APPLICATION NOTE

Simultaneous nanoindentation and electrical probing inside an SEM

In collaboration with

Alemnis AG
https://alemnis.com

INTRODUCTION AND MOTIVATION

Electrical properties of materials and devices change under mechanical stress. The implications of such changes for semiconductor devices and to functional materials can be immense and are of high importance to ensure safe and reliable operation and optimal design. To investigate this change on the smallest level, is not a trivial task because such experiments need to run inside a scanning electron microscope. Here, we present a proof-of-concept set of experiments on in-situ SEM monitoring the change in electrical response during nanoindentation.

This work is a collaboration between two Swiss high-precision scientific equipment producers. Alemnis develops advanced solutions for nanoindentation. Imina Technologies produces electrical micro- and nanoprobing solutions for optical and electron microscopes and other analytical tools. Both companies are a part of the In-Situ Microscopy Alliance.

An in-situ SEM combination of electrical nanoprobing and nanoindentation is useful to understand and to quantify the effect of mechanical pressure and deformation on electrical properties of a sample that is too small to be studied under an optical microscope. The reverse relationship is also possible when a displacement is caused by an electrical bias. There are several application areas, where this approach would be highly beneficial:

- Piezoresistive or piezoelectrical structures
- NEMS
- IC mechanical stress tolerance/fatigue testing
- Packaging of ICs effect on transistors performance
- Sample deformation/destruction monitoring
- Understanding the underlying mechanisms of functional materials behaviour.

EXPERIMENT

This experiment is run inside a Tescan CLARA SEM. Two of Imina Technologies' nanoprobers are integrated onto the Alemnis Standard Assembly nanoindentor. One robot is solidly attached on each side of the nanoindenter head. In this configuration, all three tips can approach the sample simultaneously. Nanoprobers are tilted with respect to the indenter head axis by 30°. Thanks to this configuration, we can tilt the setup inside the SEM and have a good overview of the sample, nanoindenter head, and the probes, while the robots sit flat with cartesian movements aligned with the SEM stage.

We use the four electrical connections available on the SEM flange: two for the nanoprobers tips and two to control the sample and nanoindenter tip potentials. This way, we achieve maximum flexibility for different experiments and biasing conditions (allow to bias, ground or float each of the tips and the sample). Long bent probes allow maximum clearance and position flexibility.

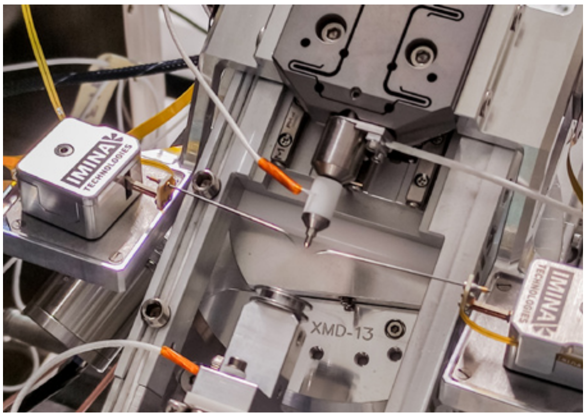

Figure 1. Integrated nanoprobers sitting on the nanoindenter head. The sample sits on the sample stage that can move independently from the tips.

As the robots sit on the nanoindenter head, all tips can be brought close to the sample surface simultaneously. Once the nanoprobers are landed on the sample, indentation can take place. Thanks to the controlled angle and position of the probing tips, they can be landed just a few microns away from the indentation site. We can apply various voltages and current biases during nanoindentation or monitor voltage/current changes caused by it.

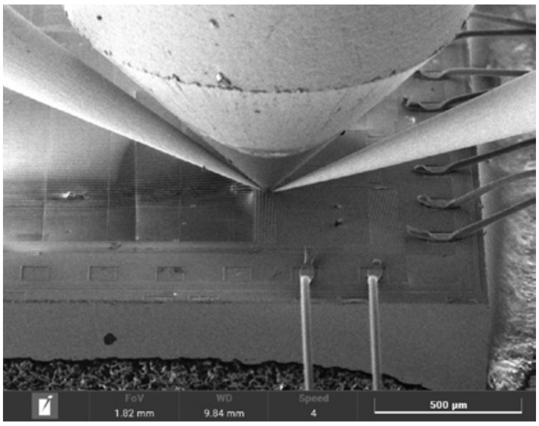

Figure 2. Two nanoprobes and the nanoindenter head landed on an IC chip.

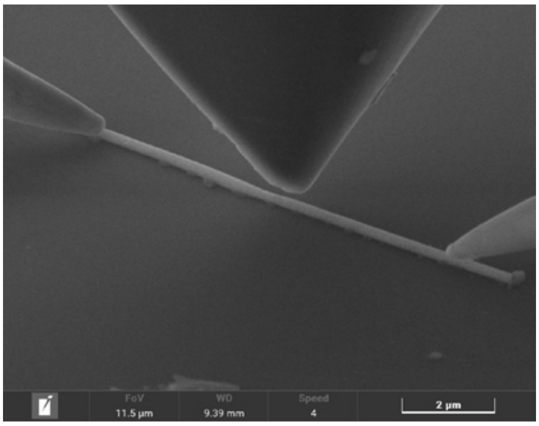

Figure 3. Two nanoprobes and the nanoindenter head landed on a piezo nanowire.

APPLICATION EXAMPLES

Piezoresistive AFM cantilever

First, we characterize the sensitivity of a piezoresistive AFM cantilever. We land probes on the Wheatstone bridge on the cantilever itself and apply a DC voltage bias while measuring the resulting current flowing between the probes. The indenter tip applies steps of increasing force on the top of cantilever. The increasing force induces changes in current and allows us to determine the gauge factor of the cantilever: we observe a clear relationship between the applied load and the output current.

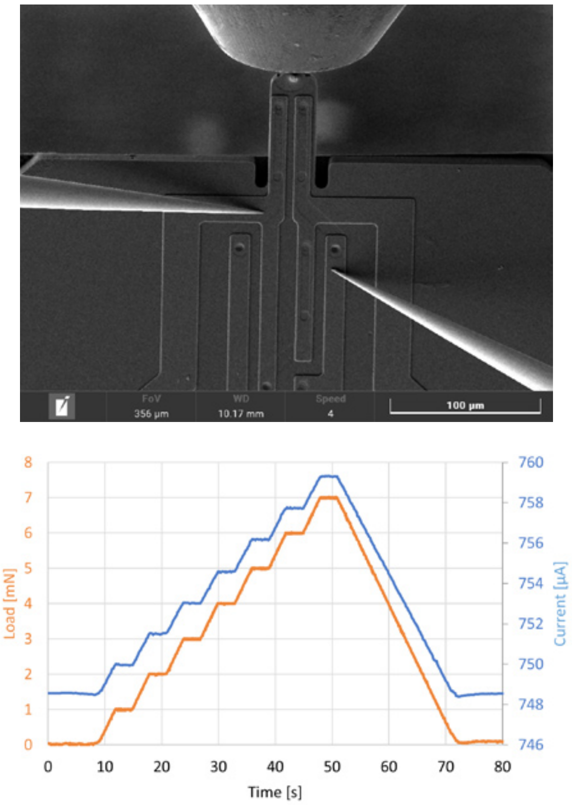

Figure 4. Two nanoprobes apply DC voltage bias and measure the current output while the nanoindenter head applies controlled pressure onto a piezoresistive wheatstone bridge. The change in current output is clearly linked to the pressure.

Indentation on a PtCr metal line

Here we analyse the mechanical stress response of a metallic line consisting of 30nm Pt on 30nm Cr. We apply a DC bias between the nanoprobes, and measure resistance change of the metal line as a function of applied stress. The resistivity of the metallic bilayer decreased, as the force increased. The stress induced permanent deformation. When the nanoindenter head was lifted, the line's shape has locally changed, increasing the overall resistance, and the current didn't return to its initial value after indentation.

Figure 5. Two nanoprobes apply DC bias and monitor the resistivity change as the nanoindenter head applies stress onto a PtCr line. The resistivity change clearly follows the applied pressure and reveals irreversible sample deformation after the nanoindenter is lifted.

CONCLUSION

We present a combined in-situ SEM nanoindentation and electrical nanoprobing solution jointly developed by Alemnis and Imina Technologies. The two capabilities are fully integrated and can be used for a wide range of materials science and nanoelectronics experiments. We have shown a few examples of such experiments, which were done as a proof-of-concept. Such experiments provide deep insight into what happens to materials and devices under mechanical stress, or how they respond mechanically to electrical biasing. The presented solution is straightforward to use, is easy to learn and is aimed to enhance our understanding of microscale phenomena and to help design safer electronic applications.

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Data subject to change without notice. (v1 - 12/2023)