Easy AFM: Atomic Force Microscopy made simple.

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INTRODUCTION

Designed with the infrequent or novice user in mind, Easy AFM® provides a single interface that presents the user with all of the inputs required to obtain high quality Tapping Mode® images on a majority of samples in air.

Designed using LabVIEW® and implemented as a stand-alone executable, Easy AFM® utilizes the open architecture of NanoScope 7.0 software and is implemented as a stand-alone executable. This latest version of the NanoScope software is available with the NanoScope V controller.

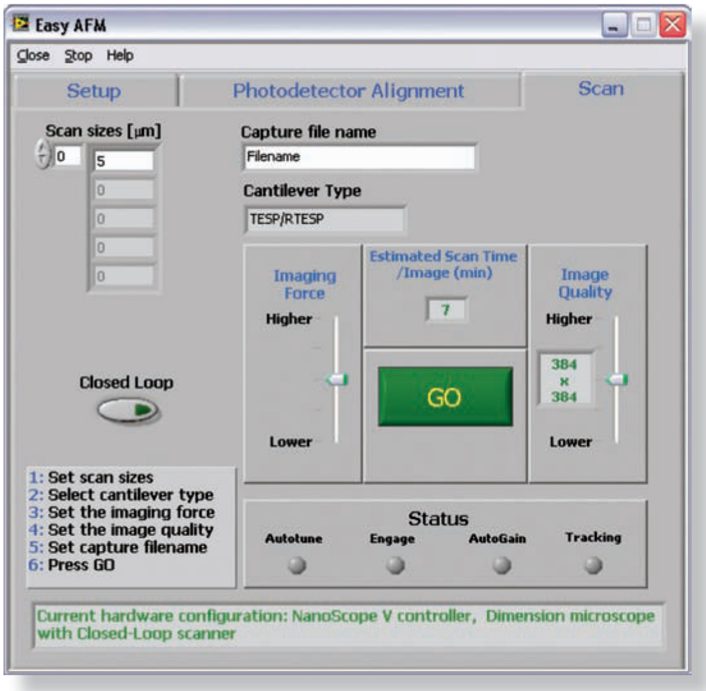

Figure 1. Easy AFM® - A simple one button interface for the MultiMode® V and Dimension® V series of AFMs.

ANIMATED GUIDES

Two of the hardest things for new users to become familiar with is the process of mounting cantilevers and the alignment of the laser used for feedback detection. More than just an automated algorithm interface, Easy AFM guides the user through the basics of changing the cantilever and aligning the laser using a series of hardware specific pages. As shown in figure 1, the instructions are arranged in a logically ordered row of tabs along the top of the interface, and lead the user through the entire imaging process. Individual guides are selected from the setup panel. The user is presented with an embedded document that describes in detail the process required to complete the selected operation, (see figure 2).

New or infrequent users are encouraged to follow the outlined steps, while, more advanced users can proceed directly to the scan tab.

Although the guides themselves may be skipped by more experienced users, the algorithm ensures the system is set up correctly before allowing the AFM to engage.

For the Dimension V series of microscopes, an additional guide has been added to aid in the alignment of the laser onto the center of the photodetector. With both visual and audio feedback, this results in a faster and more intuitive alignment procedure for new users.

SCANNING

With the cantilever mounted and the laser alignment optimized, the system is ready to begin imaging. Minimum user input is required prior to engaging, and in most cases the default parameters can be used. The parameters available to the user at this stage include:

1) Scan Size
Scan size(s) can be entered to allow the AFM to collect either single or multiple images from the same sample.

2) Cantilever Type
Select the cantilever type in order to restrict the frequency range used during the autotune process. This significantly speeds up the search for the cantilever's resonant frequency.

3) Imaging Force
The imaging force is controlled by both the cantilever oscillation amplitude and the amount by which that amplitude is reduced once the tip is on the surface.

4) Image Quality
The image quality is given by the number of lines and the number of samples per line in the final image. Throughout the Easy AFM imaging process, square pixels are maintained regardless of the quality setting. This square-pixel setting ensures a more consistent off-line image analysis.

Once these parameters have been set, the system is ready to image. The imaging process is initiated by simply clicking on the green GO button (see figure 1).

Once the imaging process is started, the system will tune the cantilever, engage on the sample and optimize the scan parameters with no further user input required.

IMAGE OPTIMIZATION

Easy AFM® starts with a set of default engage parameters that are calculated from the imaging force and cantilever-type user inputs. Default engage parameters are designed to allow the system to engage successfully for the vast majority of samples. Once engaged on the surface with a zero scan size, the system will proceed to increase the scan size while optimizing the scan parameters to ones more appropriate to the topography of the sample being imaged. This is done in several stages.

The RMS amplitude of the cantilever at zero scan size as a function of the feedback gains is an indicator of the noise on the system and is cantilever specific. Hence, continuously monitoring the RMS amplitude of the cantilever as the feedback gains are increased will help determine the gain levels required for the chosen cantilever type. Once the RMS amplitude reaches a predetermined limit, the system is switched to image mode at 105% of the requested scan size. The software now obtains a low-resolution topography image at this scan size in order to determine the height variation of the sample.

From the initial survey scan, imaging parameters are calculated using the measured height variation. These parameters are subsequently used for the final high-resolution scan. The derived scan parameters are functions of the measured sample roughness, imaging force selected by the user, and scan size.

The variables are set using the following algorithms:

• **Scan rate (Hz)**
The scan rate is initially set based on the sample roughness with an additional factor to account for the scan size and imaging force.

The scan size correction factor reduces the scan rate as the scan size increases in order to limit the tip velocity relative to the sample. This ensures that the tip will track surface topography regardless of scan size.

The correction is only applied for scan sizes above 1µm. For scan sizes of 1µm or less, the correction factor is set to 1.0, and hence, from equation 1, as the sample roughness tends to zero the maximum scan rate tends to 2.65Hz (see equation 1).

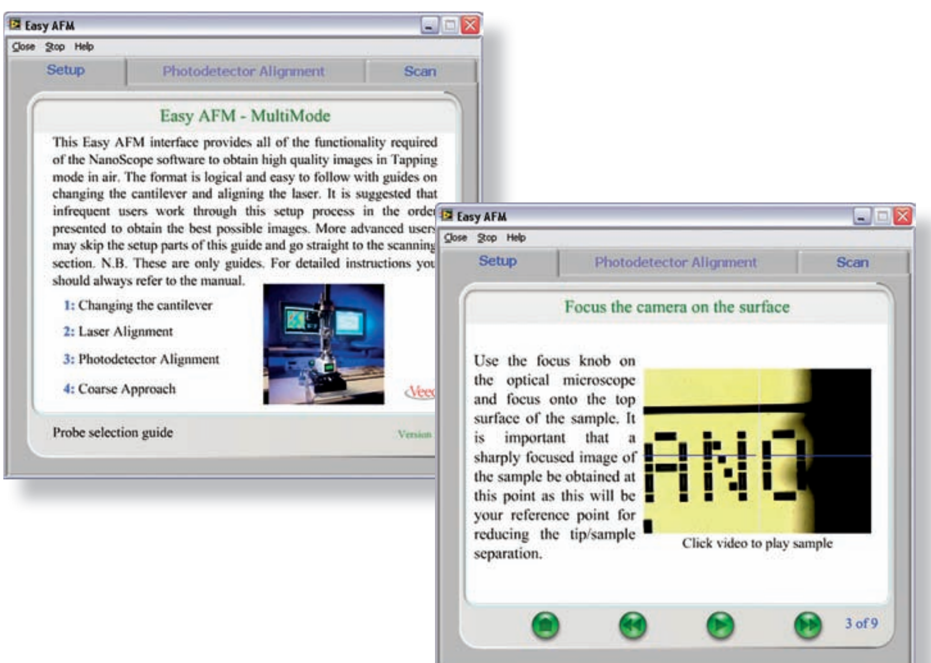

Figure 2. Animated guides help the new user with fundamental tasks such as changing the cantilever and aligning the laser.

• Set-point reduction
The amplitude set-point is reduced, which creates a higher tip/sample force and enables the feedback loop to better track the sample topography. The set-point reduction factor is further modified to ensure that set-point reduction is scaled appropriately when imaging samples with light forces. The set-point reduction factor is calculated by equation 2.

• Gain scalar
The initial feedback gains set to capture the initial low-resolution scan are modified based on the measured roughness of the sample. Samples with little topography require lower gains for the feedback loop to track the surface, whereas samples with rougher surfaces require a higher feedback gain at the same scan rate.

The corrections given by these equations allow the feedback loop to better follow the surface topography for a sample with a given roughness.

Finally the Z-limit is reduced to a value appropriate for the measured roughness in order to maximize the resolution in this axis.

With the calculated scan parameters for the final high-resolution image set, the system will attempt to optimize them further in order to ensure the highest possible image quality. Optimization of the scan parameters for the final image is measured by the ability of the tip to correctly track the surface topography using both trace and retrace data. Variations in measured trace versus retrace data will cause the system to take the following actions:

• Increase the tapping force
The amplitude set-point is reduced to 90% resulting in an increase in the tip/sample interaction force. Increased tip/sample forces generally allow the system to track surface topography better.

• Increase the feedback gains
The integral and proportional gains are increased by a factor of 1.2 and 1.4 respectively, which increases the ability of the AFM to track topography.

$$\text{Scan Rate} = 2.65\ \exp^{-6\text{x}10^{-4}\,(\text{rms amplitude})} \ \text{x} \left(\frac{4}{\sqrt{\text{scan size } (\mu\text{m})}}\right) \qquad \text{(equation 1)}$$

$$\text{Reduction Factor} = \frac{1}{\exp^{-6\text{x}10^{5}\,(\text{rms amplitude})} \ \text{x} \left(\frac{1}{\text{Setpoint Delta}}\right)} \qquad \text{(equation 2)}$$

$$\text{Gain Scalar} = [0.35\ 1\text{n}\ (\text{rms amplitude})] - 1 \qquad \text{(equation 3)}$$

Equations used to calculate image parameters are based on the measured sample roughness.

• Reduce the scan rate
The scan rate is reduced to 90% enabling the system to better track the topography with the existing tapping force and gain settings.

• Increase the drive amplitude
The drive amplitude is increased by a factor of 1.15. This has the effect of increasing the tapping force while preventing the set-point from becoming too low when imaging with light tapping forces and low drive amplitudes.

Between each of these four adjustments, tracking is remeasured. Hence, only those actions necessary for good image quality are carried out. Once the scanning parameters are finalized the scan is started from the top of the frame and the system is set to capture the resultant data.

OPTIMIZED DATA

Once the optimization process has determined the final scan parameters, the AFM will capture the resultant image. Following capture, the "Tracking Factor" is measured and compared to that recorded before the image was acquired. The first value is taken at the top of the image, while the second is measured at the bottom. If tracking in both of these regions was not optimum then a warning is shown allowing the user to decide whether or not to rescan the sample.

For the majority of samples imaged with Tapping Mode® in air, the resulting data will be in the form of high quality images. These images will contain both height and amplitude data and may be processed in the usual way using NanoScope's off-line functionality.

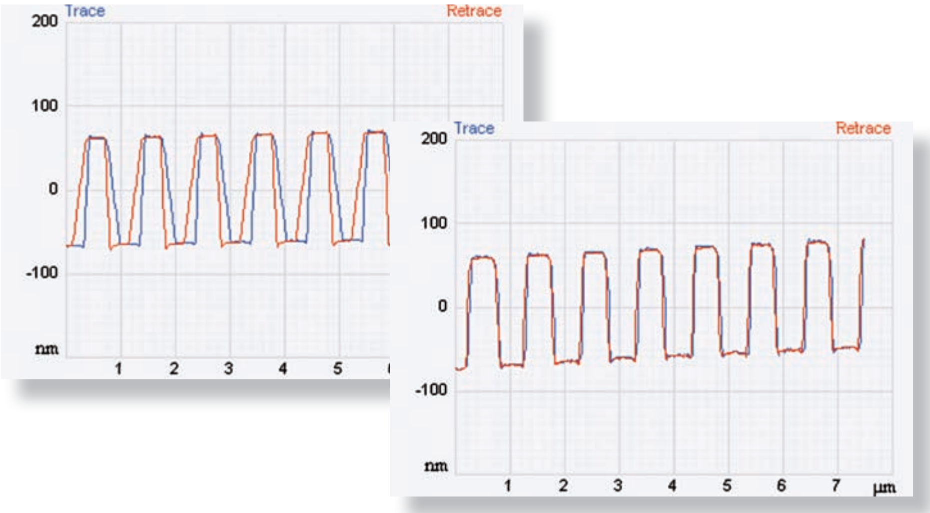

Figure 3. Data before (left) and after (right) the optimization process shows an improvement in the ability to track surface topography.

Figure 4 shows data from three samples.

The first is a 1µm calibration standard imaged at a 7.5µm scan size. The image shows good tracking with sharp edge transitions. Though the calibration standard is a common sample found on every system, it is nevertheless a challenge to image correctly because of its 200nm vertical side walls.

The second sample is a collagen sample imaged in air at a 3µm scan size. The well characterised 67nm banding is observed clearly. These features are generally indicative of good tip/sample tracking.

The final sample data presented is an 18µm scan of a CD stamper. Like the calibration grid, the CD stamper is made up of a flat substrate with near vertical bumps almost 125nm tall.

Overall, the Easy AFM interface can enable inexperienced users of both the MultiMode and Dimension series AFMs to obtain high-quality images, in Tapping Mode, in air.

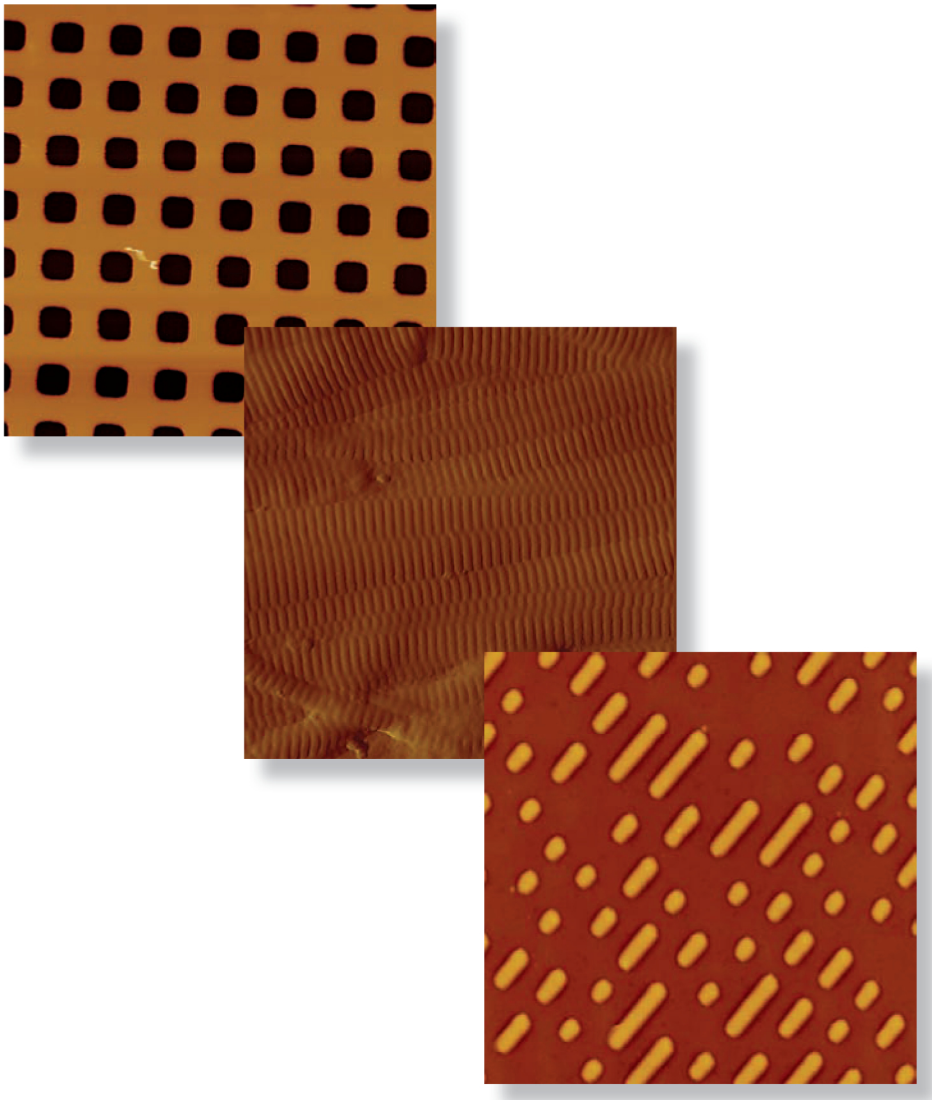

Figure 4. Final image data from the calibration standard, top, shows good surface tracking with a 7.5µm scan. Height data from a 3µm scan of collagen (centre) and a 18mm scan of a CD stamper (bottom) collected with Easy AFM®.