APPLICATION NOTE

# Advanced AFM with simultaneous electrical probing

## INTRODUCTION

Atomic Force Microscopy (AFM) is a powerful high-resolution imaging technique. It can be further augmented with other characterization methods to access electrical, mechanical, thermal, and other physical properties of materials and devices. Such measurements are often performed on operating or actuated devices, including measurements under specific external stimuli: magnetic fields, specific illumination or electrical drive signals.

In this application note, we show how Imina Technologies' miBot™ nanoprobers can be integrated into a Bruker Dimension® AFM to obtain Kelvin Probe Force Microscopy (KPFM) images of various metallic structures and semiconductor devices under operating conditions.

## SETUP

A Bruker Dimension® AFM (Dimension Icon® and Dimension Edge™) is optimal for integrating AFM with electrical nanoprobing experiments. It has:

- A sufficiently large sample area that fits both the samples and the probers.
- A 'scan-by-tip' design: additional probers and cabling would add weight on the scanner of 'scan-by-sample' instruments, which could limit the scan speed or other parameters.
- A tip holder with high clearance that provides enough room to position miBot™ nanoprobers close to the tip/sample contact without interfering with the AFM hardware.
- Spare channels to create & apply signals (AC & DC) to the nanoprobers, all controlled from within the AFM software.

The measurements are also possible inside a glovebox on the glovebox-compatible versions of these AFMs. The AFM can also be equipped with advanced add-ons for specific electrical AFM measurements such as Scanning Capacitance Microscopy (SCM), Scanning Spreading Resistance Microscopy (SSRM), Conductive AFM (C-AFM) and Tunneling AFM (TUNA).

Imina Technologies' miBot™ nanoprobers are ideal for combined AFM/Nanoprobing applications as they meet all requirements set by AFM-level measurements:

- Compact design.
- Combination of coarse and fast movements over centimeter distances and fine nanometer movements in various directions (XYZ, rotation).
- Straightforward adaptation to different experimental setups and samples.
- High mechanical and thermal stability (low drift) resulting in stable positioning over long periods of time.
- Easy, rapid, and safe probe-landing.
- Low electrical noise.
- Compatibility to a wide variety of nanoprobe needles and electronics.

Figure 1 show Imina Technologies' miBot™ nanoprobers positioned on the Bruker Dimension Icon® AFM with the PeakForce TUNA™ module hardware mounted onto the AFM scanner head. The probers are sitting around a small sample mounted on a SEM-compatible stub and a wafer sample.

*Figure 1. Imina Technologies' miBot™ nanoprobers positioned onto a small sample (mounted on a SEM-compatible stub) on the Bruker Dimension Icon® AFM equipped with the PeakForce TUNA™ application module.*

## WORKFLOW

A typical workflow consists of the following steps:

- Load the sample and AFM tip. Perform the standard ‘focus tip’, ‘focus surface’, and ‘navigate to area of interest’ steps.
- Use the integrated into the AFM optical camera as a guide to bring the nanoprobers near the area of interest. Land the tips onto the device of interest, leaving some space for the AFM tip.
- Follow the standard engage procedure to bring the AFM tip to the area of interest, start scanning, and perform a fine positioning of the AFM tip.
- Activate the electrical settings and perform the in-situ AFM experiment.

Figure 2 shows the optical camera view of 3 miBots™’ tips landed onto the contacts pads of a device (step 2 in our workflow) and a control panel of Imina Technologies’ Precisio software. One can easily position nanoprobes’ tips with micrometric resolution (limited by the optical resolution of the integrated camera). The red crosshair shows the position where the AFM tip will engage onto the sample surface.

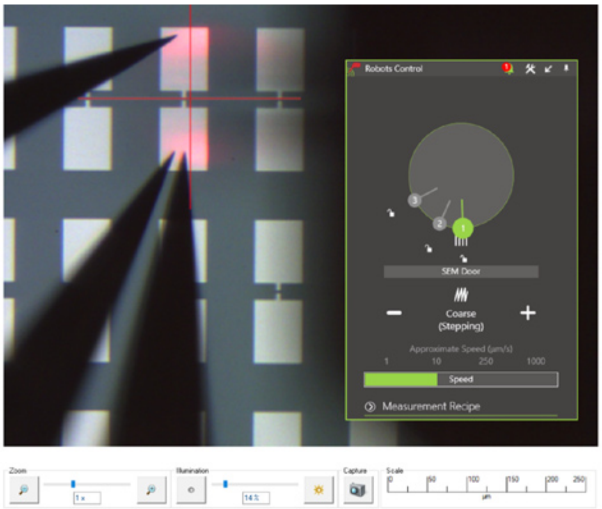

*Figure 2. Software view of 3 miBots™ in contact with the device pads, prior to engaging the AFM tip onto the sample surface, and a control panel of Imina Technologies’ Precisio software.*

## EXPERIMENTS

### Surface potential of biased metallic lines

In the first experiment, we map the potential distribution on ca. 10-µm-width metal lines deposited on an insulating substrate, as shown in Figure 3. The ‘even’ lines are electrically connected to each other on the left side of the sample; ‘uneven’ lines are connected on the right side of the sample (see the schematic in Figure 3).

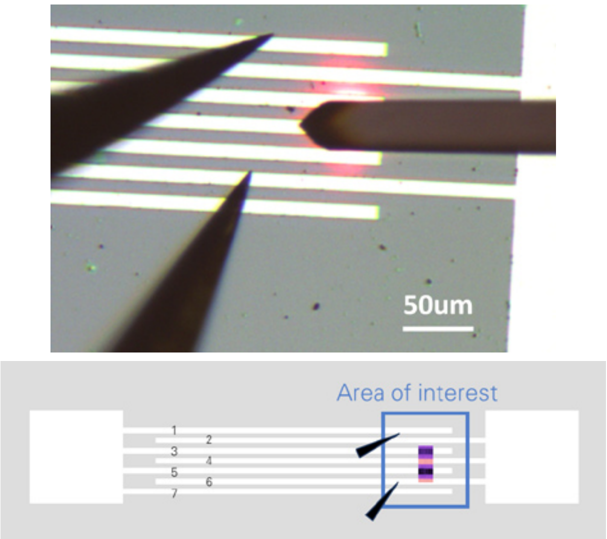

*Figure 3. View from the optical camera integrated into the Bruker Dimension Icon® AFM showing 2 miBots™ nanoprobers & AFM tip positioned onto a structure with metallic lines. The schematic representation shows the location of the probes are and where KPFM data were collected.*

We landed two miBot™ probes on the selected lines and applied DC voltage generated by the AFM controller: -2V to the ‘uneven’ lines and +2V on the ‘even’ lines. The AFM tip scanned across multiple lines in KPFM mode to map the distribution of the surface potential (Figure 4).

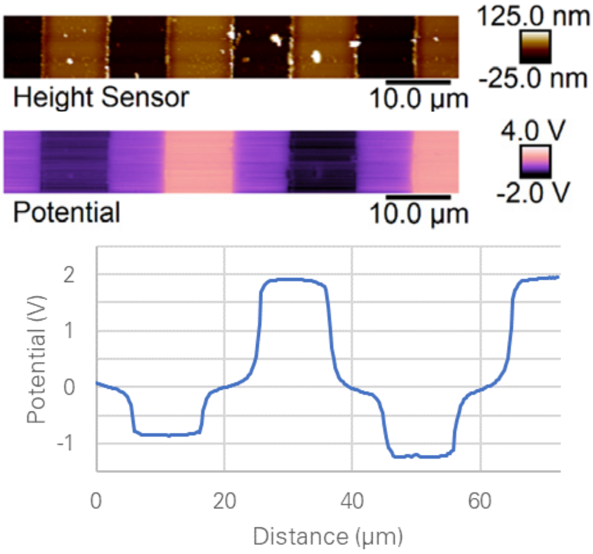

*Figure 4. Topography and surface potential maps acquired in KPFM mode on a network of interlaced lines, a voltage of -2V is applied to the ‘uneven’ lines and +2V on the ‘even’ lines. Average potential profile is plotted.*

The potential profile averaged across the full structure showed the potential of almost 2V on the ‘even’ lines. The potential on the ‘uneven’ lines was around -1V and varied from line to line. We also observed how the potential gradually changed in the isolating areas between individual lines. This difference in the ‘uneven’ lines could be due to resistance losses. The measurement location was somewhat away from the electrical contact area and much farther from the connection point of ‘uneven’ lines than from that of the ‘even’ lines.

## Surface potential on the insulating substrate between two biased metallic contacts

In our second experiment, we measured the surface potential of two metal pads connected by a 5-µm-wide metal line with a gap in the middle (Figure 5, inset). We imaged the surface potential distribution in this device using KPFM, with +0.5V and -0.5V applied to the contacts by miBot$^{TM}$ nanoprobers.

The color plot of the surface potential maps the voltage gradient on both contacts and in between, and the grayscale contour-plot shows equipotential lines in the dielectric area between the contacts.

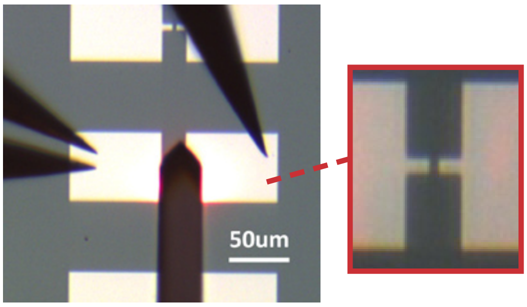

*Figure 5. View from the optical camera integrated into the Bruker Dimension Icon® AFM showing 3 miBots$^{TM}$, with an AFM tip positioned onto the ‘open circuit’ structure.*

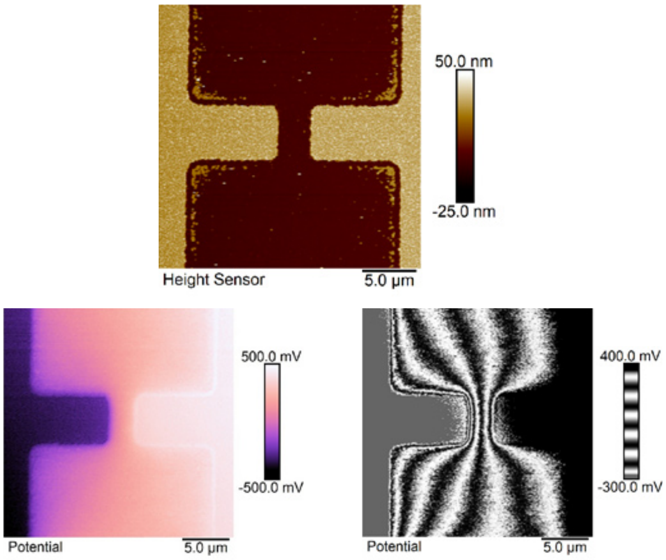

*Figure 6. KPFM measurement on the ‘open circuit’ device while applying -0.5V and +0.5V on both contacts.*

## Surface potential of an electrically biased SRAM memory sample

In our third experiment, we imaged the surface potential of a de-processed SRAM memory sample. miBot$^{TM}$ tips could easily and precisely land on tightly packed few-micron source/drain contacts, as shown in Figure 7. KPFM was performed on devices next to the probes (Figure 7, insert).

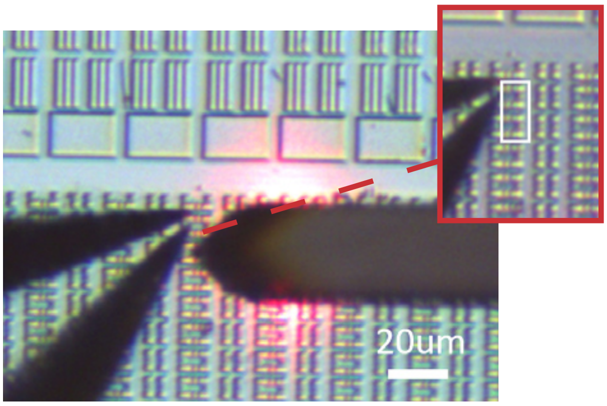

*Figure 7. Two miBot$^{TM}$ probes landed a few micron apart on the source/drain regions of transistors in a SRAM memory. Insert: The white rectangle marks the SRAM area where KPFM data were collected.*

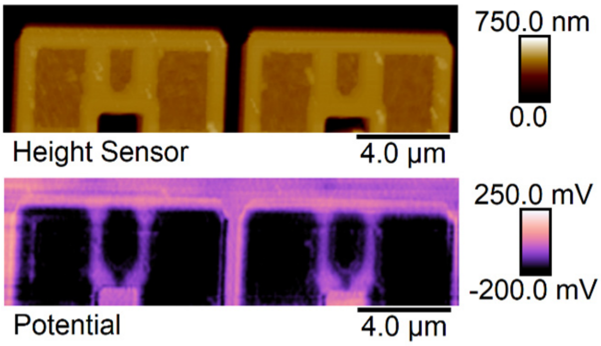

*Figure 8. Topography and KPFM scans on transistors in SRAM memory highlighting source/drain (dark) and channel (light) areas. The devices are biased by nanoprobers as shown in Figure 8.*

## CONCLUSIONS

The combination of Imina Technologies' electrical probing system with Bruker's Dimension Icon® AFM is optimal to study electrical, mechanical, thermal and other physical properties of materials and devices. This combination enables users to characterize biased or actuated devices and surfaces.

Thanks to the tip holder with a large clearance of the Dimension Icon® AFM, miBots™ fit on the sample stage while leaving sufficient room for the AFM tip. miBots™' compact design makes it is easy and safe to land the probes on the sample close to the AFM tip. With the 'scan-by-tip' design, integration of miBots™ doesn't compromise the AFM scanning speed and quality.

Electrical nanoprobing is compatible with many advanced characterization modes, such as Electric Field Microscopy (EFM), Kelvin Probe Force Microscopy (KPFM), Magnetic Force Microscopy (MFM), Piezoresponse Force Microscopy (PFM), Conductive-AFM, Tunneling-AFM (TUNA), Scanning Capacitance Microscopy (SCM), Scanning Spreading Resistance Microscopy (SSRM), Scanning Thermal Microscopy (SThM), to name a few.

Imina Technologies' miBots™ can be easily added to existing Dimension Icon® setups. They are easy to install, use, and can be integrated into other lab setups (optical microscopes, etc) if needed.

**Authors:**

Peter De Wolf, Bruker Nano Surfaces & Metrology

William Courbat, Imina Technologies

**Imina Technologies SA**
Route de Montheron 8b, 1053 Cugy (VD), Switzerland

www.imina.ch