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### ► To cite this version:

François Piquemal, Khaled Kaja, Pascal Chrétien, José A. Morán-Meza, Frédéric Houzé, et al.. Calibrating Resistance Measurements in Conductive Probe Atomic Force Microscopy: development of the first universal standard sample. *Nanoscale 2023: 13th Seminar on Quantitative Microscopy (QM) and 9th Seminar on Nanoscale Calibration, Standards and Methods*, Oct 2023, Helsinki (Finland), Finland. pp.77-78. hal-04230175

**HAL Id: hal-04230175**

**<https://centralesupelec.hal.science/hal-04230175>**

Submitted on 5 Oct 2023

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# Calibrating Resistance Measurements in Conductive Probe Atomic Force Microscopy: development of the first universal standard sample

F. Piquemal,<sup>1,a)</sup> K. Kaja,<sup>1,2</sup> P. Chrétien,<sup>3,4</sup> J. Morán-Meza,<sup>1</sup> F. Houzé,<sup>3,4</sup> C. Ulysse,<sup>5</sup> and A. Harouri<sup>5</sup>

<sup>1</sup> Laboratoire national de métrologie et d'essais - LNE, 78197 Cedex, Trappes, France

<sup>2</sup> Present address: Oxford Instruments Asylum Research, 9 Avenue du Canada 91940, Les Ulis, France

<sup>3</sup> Université Paris-Saclay, CentraleSupélec, CNRS, Laboratoire de Génie Électrique et Électronique de Paris, 91192, Gif-sur-Yvette, France,

<sup>4</sup> Sorbonne Université, CNRS, Laboratoire de Génie Électrique et Électronique de Paris, 75250, Paris, France

<sup>5</sup> Centre de Nanosciences et de Nanotechnologies - C2N, Université Paris-Saclay, CNRS, UMR 9001, Palaiseau, 91120, France

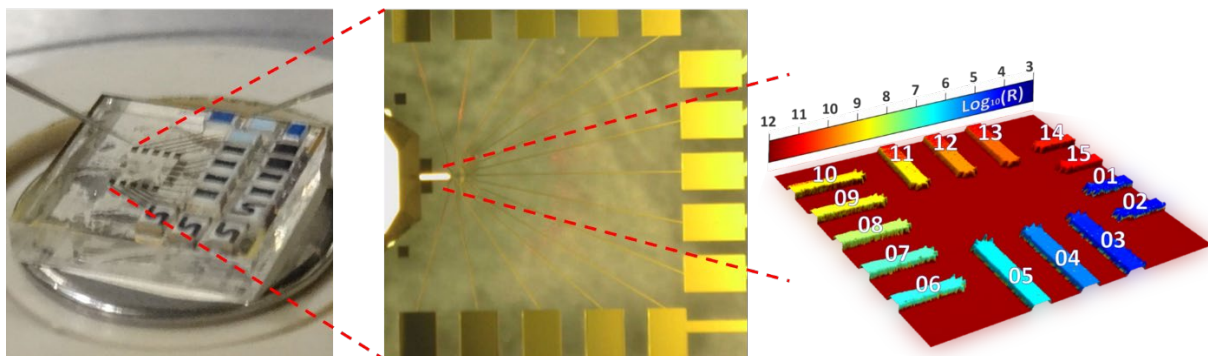
As technological advances keep pushing the limits of devices' fabrication to incredibly smaller scales, a commensurate development of measuring tools and methods is inevitably required. Conductive probe atomic force microscopy (C-AFM) is a scanning probe microscopy method designed to measure nanoscale currents and resistances. It has witnessed a recent rise in popularity owing to the versatility of its application in mainstream technologies, such as memories, photovoltaics, and semiconductors.

Despite the considerable contributions of C-AFM to understanding materials and devices' properties, measurements have remained prone to an arsenal of artifacts-inducing factors. No universal referencing approaches have been addressed so far, which has hindered the applicability of C-AFM in the development of fabrication and synthesis processes.

In this communication, we present the development of the first standard reference sample for the multi-resistance calibration on C-AFM measurements covering the range between 100  $\Omega$  and 100 G $\Omega$ . We discuss a set of measurement protocols using resistance mapping and current-versus-voltage (I-V) spectroscopic approaches to comprehend the quantitative measurement of resistances in C-AFM. For this, we address various factors involved in accurately evaluating the complete C-AFM setup resistance, including experimental, instrumental, and environmental factors.

Our findings show that using the multi-resistance wide-range resistance standard sample developed in this work allows a universal calibration of C-AFM measurements applicable to all available systems and with a 1% achievable relative uncertainty level. Further developments are underway to improve the measurement's accuracy of the lowest resistances (from 100  $\Omega$  to 10 k $\Omega$ ) and expand the resistance range to 1T $\Omega$  or higher.

This new development paves the way for reliable quantitative measurements of resistances and currents at the nanoscale, which is expected to propel the understanding of the nano-electric properties at the level of individual devices and components.



**Figure 1.** (left to right) Photograph of the developed resistance standard sample, top-view of the large and small measurement electrodes showing a conductive AFM probe, and a 3D map of resistances obtained from a C-AFM scan over 15 electrodes covering the range between 100  $\Omega$  and 100 G $\Omega$ .

## **Acknowledgment**

This research work was carried out in the framework of the ELENA project (EMPIR 20IND12), which is supported by the European Metrology Program for Innovation and Research (EMPIR). The EMPIR initiative is co-funded by the European Horizon 2020 research and innovation program and the EMPIR Participating States.