Application Note

#159

Electrical Probers on Dimension AFMs

The high-resolution imaging capability of atomic force microscopy (AFM) can be extended to enable a wide range of characterization methods to study electrical, mechanical, thermal, and other properties of materials and devices. Devices are often measured via AFM during operation or actuation, with applied external stimuli such as magnetic fields, specific illuminations, or electrical drive signals. For nanoelectrical structures such as semiconductor devices, 1D/2D materials, and quantum devices, it can be necessary to characterize the response to signals applied to multiple electrical contacts under operating conditions. However, adding electrical contacts to structures of interest can be a challenging task often realized by wire bonding, silver paint application, or metal deposition—work-intensive methods that can be limited to certain device geometries or sample types. Microprobers provide a flexible, easy-to-use alterative for AFM experiments requiring multiple electrical contacts. This application note describes how to easily implement microprobers on Bruker's Dimension® AFMs and provides case studies illustrating the flexibility and capability of this approach.

Instrumentation

Bruker's Dimension AFMs offer all the necessary features and components critical for combined AFM/microprobing experiments both in air and in a glovebox (for glovebox-compatible instruments). The low-drift, low-noise platform supports a large sample area that can accommodate multiple microprobers and a wide variety of sample sizes and geometries. By using a *scan-by-tip* design, the Dimension AFMs enable the addition of microprobers and cabling without degrading performance, in contrast with *scan-by-sample* instruments that can be hindered by additional mass or constrained by moving cables. Bruker also offers an optional AFM tip holder that has a high clearance, providing maximum flexibility to position the microprobers close to the tip/sample contact. Finally, the Dimension AFMs have powerful control electronics, with spare channels that can be used to create and apply AC or DC signals to the microprobers; signals that are easily controlled from within the native AFM software.

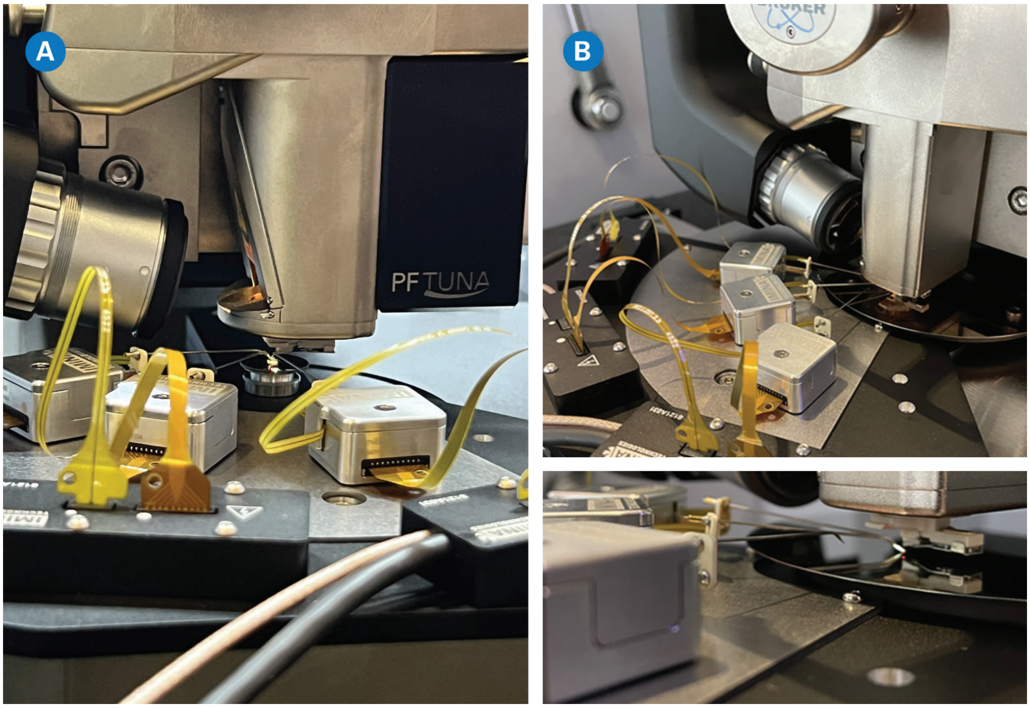

FIGURE 1.

A Dimension Icon AFM with three Imina microprobers positioned onto (a) a small sample mounted on a SEM-compatible stub, and (b) a wafer sample with tip holder optimized for high clearance.

Imina Technologies' probers, already well-proven for similar measurements inside SEMs, were selected because they meet all requirements set by AFM-level measurements. The miBot™ microprobers have a compact design with a combination of coarse movement control over centimeter-scale distances and fine nanometer-scale movements for XY, rotation, and tilt. Their flexible installation and compatibility with a variety of needles/electronics facilitate straightforward adaptation to different experimental setups and samples. These low-drift, low-noise microprobers also feature easy, rapid, and safe probe landing.

Setup and Workflow

Figure 1a shows three Imina probers positioned onto a small sample (mounted on a SEM-compatible stub) in a Dimension Icon® AFM. The AFM is equipped with a *high-clearance* tip holder. The Dimension 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). The instrument in Figure 1a shows—for example—the PeakForce TUNA™ module hardware mounted onto the AFM scanner head. Figure 1b shows a similar setup with a wafer sample.

A typical workflow consists of the following steps:

1. Load the sample and AFM tip. Perform the standard *focus tip*, *focus surface*, and *navigate to area of interest* steps.
2. Use the optical camera, integrated into the AFM, as a guide when bringing the Imina probers near the area of interest. Position the probers onto the device of interest, leaving free space to position the AFM tip.
3. Follow the standard engage procedure to bring the tip to the area of interest, start scanning, and perform a fine positioning of the AFM tip.
4. Activate the electrical settings and perform the in-situ AFM experiment.

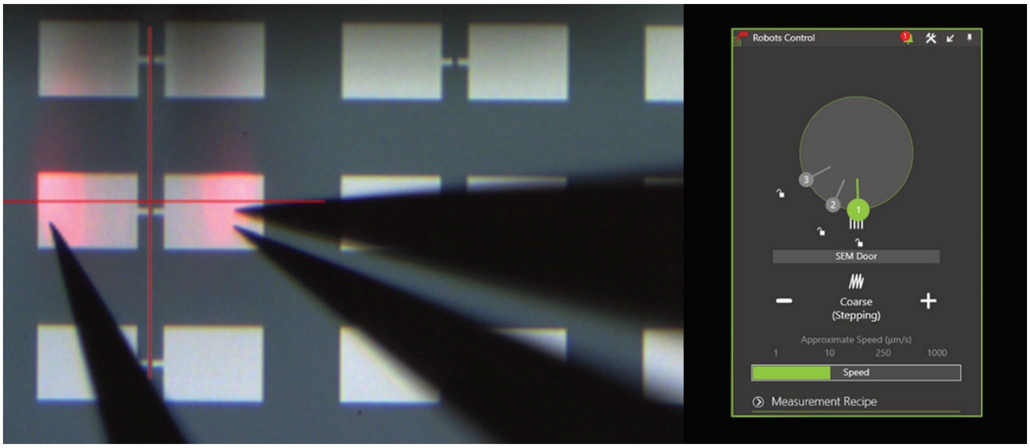

FIGURE 2.

Software view of three Imina microprobers positioned onto the device, prior to engaging the AFM tip onto the sample surface. The Imina Technologies Pricisio™ software is also displayed.

Figure 2 displays the optical camera view of three Imina probes positioned onto the contact pads of a device (step 2 in the above workflow) and the Imina probe navigation software. The microprober needles can easily be positioned with micrometer resolution (limited only by the optical resolution of the integrated camera). The position where the AFM tip will engage on the sample surface is indicated by the red crosshairs.

Case Studies

In the first case study, potential distribution was mapped on a sample with metal lines on an isolating substrate. The metal lines formed an interlaced network; *even* lines were electrically connected to each other towards one side of the sample, while *odd* lines were connected towards the other side of the sample. Two Imina microprobers were positioned on selected lines (one *odd*, one *even*) as shown in the schematic in Figure 3a and the optical image in Figure 3b, and DC voltages generated by the AFM controller were applied to the microprobers. When the AFM tip scanned across multiple lines in KPFM mode, the distribution of surface potential was mapped across the device structure.

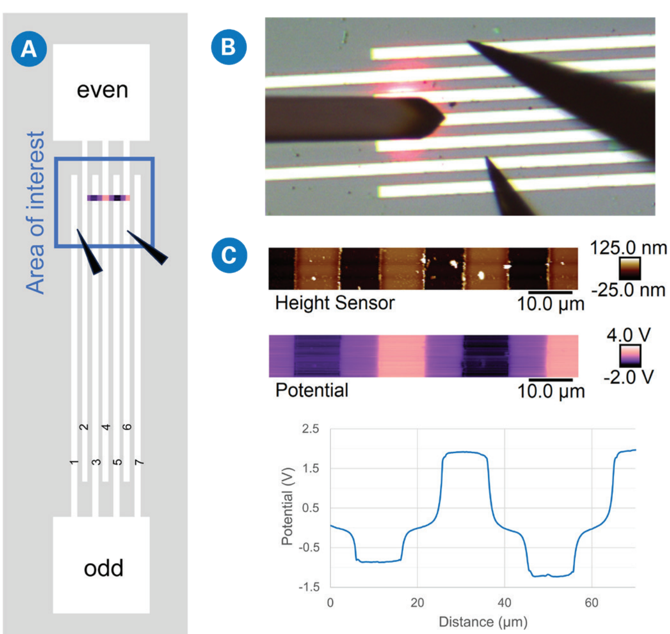

FIGURE 3.

(a) Schematic representation and (b) optical camera image of Imina microprobers positioned onto a structure with interlaced lines. (c) KPFM data collected from the area of interest in (a) while a voltage of -2 V is applied to the odd lines and +2 V to the even lines. The average potential profile is also plotted over the same scan distance.

A voltage of -2 V was applied to the *odd* lines and +2 V to the *even* lines, and the KPFM results across several lines are given in Figure 3c. The potential profile averaged across the structure shows the voltage is near 2 V at the *even* lines, while it is closer to -1 V at the *odd* line. Not all *odd* lines show the same potential value. The potential also gradually changes in the isolating areas between individual lines. The observed potential drops in the odd lines can be explained by a resistance drop in the metal lines—the measurement location is relatively far away from where the microprober applies the voltage.

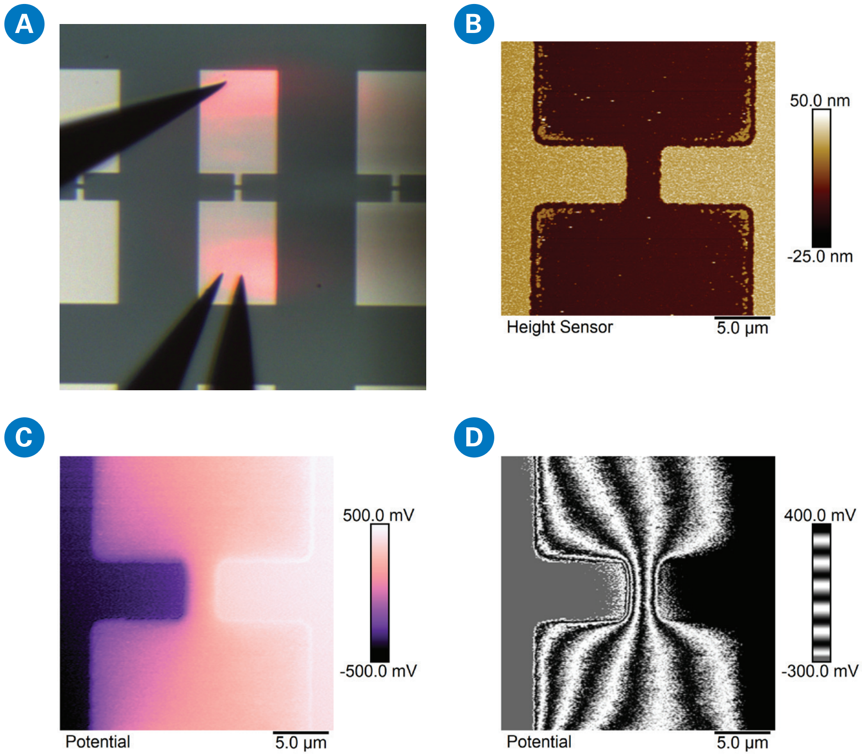

FIGURE 4.

(a) View from the optical camera integrated into the Bruker Dimension Icon AFM showing three Imina microprobers and area of interest on an open-circuit device for KPFM scan. (b) AFM height map of the area of interest marked in (a). (c, d) KPFM potential measurement on the open-circuit device while applying -0.5 V and +0.5 V to the contacts.

In the second case study, three Imina probers were positioned onto two metal pads connected by a 5 µm wide metal line as seen in the optical image (Figure 4a) and AFM height image (Figure 4b). KPFM was employed to measure the surface potential distribution in the marked area of interest on this device, while applying +0.5 V and -0.5 V to the contacts. The surface potential color image (Figure 4c) highlights the voltage present on both contacts, while the greyscale contour-line image (Figure 4d) delineates the equipotential lines in the dielectric area between the contacts.

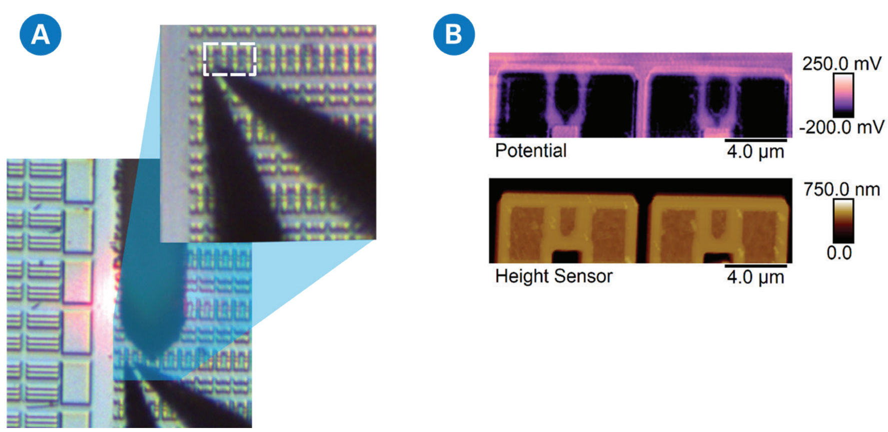

FIGURE 5.

(a) Two Imina microprobers positioned only a few microns apart on the source/drain regions of transistors in an SRAM device, shown with and without (inset) the AFM probe inserted. (b) KPFM data collected in the marked area of interest highlighting source/drain (dark) and channel (lighter) areas.

Positioning of the Imina probers is quite flexible, as illustrated by Figure 5a, which shows two microprobers directly positioned onto the source/drain areas of a de-processed SRAM sample. Spacing between the microprobers is only a few microns. KPFM was performed on devices immediately adjacent to the positions of the microprobers (Figure 5b) and reveals the source/drain (dark) and channel (brighter) areas of four transistors in this memory cell.

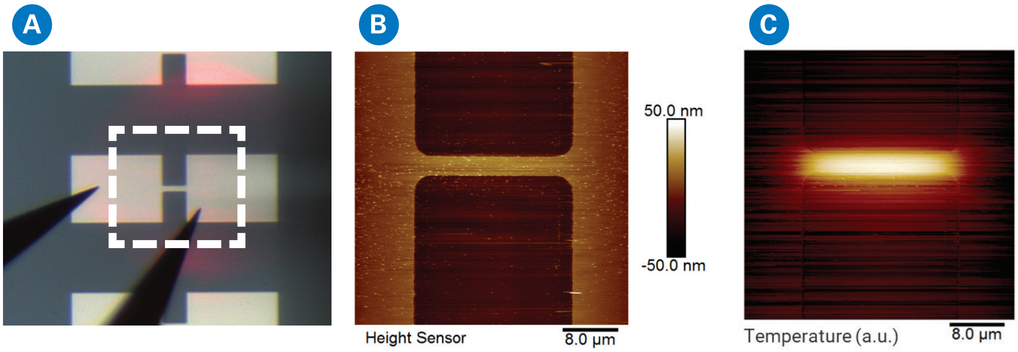

FIGURE 6.

(a) Optical camera image of a short-circuit device with marked area of interest for (b) AFM height map and (c) SThM measurement while applying a current through the metal line.

The proposed configuration is compatible with a variety of advanced characterization modes, including—but not limited to—electric field microscopy (EFM), Kelvin probe force microscopy (KPFM), magnetic force microscopy (MFM), piezoresponse force microscopy (PFM), conductive AFM (C-AFM), tunneling AFM (TUNA), scanning capacitance microscopy (SCM), scanning spreading resistance microscopy (SSRM), and scanning thermal microscopy (SThM). To illustrate this, SThM was applied to the device shown in Figure 6, with a *short circuit* nature. SThM maps reveal the 2D temperature profile created when passing a current through the line, with higher temperatures observed at the center of the line (Figure 6c). Note that for SThM, the dedicated SThM tip holder, and not the high-clearance tip holder, is used.

Conclusions

Nanoscale imaging of electrical devices under operation can be facilitated by combining AFM with one or multiple compact microprobers, positioned to within a few microns from the AFM tip/sample contact. Bruker's Dimension AFMs are ideally suited for this type of integration, as they maintain their performance level and wide range of operating modes when adding microprobers.

Resources

Discover the Dimension Icon at bruker.com/Dimension-Icon, and explore Bruker's many available AFM modes at bruker.com/afmmodes. For additional information regarding Imina Technologies and their nano- and microprober solutions, visit imina.ch.

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