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# ELENA project – electrical nanoscale metrology in industry: key outcomes

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**Abstract— The measurement of electrical properties at the nanoscale allows evaluating the performance of nanomaterials developed for consumer electronics, innovative quantum technologies, and IoT applications. Local DC resistances and high frequency (HF) impedances are among the most prominent properties to measure for nowadays advanced devices. Currently, Conductive Atomic Force Microscopy and Scanning Microwave Microscopy are two main techniques used for the characterization of these properties. Although powerful, these two techniques suffer from major drawbacks: costly, complicated implementation, and lack of traceability. Measurements are thus unreliable. The project ELENA aimed at pioneering the traceability of such measurements, with stated uncertainties, increasing the affordability of these methods by developing and testing cost effective instrumentation and reference standards spanning the range from DC to GHz. Elaboration of robust calibration methods and good practice guides using simplified uncertainty budgets was planned to underpin this effort. This paper describes the key outcomes of this project and gives some perspectives.**

## I. INTRODUCTION

A competitive advantage in the semiconductors industry is gained through the exploitation of new materials and processes, translating into improved components' performances. This requires a metrological infrastructure allowing reliable nanoscale characterisation of new materials and devices, particularly in terms of their electrical parameters and properties. Traceability and reliability of nanoscale measurements stand as a major challenge for electrical properties (*i.e.* resistance, impedance) using conductive atomic

force microscopy (C-AFM) and scanning microwave microscopy (SMM) techniques. The non-destructive analysis nature of these two methods is of paramount importance for the characterization of devices and components. However, the state of the art still lacks established measurement protocols, easy to use reference standards, well-defined best practice guides and easy to use 3D models to assess environmental and external stimulation effects. Moreover, costly instrumentation, particularly for high-frequency measurements, still hinders efficient advancements in these directions.

## II. OBJECTIVES

ELENA was a 3-years European project (start date: 1<sup>st</sup> September 2021; end date 31<sup>st</sup> August 2024) that aimed at bringing solutions to the aforementioned difficulties [1]. Its overall objective was to establish a European metrological infrastructure and cost-effective technologies for C-AFM and SMM providing means for industries to conduct traceable measurements of the electrical properties of materials and devices at the nanoscale. This is achievable by developing and validating reference samples, probes and devices (covering the range from DC to GHz range) for current, resistance and impedance measurements, targeting uncertainties in the order of 10 % or less. Also, developing calibration methods for C-AFM and SMM techniques, including the quantification of uncertainty contributions due to influencing factors such as those arising from the samples design, tip-sample interactions and those originating from the measurement's instrument itself in the laboratory environment. On the simulation side, the

development of reliable 3D multi-physics models based on analytical or numerical approaches was planned, to evaluate the effect of the water meniscus (at the tip-sample interface) as well as the effects of the tip's real shape and composition on electrical measurements. Finally, the Elena consortium was expected to establish simplified uncertainty budgets for the C-AFM and SMM and developing both calibration methods and reference electrical standards for DC current (fA to  $\mu$ A), DC resistance ( $100 \Omega$  to  $100 T\Omega$ ) and HF admittance (100 nS to 100 mS) for use in industrial applications. The scientific results should have been subject for standardization in Technical Committee 113 at the International Electrotechnical Commission (IEC).

We shall present in this communication the key results obtained in this project and give some perspectives.

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#### REFERENCES

- [1] Elena Project website: <http://projects.lne.eu/jrp-elena/>