Electrostatic Force Microscopy with the Nano-R™:

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The Electrostatic Force Microscope is a modified AFM where the cantilever is connected to an independently controlled bias. The bias is used to create an electrostatic field between the tip and the substrate. It is intuitively obvious that the size and form of the tip is expected to be a crucial factor limiting the detection and observation of images. However in previously published theoretical studies of EFM (in all its forms), the tip characteristics do not appear explicitly in the imaging process. In an alternative, reciprocal, approach to understanding force microscopy originally applied to magnetic force microscopy (MFM) systems, the role of the tip is quite obvious. The high-resolution capability makes the EFM a powerful tool for characterizing electronic nanosystems.

EFM can be used to distinguish conductive and insulating regions in a sample. There are two different types of measurements that an AFM can perform in EFM mode. The first images electric field gradients on the surface of the sample, and the second images the surface potential of the sample. The electric field gradient method measures the changes in the internal electric field of a sample by monitoring the force on the scanning tip. In this case, no feedback is required and a constant voltage is maintained on the tip. As the tip moves over an attractive electric field gradient, it is pulled toward the sample,. When the tip traverses a repulsive gradient it is pushed away from the sample. Both these effects can clearly be observed by measuring the deflection of the cantilever as it is scanned at some height above the surface.

The surface potential method measures the surface voltage on the sample by adjusting the voltage on the tip. In order to maintain feedback the applied voltage on the cantilever is adjusted such that a constant amplitude or deflection is maintained. Although the Nano-R™ is capable of imaging with the surface potential method by using LabView, for simplicity all these studies were conducted in the field gradient mode.

The method is similar to MFM. Images can be collected in DC (contact mode) by recording the deflection of the cantilever or by AC mode (close contact mode) where the cantilever is oscillated above the surface and either the phase or amplitude of the cantilever is recorded. In this work we chose to do DC imaging. However, there is no reason that AC imaging cannot be performed and by following the MFM application note this can easily be done.

Materials:

1. CONTPt for DC EFM imaging or EFM POINT-PROBE for AC imaging - NanoWorld (www.probestore.com)

2. DC power supply to apply a voltage to the tip and substrate (for these studies we used a HP 6024A DC Power Supply, (0-60v, 0-10A, 200W) and Tektronix DMM 916, Volt/Current meter)

3. Conductive Adhesive

Procedure:

1. Mount EFM cantilever to tip holder using conductive adhesive.

2. Insert EFM cantilever and sample into standard positions.

3. Connect sample to the power supply.

4. Connect the tip to the power supply. The tip is connected to ground via the rear grounding lug at the back of the Nano-R™.
   *(**note:** a connection can be made directly to the tip by using the metal tip holder. If this method is used, be sure to insulate the tip holder from the AFM head by coating the tip holder with nail polish or some other insulating compound on the back and sides of the metal cantilever holder)*

5. Choose contact imaging mode

6. With the power supply off, collect a topographic image of the sample surface of interest.

7. To collect an EFM image you will need to raise the tip above the surface of the sample to remove the topography component. The simplest way is to use the motors on the AFM coarse approach motors to withdraw the tip from the sample surface. The forces involved with EFM are typically larger than those with MFM (since we can control the applied voltage to some extent) which allows more freedom with the tip sample spacing. We typically raised the tip approximately 800 nm above the sample surface (one step of the stepper motor).

8. Turn off the PID (by using Settings/PID ON/Off menu option) or decrease the gain settings to 1. This will prevent the AFM from trying to go into feedback when a deflection of the cantilever is recorded.

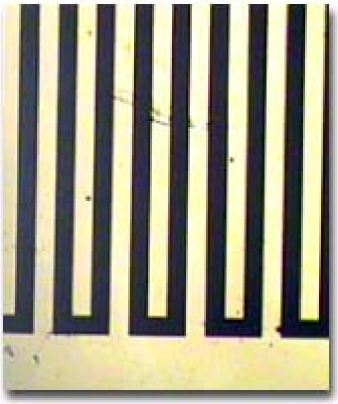
9. Start scanning the sample while slowly increasing the applied bias on the tip and/or substrate (we were able to record EFM images with a bias of less than 3 V on a conducting gold substrate).

10. The image will appear by recording the error (deflection) signal.

11. A quick check can be performed to determine if the measured signal is an EFM image by reversing the applied bias which should invert your image. Depending on your sample, this may not be possible.

12. We were able to collect EFM images gold patterned substrate within 5 minutes of imaging.

Figure 1

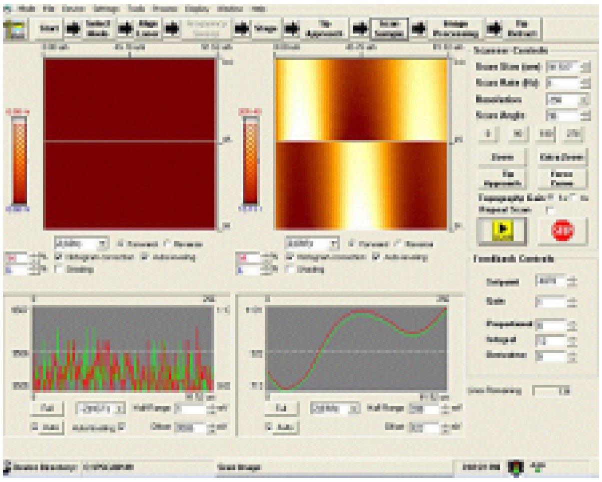


Optical image of gold fingers on a glass substrate.

Figure 2

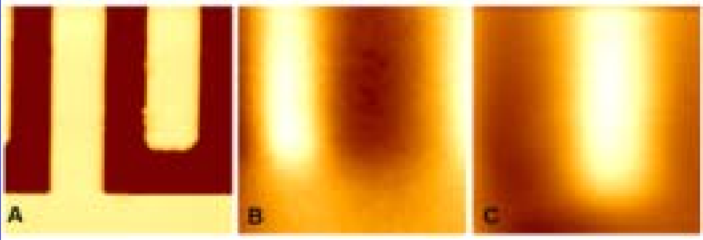
91 x 91 µm scans of gold fingers on a glass substrate. The fingers alternate in applied bias. A) Topographic, contact, image. B) EFM images where + 17 V is applied to the tip. C) -17 V applied to the tip. In both B and C, the fingers with the same bias appear dark.

Figure 3



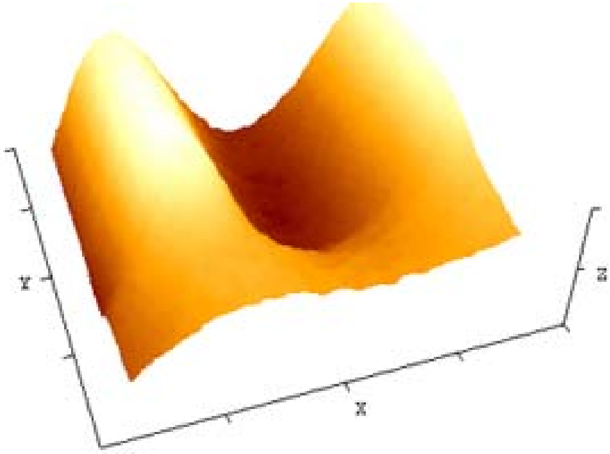
Screen capture of the data collected in figure 2 halfway through the scan while changing the bias. This effect can clearly bee seen in the Z(ERR) window where a reverse of contrast is evident. The gain is set to 1 with the PID on.

Figure 4



76 x 76 µm scans of the ends of gold fingers on a glass substrate. The fingers alternate in applied bias. A) Topographic, contact, image. B) EFM images where + 17 V is applied to the tip. C) -17 V applied to the tip.

Figure 5



3D reconstruction of figure 4B. This image shows how the electric field dissipates over the surface. It is interesting that the electric field is higher on the arms further away from the base, even though they are at the same bias.

References

1: *D. Bonnell, Scanning Probe Microscopy and Spectroscopy, WILEY-VCH, NY,(2001).*