

## **Title: Nanoscale traceable electrical quantity measurements**

### **Abstract**

This SRT is intended to enable meaningful comparisons of nanoscopic measurements. Semiconductor development and inspection rely on nanoscopic measurements of electrical quantities from DC up to several GHz. The C-AFM (Conductive Atomic Force Microscope) and the SMM (Scanning Microwave Microscope) can be used to measure the relevant parameters of semiconductors: dopant density, sheet conductance, dielectric properties and miniaturised lumped element impedance. There is a strong need in National Metrology Institutes (NMIs) to introduce SI-traceability and uncertainty calculations to these methods.

### **Keywords**

Nanoscale electrical measurements, conductive atomic force microscope, scanning microwave microscope, micro-electronics nano-electronics, calibration method, modelling, standards, traceability.

### **Background to the Metrological Challenges**

Electrical Scanning Probe Microscope (eSPM) techniques are widely used for the development of micro and nanoelectronic devices and to qualify emerging materials. They are implemented to measure various electrical quantities at the nanoscale such as DC current, DC resistance and voltage, low frequency capacitance, microwave impedance, etc. eSPM, C-AFM and SMM are techniques which are versatile and capable of making such measurements traceable to the SI. These techniques enable the determination of key electrical and electronic properties such as doping concentrations, contact or sheet resistances, leakage currents in dielectric layers, and dielectric constants. Partly based on the results of previous EMRP projects IND02-EMINDA and ENG51-SolCell, first implementations of calibration samples (capacitance, doping concentration) and calibration methods have been realised.

The development of metrology around C-AFM and SMM has just started. C-AFM is used in AFM contact mode and shows a resistance and current mapping of the sample in the DC range. It could achieve a high spatial and electrical resolution. Some calibration samples exist for the doping concentration, but nothing exists concerning resistance or current calibration.

SMM offers the ability to acquire electrical quantitative results with high sensitivity and dynamic range by acquiring the magnitude and phase of the microwave scattering S-parameters. SMM allows to both determine the precise position of subsurface nanostructures in 3D and to quantify the sheet conductivity. The technique requires no special sample treatment and is non-invasive, leaving the samples unaltered by the measurements. However, SMM measurements are not yet SI-traceable. Missing SI-traceability and GUM-compliant uncertainty budgets are a serious impediment to the comparison of measurement results and their subsequent use.

### **Objectives**

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceability to SI units at direct current (DC) and GHz frequencies for nanoscale measurements of materials and devices.

The specific objectives are

1. To validate and cross check established and new calibration and measurement methods in the area of DC-current measurement, high frequency (from 1 GHz to 50 GHz) material and impedance measurement involving conductive atomic force microscope (C-AFM) and GHz scanning microwave microscope (SMM) techniques. This includes development of probes, electrical reference standards, and calibration techniques.
2. To conduct experiments with the C-AFM and SMM for quantification of uncertainty contributions coming from the standards used, tip-sample interactions and the measurement instrument.
3. To develop reliable 3D multi-physics modelling, with 10 % or less error margin, based on analytical or numerical approaches in order to evaluate the effect of the water meniscus at the tip-sample interface, as well as electromagnetic interaction between tip and sample, real tip shape and material on the electrical measurement.
4. To establish uncertainty budgets using 2.) and 3.) and to develop calibration methods for the key electrical measurands; DC current from 1 fA to 1 mA, DC resistance from 100  $\Omega$  to 100 T $\Omega$  and HF admittance from 3 mS to 100 mS.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs and industrial and academic R&D labs), standards developing organisations (IEC TC 113) and end users (industry in the sector of micro-/nanoelectronics and electrical scanning probe microscope producers), including the provision of good practice guide for DC current, DC resistance and HF admittance measurements at the nanoscale.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP IND02-EMINDA and EMRP ENG51-SolCell and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the electronics sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

## **Time-scale**

The project should be of up to 3 years duration.