Université Lille Nord de France
Pôle de Recherche et d'Enseignement Supérieur

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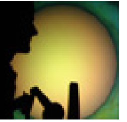

Titre Thèse	Elena - Electrical nanoscale metrology in Industry	
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Financement prévu	Contrat Doctoral Etablissement	ULille ☒ UPHF ☐ Centrale Lille ☐ Yncrea ☐
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Financement acquis ? ☐	Contrats de Recherche ☐ Préciser	Autre ☒ Projet européen H2020 EMPIR ELENA Mai 2021 – Mai 2024 (fonctionnement, équipement)

Overview & Need: Consumer electronics, innovative quantum technologies, and IoT applications all rely on semiconductors where reliable characterisation of electrical properties at the nanoscale is essential for European innovation and competitiveness. Currently, Conductive Atomic Force Microscopes (C-AFM) and Scanning Microwave Microscopes (SMM) enable nanoscale electrical characterization but they are costly, complicated and in many use cases not traceable. This project aims at making such measurements traceable, with stated uncertainties and affordable by developing and testing cost effective instrumentation and first "out of lab" reference standards from DC to GHz. Robust calibration methods and guides using simplified uncertainty budgets will underpin this effort. Micro- and nano-electronics are considered by the European Commission (EC) a Key Enabling Technology (KET) with high potential for innovation throughout the economy, enabling currently 10% of EU Gross domestic product (GDP), and fostering highly skilled employment. A competitive advantage in the semiconductor industry is gained through the exploitation of new materials and processes. This requires reliable nanoscale characterisation of new materials and devices, particularly in terms of electrical parameters such as DC current, DC resistance and high frequency admittance. These quantities finally translate to the speed of transistors and processors, read/write memory access, secured data storage, and telecommunication applications, or to failure analysis. They are also critical to the performance of sensors used in automotive, aerospace and healthcare, as well as to power electronics and clean energy applications, which are crucial for the EC target of Green Manufacturing. Within this context, improved electrical nanoscale metrology has been clearly identified in the Nanoelectronics Standardization Roadmap by the International Electrotechnical Committee (IEC-TC113).

Objectives: The specific objectives are:
1. To develop and validate probes, measurement microwave electronics, and broadband impedance matching procedures for GHz near field scanning microwave microscopes (SMM) and reference standards.
2. To use the results from objective 1 to develop calibration methods for two eSPM techniques: C-AFM and SMM. This should include the quantification of uncertainty contributions such as those that arise from the standards, from tip-sample interactions and those resulting from the measurement instrument itself.
3. To develop reliable 3D multi-physics modelling based on analytical or numerical approaches. This should also include an investigation of the effects of the tip's real shape and composition, and of the tip-sample electromagnetic interactions, on the electrical measurement.
4. To establish simplified uncertainty budgets for the C-AFM and SMM techniques using the results from objectives 2 and 3.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain in the micro- and nano-electronics sector (European industry, electrical scanning probe microscope producers), standards developing organisations (IEC) and end users (NMIs and DIs, and academic and industrial R&D labs).

Relevant publications:

[1] Haddadi, K., & *et al* (2012). Formulation for complete and accurate calibration of six-port reflectometer. *IEEE transactions on microwave theory and techniques*, 60(3), 574-581.
[2] Haddadi, K., *et al*. (2011). A 60 GHz scanning near-field microscope with high spatial resolution sub-surface imaging. *IEEE microwave and wireless components letters*, 21(11), 625-627.
[3] Haddadi, K., *et al*. (2017, September). Combined scanning microwave and electron microscopy: A novel toolbox for hybrid nanoscale material analysis. *In 2017 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)* (pp. 1-3). IEEE.
[4] Ren, D., *et al*. (2020). An ultra-high bandwidth nano-electronic interface to the interior of living cells with integrated fluorescence readout of metabolic activity. *Scientific reports*, 10(1), 1-12.