Typical out of plane motion of a good AFM has less than +/- 2nm over the entire 100μm scan area, having repeatability < 0.5 nm at scan rates 0.5, 1, and 2 Hz. The repeatability is defined as the maximum variation between the averaged profiles of two or more scans. The tests can be done in both fast scan directions of X and Y.

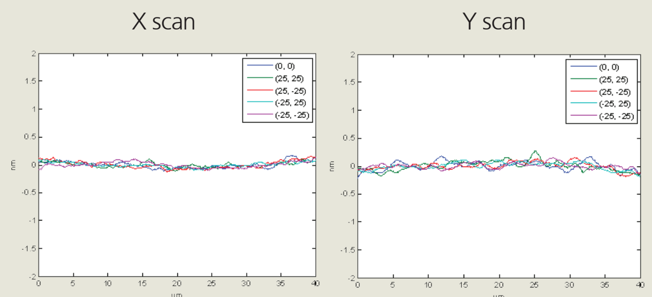


Figure 4. Typical out of plane motion of a good AFM has less than +/- 2nm over 40μm scan range, having repeatability < 0.5 nm with XY offsets of (0, 0), (25μm, 25μm), (25μm, -25μm), (-25μm, 25μm) and (-25μm, -25μm). The repeatability is defined as the maximum variation between the averaged profiles of two or more scans. The tests can be done in both fast scan directions of X and Y.

XY Scan Linearity

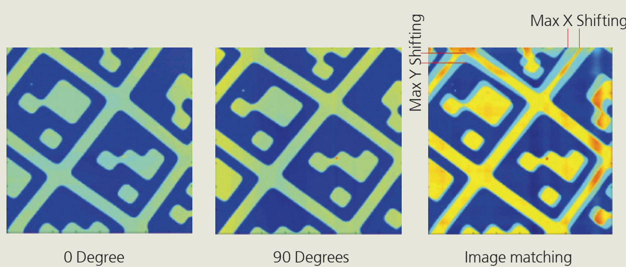
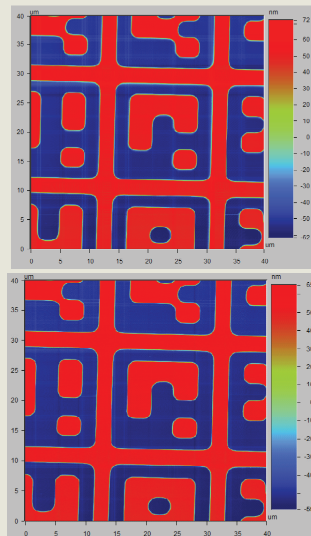


Figure 5. The X-Y linearity is evaluated by matching two orthogonal scans after changing the direction of the fast scan axis. A test can be performed on a 40μm x 40μm size site at a random offset coordinate.

Figure 6. A good AFM should show no visible mismatch in the two orthogonal scans, demonstrating the excellent XY scan linearity.

The XY scan linearity is another important feature of any AFM that determines the accuracy of the imaging results an AFM can provide. If the X and Y scan movements are coupled, as in a tube scanner, an extension in the X direction will directly influence the scanner's Y position. The XY scan linearity is measured using two orthogonal scans and subsequent image matching as shown in Figure 5. The amount of mismatch in two images taken by the scanner will reveal how linear its X and Y scan movements are.

Hence, a customer must look for a scanner design which maximizes the XY scan linearity. A good AFM scanner must keep the XY scan linearity less than 0.05% at a random coordinate (see Figure 6), independent of scan rate (see Figure 7) , scan size, and scanner offset (see Figure 8).



1 Hz

2 Hz

Figure 7. A good AFM should show no visible mismatch in the two orthogonal scans, demonstrating the excellent XY scan linearity, at different scan rates of 1 and 2 Hz.

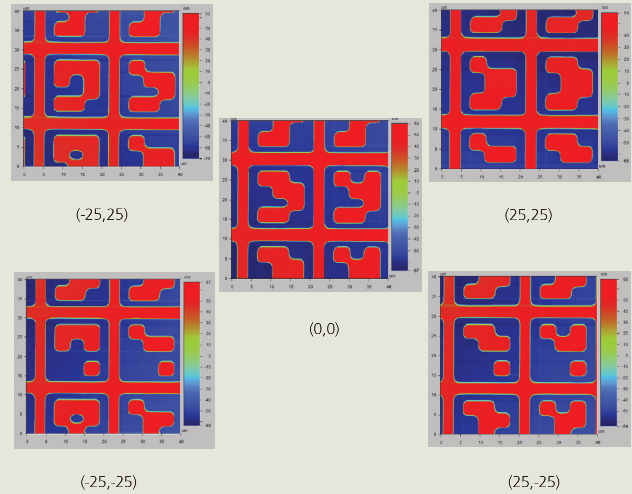


Figure 8. A good AFM should show no visible mismatch in the two orthogonal scans, demonstrating the excellent XY scan linearity with XY offsets of (0, 0), (25µm, 25µm), (25µm, -25µm), (-25µm, 25µm) and (-25µm, -25µm)

Tip Life

Tip life is an important factor in getting high-quality images with consistency and reliability. When the tip touches the sample and becomes blunt, it limits the resolution of the AFM and reduces the quality of the image. For softer samples, tip-surface contact damages the sample as well as the tip, compounding the inaccuracies of sample height measurements. Consequently, preserving tip integrity enables consistent high-resolution and accurate data.

A good way to test the tip life of an AFM system is by imaging CrN, which has sharp and pointy features on a very hard surface. If a tip becomes blunt or damaged, it can no longer reach the bottom of the features, and the images become blurred..With a good AFM, the sharpness of the tip can be preserved even after 100 image scans of the CrN sample as shown in Figure 9, while maintaining the same sample surface roughness (see Figure 10).

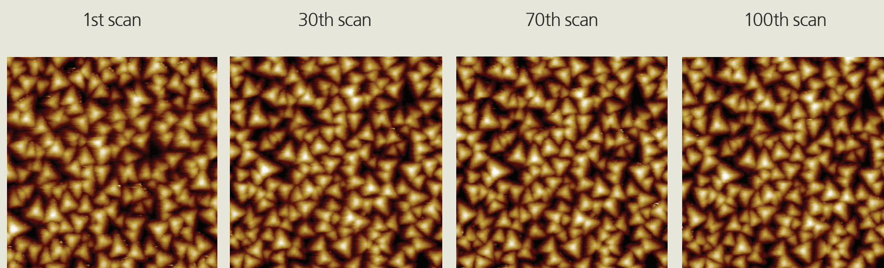


Figure 9. One can easily perform tip wearing experiment with CrN sample, so called Tip Checker. With a good AFM, the sharpness of the tip is preserved even after 100 scans. If tip life is not long enough, one can see blurred images without sharp triangular features which are consequences of worn and damaged tips.

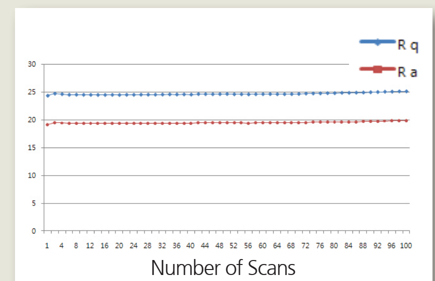


Figure 10. With a good AFM, the sharpness of the tip is preserved, and the sample surface roughness value remains the same.

Thermal Drift

An AFM tip may experience undesired motion due to the thermal expansion or contraction of mechanical parts within the instrument. This undesired motion, called thermal drift, must be minimized to accurately image samples smaller than 1 µm. The drift rates in the X and Y directions are determined by marking the locations of characteristic structures on the sample surface and measuring deviations from these points after several scans. A good AFM has a drift rate smaller than 1.5 nm/minute/℃.

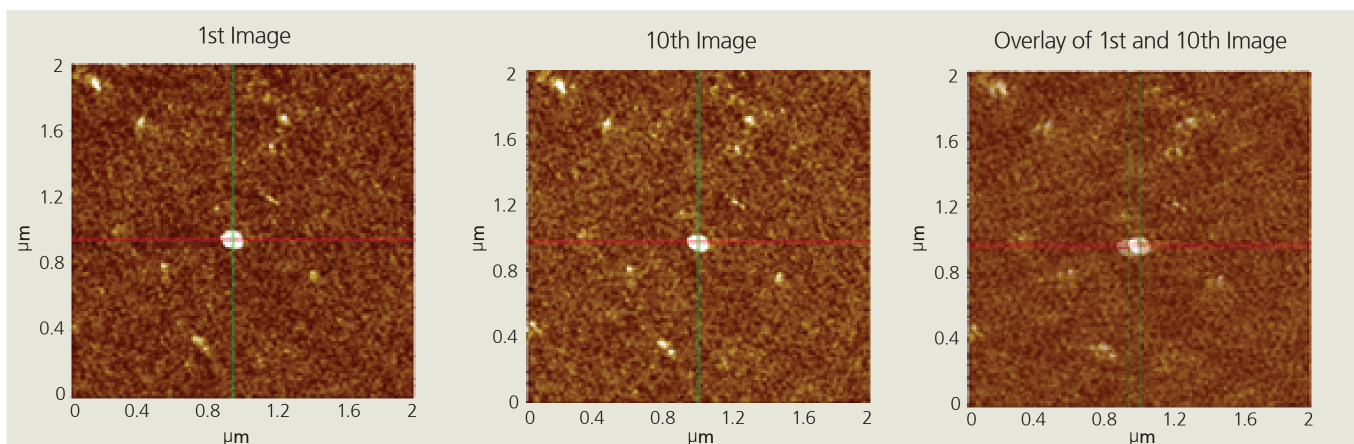


Figure 11. In this XE-100 example, a small nanoparticle on a Si wafer is used as a reference point during sequential scans at 2 x 2 um, 256 x 256 pixels, with a 1 Hz scan rate. The scans were taken after a fresh new sample and a new cantilever were loaded to the XE-100, without any system warm-up prior to the scans. The measured X drift rate was 0.738 nm/min and the Y drift rate was 0.523 nm/min

Available SPM Modes

Since its inception in the 1980s, the AFM has evolved into one of the most powerful tools for nanoscale measurement. Today's users utilize AFM as a functional tool to characterize a wide range of physical properties. The different SPM modes allow AFM users to obtain the physical information. The choice of the appropriate SPM mode depends on the specific sample and application of a customer.

Hence, a customer must look for the list of available SPM modes offered by an AFM. A good AFM must provide the complete range of the SPM modes for the measurement of different sample properties. Of particular importance are the SPM modes of the following properties:

- Standard imaging
- Chemical properties
- Dielectric/piezoelectric properties
- Force measurement
- Electrical properties
- In-liquid imaging
- Magnetic properties
- Mechanical properties
- Optical properties
- Thermal properties

Option Compatibility

The AFM can be operated in many ways, and different techniques provide a variety of capabilities for imaging samples under varying conditions and generating a wide range of information. There is a continuum of possible imaging techniques, due to differing sample environments, as well as the detection scheme used.

Hence, a customer must look if the particular option of a customer's requirement is compatible with an AFM. A good AFM must provide a wide range of option compatibility in order to facilitate the diversifying measurement conditions and sample environments. Of particular importance are,

- SLD (Super Luminescence Diode) light source for low coherence
- Z scanner with scan range of 25 microns
- Heating & cooling sample stage
- Liquid cells
- Live cell chamber
- Motorized XY sample stage
- Signal access module
- Step and scan function for automatic sequential imaging
- Tunable magnetic field generator