

## **Delta height Information for Asylum Research MFP-3D AFM**

### First and second pass

Higher mode imaging, such as MFM, EFM and SKPFM, are usually a two pass scanning technique. The first pass is scanned in AC mode, with feedback on the amplitude of the lever-oscillation controlling the Z-position of the tip to measure surface topography. The tip is kept close to the sample, so that the tip-sample interaction is dominated by short-range interactions. The second pass usually retraces over the same path as the first pass. The topography signal from the first pass is used to control the Z-position, keeping the tip at a fixed height away from the surface. Here, tip-sample interaction is dominated by long-range forces, such as those arising from the electric or magnetic field of the sample. Simply, in the second pass, the topography measured on the first pass is traced, plus or minus some offset (the delta height) whilst monitoring the phase at a frequency near the free cantilever resonance. Changes in the phase give an indication of how far the resonance has shifted, which is directly related to the net force acting on the probe.

### Delta height values

A zero delta height means that the tip traces exactly the path it moved through on the first pass. A positive delta height means the tip is moved further away from the surface; a negative delta height pushes the tip closer towards the surface. In AC mode, the lever is oscillating, so the tip-sample distance changes all the time. It's useful to consider the 'mean height', or time-averaged height, of the tip above the surface, and the 'amplitude' of the lever. First of all, we need to know how we get from an 'Amplitude' signal in volts to cantilever amplitude in nm.

### Optical lever sensitivity

The 'Amplitude' signal in the sum and deflection meter corresponds directly to the cantilever amplitude in terms of distance - i.e. how far the lever moves up and down. The two quantities are related by the Optical Lever Sensitivity (OLS) or, by convention, the reciprocal of this value, called the 'Inverse Optical Lever Sensitivity', or InvOLS. The lever bends slightly differently under static load compared to how it bends dynamically when it is shaken, so there are two types of InvOLS commonly used - the 'DC', 'static' or 'Deflection' ('Defl') InvOLS, and the 'AC', 'dynamic' or 'Amplitude' ('Amp') InvOLS. In EFM, MFM and SKPFM, we're interested in the amplitude of the cantilever motion, so the AC InvOLS is used.

The AC InvOLS varies from lever to lever, and system to system, and is dependent on the alignment of the laser. It's possible to calibrate the AC InvOLS quite straightforwardly, but this is not always necessary when you only need a rough idea of the lever's real amplitude: for a given lever type and a particular AFM system, if the laser is generally aligned in roughly the same way, the InvOLS will be roughly the same - enough for us to get some idea of the amplitude of lever motion.

For many standard silicon and silicon nitride cantilevers the AC InvOLS is roughly 50 nm/V. Furthermore, I can say that if I see an amplitude of 1V at the sum and deflection meter (after tuning the cantilever), then the lever is moving with an oscillation amplitude of around 50 nm. In air, the motion is close to sinusoidal, so it follows the equation  $x = A \sin(2 * \pi * f * t)$ , where A is the oscillation amplitude, f is the frequency and t is time. The sin function sweeps from -1 to +1, so the peak-to-peak motion of the tip is 2 \* A, or 2 \* (Amplitude signal in volts) \* AC InvOLS.

### Minimum delta height

If I engage the lever on the surface using a set point of, say, 600 mV, I know that the feedback loop is controlling the tip-sample distance so that the lever amplitude is  $0.6V * 50 \text{ nm/V}$ , or 30 nm. To a first approximation, we can assume that the probe tip just makes contact with the surface at the bottom of its motion, and that the cantilever motion is symmetric: i.e. that the lever bends down towards the surface as much as it bends up away from it, so its time-averaged position is half-way between these two extremes. As long as the feedback tracks the surface accurately, we can then say that, during the first pass, the \*mean height\* of the end of the tip above the surface is roughly the half peak-to-peak lever oscillation, which is given by AC InvOLS \* set point.

To determine how much we have to lift the tip to clear the surface in the second pass, we need to know the free-amplitude of the lever during that pass - that is the amplitude of the lever in free space, with no sample surface to impede its motion. The free amplitude can be determined by setting the drive amplitude and drive frequency to the values used in the second pass, and observing the Amplitude signal; multiplying this voltage by the AC InvOLS gives the free amplitude of the lever's motion in nm.

If the mean height of the tip above the surface is just greater than half the free amplitude, then we know that the tip will just clear the surface, since the lever bends down as far as it bends up. We know that during the topography pass, the mean tip-sample distance was AC InvOLS \* set point. We need the height during the second pass to be AC InvOLS \* 2nd-pass free amplitude. The delta-height needed to just clear the surface during the second pass is simply the difference between these two values.

### Examples

Let's consider a few examples, using an AC240TM in the system I mentioned earlier.

The AC InvOLS is around 50 nm/V. I tune the system so that I see 1V Amplitude in the sum and deflection meter.

In the first pass, I use a set point of 600 mV. The mean tip height is roughly  $0.6 V * 50 \text{ nm/V} = 30 \text{ nm}$ . In the second pass, I use the same drive amplitude - it gives an Amplitude signal of 1V, so I need the tip to be  $1V * 50 \text{ nm/V} = 50 \text{ nm}$  above the surface to just clear it. So, I need a delta height of at least 20nm in order for the tip to clear the surface.

Let's say that, instead, in the second pass, I use a larger drive amplitude - sometimes this is necessary to overcome very strong tip-sample attractions. I check what free amplitude that drive amplitude gives me, and see an Amplitude signal of 2V. To clear the surface this time, I need to keep the tip  $2 V * 50 \text{ nm/V} = 100\text{nm}$  above the surface, requiring a delta height of  $100\text{nm} - 30\text{nm} = 70\text{nm}$ .

When using smaller drive amplitudes for the second pass, the delta-height can be negative before the tip makes contact with the surface:

for example, 0.5V free amplitude in the second pass requires a 25 nm tip-sample separation to clear the surface, so the tip won't hit the surface until the delta height becomes more negative than -5 nm.

### Factors to be aware of

When using an approximate or assumed InvOLS, the real InvOLS may be significantly different. If this is the case, then the tip could hit the surface before the calculated minimum delta-height has been

reached. One way around this is to measure the InvOLS, by determining the slope of the straight-line portion of an amplitude-distance curve: after tuning and engaging to find the surface, measure an amplitude-distance curve, triggering on AmpVolts with a trigger point around 10% of the Amplitude signal far from the surface; then, place cursors on the straight-line portion of the amplitude plot, open the 'cal. tab in the force panel, and choose 'Set Sensitivity'->'Amp InvOLS --- the value will be reported in the 'Amp InvOLS' display just above 'Set Sensitivity'.

Another situation in which the minimum delta-height may be underestimated is if the drive frequency in the second pass is off-resonance. In this case, the force on the probe may cause the resonant frequency to move closer to the drive frequency, increasing amplitude of the cantilever motion --- if this amplitude increases, then the clearance height also increases. It is therefore advisable to work on-resonance on the second pass, rather than just off-resonance as is normal for the topography pass; working on-resonance may also maximise the sensitivity of the phase measurement, which can be beneficial as phase is generally the observable of interest in MFM and EFM.