

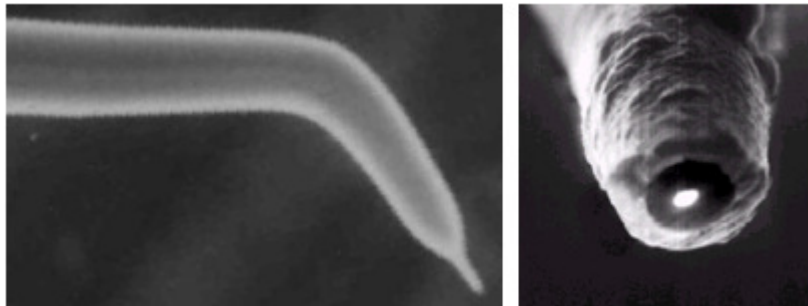


NANONICS  
IMAGING

USER GUIDE

# ELECTRICAL MEASUREMENTS

Conductive-AFM with Nanonics **MultiView** SPM Series



Feb 2009 – Version A

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Published 2009

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### **Note on Printing**

This manual is designed to be printed in color, single-sided on A4 paper

## Introduction

Electrical measurements or Conductive Atomic Force Microscopy (C-AFM) is an imaging mode for electrical nano characterization in the fields of nano-electronics, molecular electronics and material sciences. The electrical properties are obtained simultaneously with full correlation to the topographic image obtained with the same probe.

A DC bias is supplied to the tip or the sample and the current is measured through the sample while the AFM feedback is established to create the electrical contact. The scheme below describes this C-AFM configuration.

A second mode of electrical measurement is used with the Nanonics Multi-probe atomic force microscope platform for surface electrical nano-characterization and electrical nano-manipulation. With such platform, DC bias is provided through one probe and the current is measured through the other probes.

A third mode is used for I-V characterization of single point on the surface.

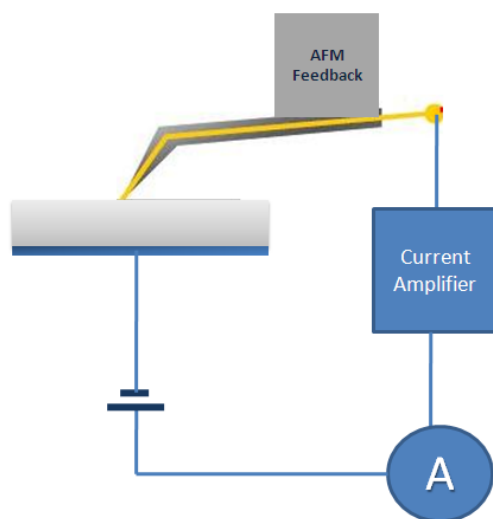


Figure 1: Electrical measurement scheme

### Associated Systems:

- MultiView4000™
- MultiView2000™
- MultiView1000™
- CryoView2000™

## ELECTRICAL PROBES

These probes are produced by glass tapering with a laser puller. They are based on tapering a pipette threaded with a platinum nanowire. The probes are effectively insulated by the glass and can even be formed with an outer metallic coating for effective grounding and coax type operation. The probes can be produced in various geometries, including a dual channel probe for electrical pulse propagation and collection. These glass probes with an exposed Pt nanowire with low oxidation and contact resistance have been applied for simultaneous and correlated electrical and topographical mapping

Nanonics Electrical probes have bent tip geometry suitable for multiprobe applications with up to four probes for point electrical measurements of a variety of nanometric structures.

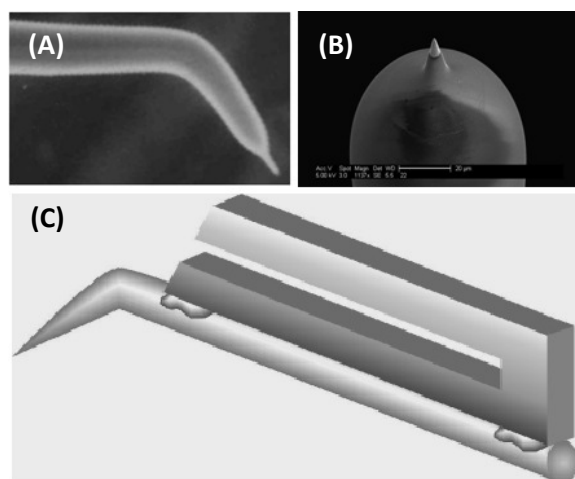


Figure 2: (A) Electrical bent cantilevered tip with Pt wire extending out. (B) SEM image zoomed at the end of the tip showing the Pt tip. (C) A tuning fork scheme with Electrical AFM tip mounted.

## List of Parts:

### 1. MultiView SPM:

All Nanonics MultiView series are suitable for carrying out the Electrical measurement mode. The MultiView2000™ and MultiView4000™ use tuning fork feedback. With such configuration the tip is mounted on the tuning fork and the system uses the tuning fork resonance frequency.

The **MV1000™** uses optical feedback and the feedback is based upon the probe's cantilever deflections.

Multi probe electrical measurements are possible with the MV4000™ with two tuning forks or with combination with beam bounce feedback.

### 2. FEMTO Current Amplifier:

Femto Current amplifier has the following functions:

- a. I/V converter: small current signals are transferred to voltage and then amplified to be coupled to the DT Interface module.
- b. Current amplification: Covers a range of  $10^3$  to  $10^{11}$ .
- c. Bias source: the Femto amplifier provides a DC bias output in the range of  $\pm 10$ v when GND/Bias knob is set to Bias position.

### 3. Load Resistor

Load resistor of 10M $\Omega$  is used for protecting the tip as high current may cause to tip damage.

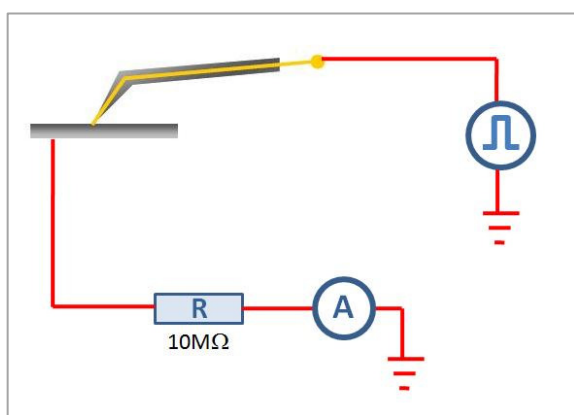
### 4. Oscilloscope

oscilloscope is much useful for providing another real time channel for monitoring the signals.

## Experimental Set up

### I. Obtaining an IV Curve of a Biased Sample with One Electrical Probe.

The scheme of such circuit is shown below in Figure 3. The circle is closed when the AFM feedback is established and the tip is brought into contact with the biased surface. The voltage is applied and the current is measured. A 10M $\Omega$  resistance is used in order to protect the tip from a large voltage drop.



**Figure 3:** The circuit for electrical measurement with a single probe.

### I1. Biasing the Sample

There are different methods for applying bias voltage to the sample:

- A. Femto Bias: The Femto current amplifier can be used to provide bias voltage when the GND/Bias knob is switched to Bias position. The BNC port at the input of the Femto is used to send the bias out through its outer contact (the one used normally for rounding).
- B. DT Interface Box: The bias in this way is provided through the NWS software (as will be described later). The output voltage will be in the range of  $\pm 10$ v at the BNC output port of the DT Interface of the SPM system.
- C. External Voltage Sources: other Voltage sources can be also used.

## How to obtain an IV curve?

### 1. Probe Mounting

Make sure the probe is mounted properly onto the Tip Holder. This is important to establish the electrical contact between the tip and the Input/output wiring. Follow the **system adjustment** part to verify that.

### 2. System set-up

Follow the scheme shown in Figure 4 for the set-up of the system.

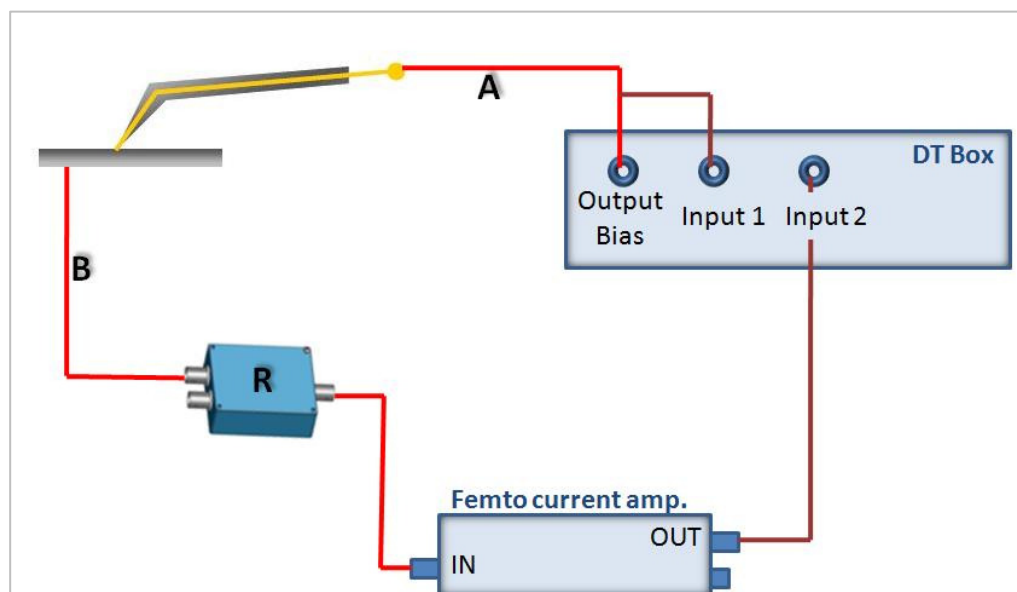


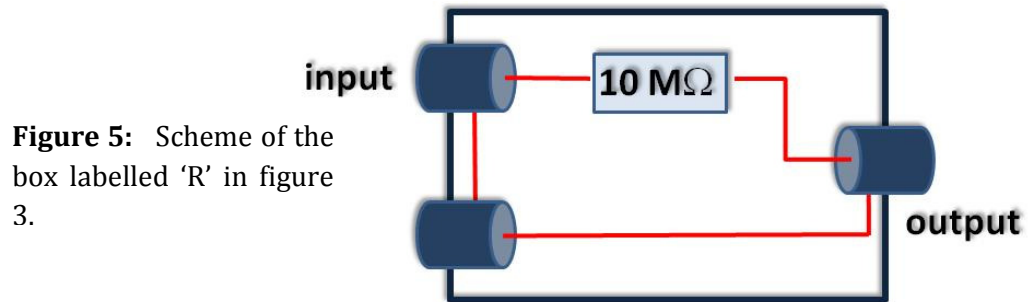
Figure 4: System set-up.

a. Connection 'A' in Figure 4 refers to the '*electrical measurements*' BNC of the cable *C-8B-EL from the SPM*. This BNC carries the electrical signal to or from the Pt wire probe. Connect this cable to the **Bias** channel on the DT box. (In previous DT versions: the bias output channel is called **OUT2**).

b. In order to take records of the voltages that are applied, use a T-BNC connector and connect 'A' to 'Input 1'. Here we will use two of the analog input channels in the DT box: **NSOM** and **AUX2** (called also STM-Bias).

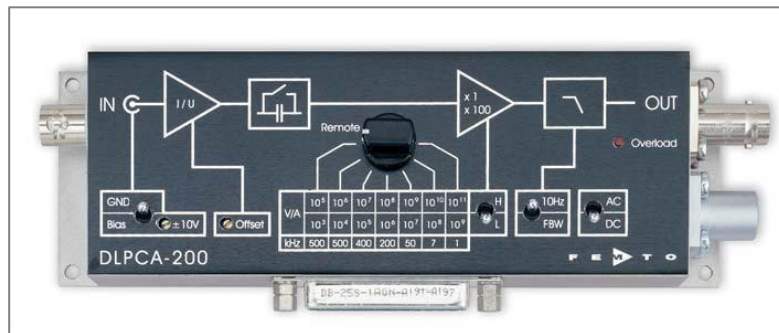
★ **Software:** When choosing the **NSOM** channel to record the bias voltages that are applied, make sure you change the NSOM channel Formula in Input Channel tab of the NWS software. Change the units to "Volts" and the Formula to x. If you want the word "Bias" to appear on the graph axis - change the name of the channel from "NSOM" to "Bias". These changes would be reflected when you choose the option of 'calculated values' instead of 'raw data'.

- c. Connection 'B' is a connection for Biasing the sample. Silver paint can be used to connect the wire to your sample.
- d. The box labeled 'R' in Figure 4 contains a 10Mohm resistance. Figure 5 shows the scheme of the connections inside this box. As mentioned above, this resistance is important in order to protect the probe and the sample.



**Figure 5:** Scheme of the box labelled 'R' in figure 3.

- e. Connect the output of the resistance box (in Figure 5) to the input of the Femto Current Amplifier using a BNC. The current is converted to voltage and the output signal is sent to the second input channel of the DT Interface: **AUX2**. See next paragraph for more details.

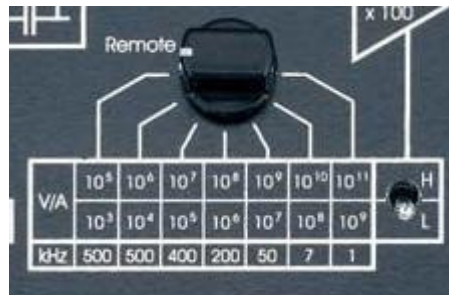


**Figure 5:** Femto Current Amplifier setting.

### 3. Femto Current Amplifier Settings

- a. Use the settings shown in Figure above: Ground, 10Hz, DC
- b. Select Gain of amplification using the rotating knob:





★ **Software:** The **AUX2** channel on the DT is called 'STM-BIAS' in the software. In order to change the name of the axis in the IV curve graph, please change the writing "STM-BIAS" to "Current". Write "microAmp" in the 'units' window. Change the formula according to the Gain of amplification that was selected on the Femto Current Amplifier. For example, for amplification of  $V/A = 10^7$  the formula should be  $x*0.1$ . These changes would be reflected when you choose the option of 'calculated values' instead of 'raw data'.

- c. Make sure that there is no voltage offset provided by the Femto Amplifier. For checking that: Connect the Oscilloscope to the output of the Femto Current Amplifier and rotate the **offset** screw until zero voltage reading at the output.

#### 4. General Settings of the AFM system

- Use the 1:7 Z-divider on the HVPD.
- Make sure that the minus K table is balanced, prior to approaching the tip.
- Use phase feedback mode.

##### **Lock-in settings:**

- Input Gains: use total gain of 5 and lower.
- Oscillation Amplitude: set the oscillation for getting amplitude peak of 8V of the resonance curve..

##### **Set-point settings:**

- Initial error value for approaching should be between 0.1-0.3V.

##### **Approach:**

Approach the sample with stepper motor speed of 50Hz. This slow approach is proposed to protect the tip when engaging the surface. You may use 600Hz for rough approach until the tip is close to surface and then stop the approach and change the stepper speed to 50Hz.

## 5. Getting an IV curve

Use the **NanoChemPlotter** tab for writing and executing a script which control the voltage applied over time.

You can save the script you composed as a \*.NIF file and load it again later. It is recommended to use one of these two versions: NWS1625 or NWS1750.

## 6. How to get a stable IV curve?

In order to get a stable IV curve, the parameters you need to change and adjust, are: Input Total Gain (5 and lower) and the error value (0.1 – 0.6V).

- *Decreasing the Input Total Gain parameter increases the oscillation amplitude of the probe. Increase in the error signal – increases the pressure of the probe on the sample.*

It is preferable first gradually lower the 'total gain' value, working with error value below 0.3V. Only if the signal is still not stable try to gradually increase the error value up to 0.6V, (or to 0.8V rarely).

Do not try to increase pressure on the probe (the error value), before you checked the rest of the system and adjusted the other parameters, as the damage to the probe is irreversible.

Changing the 'total gain' value should be carried out only when the probe is retracted from the sample, while increasing the error (set point) should be done in contact.

### Example 1

Sample: gold coated cover slip; 200nm Pt-electrical probe. The electrical scheme shown in Figure 4 was used.

The parameters were chosen as follows:

Total Input Gain 10 (in Lock-in window);

Initial error value of 0.15V;

Speed of stepper motor at 50Hz for approaching.

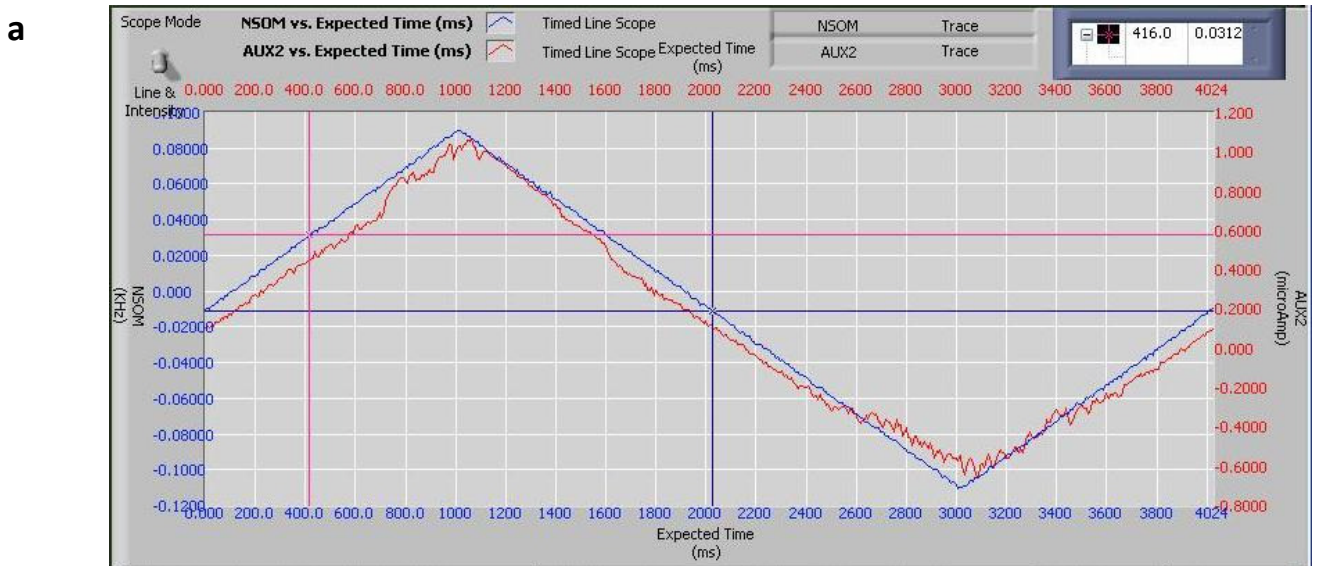
In 'Input channels' tab the following channels were marked to be acquired: height, error, NSOM, AUX2. (This way we will be able to eliminate the dependence of the current signal on height or error signals).

The formula of AUX2 was changed to have the correct calculated values of the current, in microAmp. The NSOM channel formula and units were not corrected this time, as seen on the graphs in Figure 6.

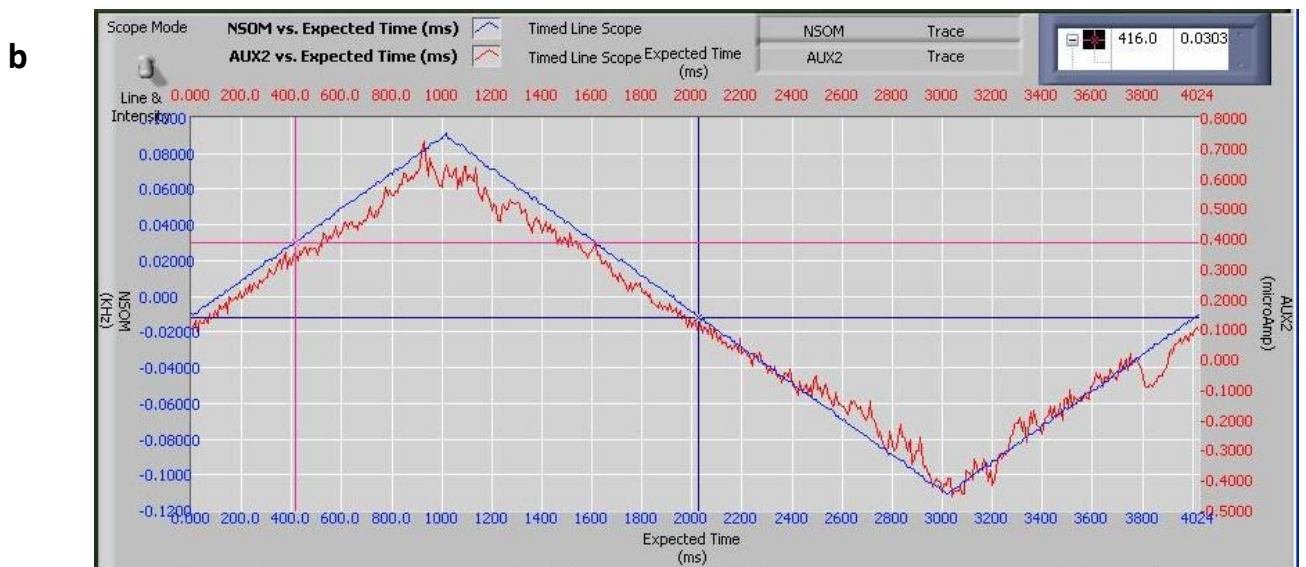
The file **em.NIF** was executed to obtain the IV curve shown in Figure 6. The voltage which was applied is shown with the blue color, while red indicates the current in the circuit.

Looking at Figure 6a you may notice that the current curve is not following exactly the voltage curve. It is not repeatable as well. Our goal is to get a stable and repeatable IV curve. Hence, we first retract the probe and decrease the 'total gain' parameter (while having the total magnitude signal at 8V by adjusting the Osc. Amp. parameter) . In Figure 6b 'total input gain of 5 was used. The curve is still not stable. In Figure 6c, however, we see an example of a stable and repeatable IV curve. This curve was obtained with the same and same settings only by reducing the 'total gain' parameter to 3. Notice that the error signal is as low as 0.2V. The Osc. Amp. parameter might differ from probe to probe.

Figure 6: IV curves obtained using different settings.



Gain 10; Osc 0.364; error (0.2 +/-0.03)V.



**Gain 5 Osc 0.5 error (0.3 +-0.03)V.**

C

**Gain 3 Osc 1.74 error (0.2 +-0.05) V**

Note: in this example the offset from the Femto Current Amplifier was not corrected and this is why the curves have some (incorrect) shift in the current. It is easy to present the IV curve in any post-processing software by saving the data as a spreadsheet file. You may choose to save the raw data or the calculated values, in the last case press 'convert' in the main window prior to saving.

**Example 2: Schottky Diode IV curve**

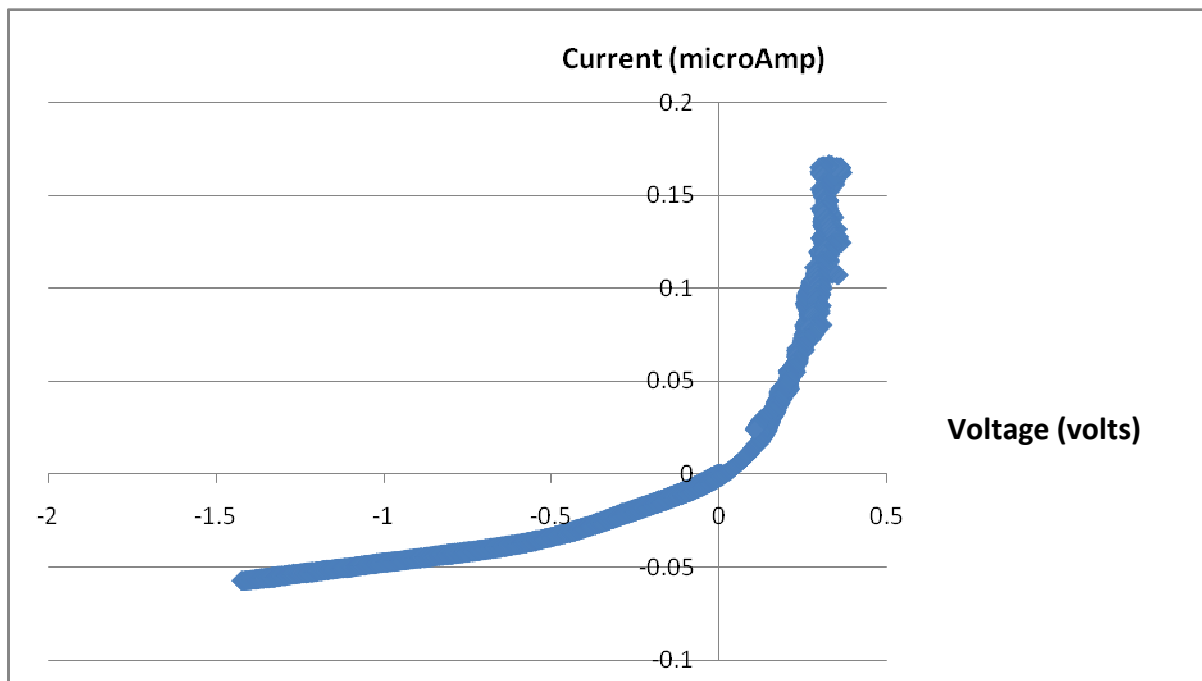
Sample: 20nm gold layer on 5nm Ti over Silicon substrate (Natural Oxide)

The IV curve shown in Figure 7 was obtained using 'total gain' of 3 and error of 0.5V.

Voltage was gradually changed from +2V to -2V and the current measured.

- *The X-axis of the graph presented in Figure 7 refers to the voltage that falls only on the sample and sample-probe interface, not on the external 10M $\Omega$  resistor.*

Figure 7: Schottky Diode IV curve.



## 7. System adjustments

Presented here are a few suggestions and troubleshooting that might ease on your work.

### a. Use a Scope

Connect the Bias Output to a scope – this way you can notice on-line if you are accidentally applying voltage.

Connect the Femto output to a scope channel – this way you can notice on-line wherever there is current in the circuit.

### b. Electrical connection check

It is possible to check whether the probe was positioned correctly on the probe mount holder. (See paragraph 1)

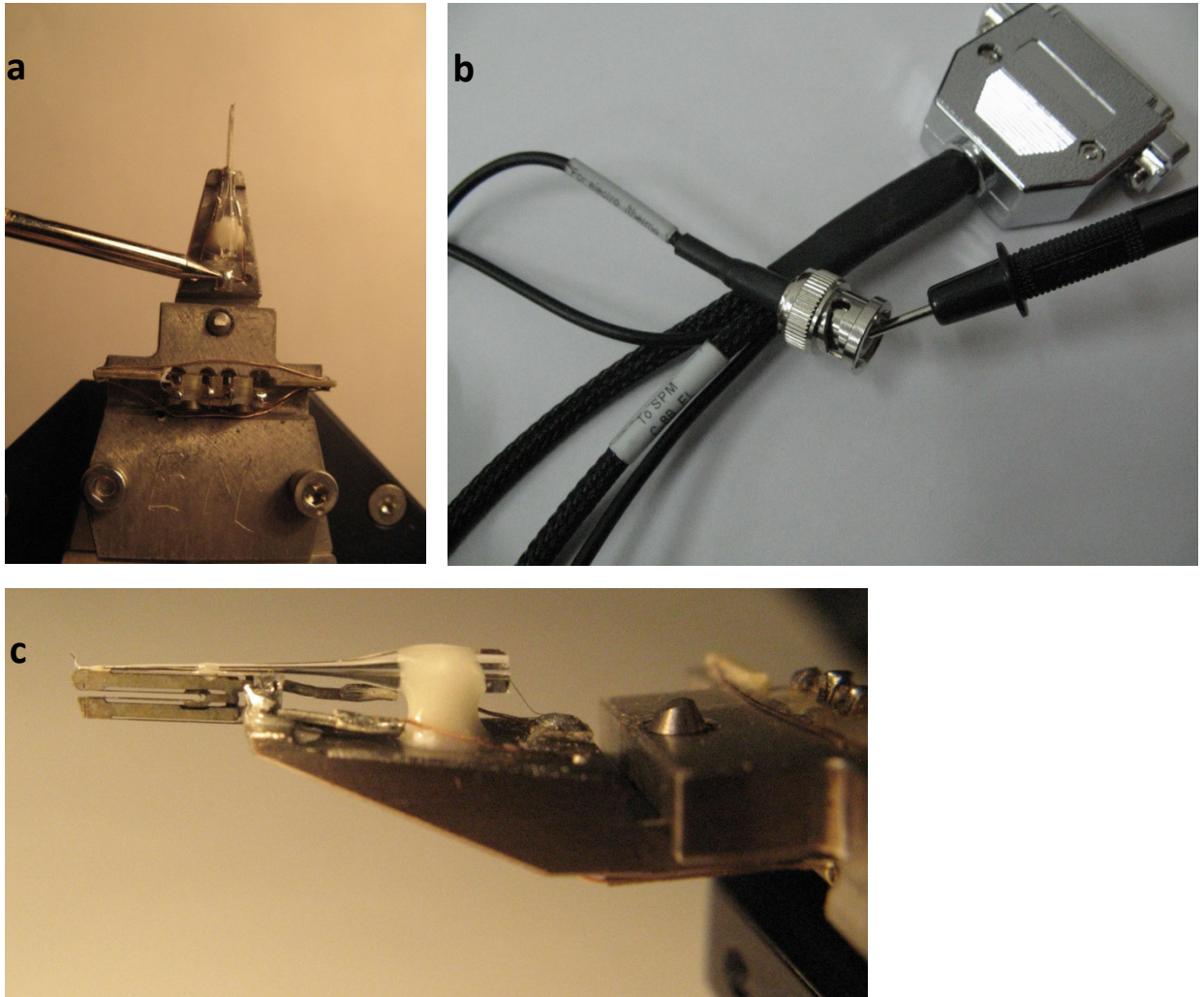
In order to check that, use a multimeter and check conductivity between the connection of the Pt-Wire on the 'probe mount' and the signal from the BNC 'electrical measurements'. See Figure 8 for details.

### c. Common Ground

Check that there is a common Ground all along the circuit you use. Remember that the analog input channels in the DT box are differential input channels, which means that their ground is the ground of the external device they are connected to. **Height** and **Bias** (or **Out2**) channels should have the same Ground, and connecting **Bias** (or **Out2**) to **NSOM** channel grounds it as well.



Check that the INPUT and the OUTPUT Grounds of the Current Femto Amplifier are the same. If it is not so, you can use a T-connector in order to connect it to some channel on the DT-Box. Use the scope when it is connected to the same power socket as the rest of the system.



**Figure 8:** Connections check. **a.** Place the first probe of the multi-meter carefully on the spot shown in the picture. Be careful not to hurt the Pt-wire that is connected to the glass probe as shown in **c.** **b.** Place the second probe of the multi-meter on the signal of the ‘electrical measurements’ BNC on the C-8B-EL cable to SPM. The multi-meter should beep for short-circuit.

### **d. Currents**

We worked with currents of up to at least 1microAmp and found out, using imaging of a scanning electron microscope, that the probe is not being altered in shape or texture for these currents.

For any further information, please contact us: [support@nanonics.co.il](mailto:support@nanonics.co.il).