European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry,
Normative and Research Potential

Selected Research Topic number: **SRT-i16**
Version: 1.0

Title: On-wafer microwave metrology for future industrial applications

Abstract

Semiconductor chips are used in many established and emerging applications, e.g., 6G telecommunications, automotive radar sensors, space-deployed radiometers for earth monitoring, and wearable electronics for healthcare. However, there is currently a lack of traceable measurement techniques for millimetre-wave and terahertz (THz) planar integrated circuits (ICs), particularly those based on compound semiconductors. Thus, in order to strengthen the European semiconductor industry and facilitate the development of next-generation semiconductor technologies, new accurate and traceable on-wafer measurement techniques are needed together with best practice guides for on-wafer measurement. In addition, improved methods are needed for the characterisation of compound transistors above 110 GHz, and for novel 2D, thin film and semiconductor materials.

Keywords

Semiconductor industry, millimetre-wave, on-wafer metrology, semiconductor technology

Background to the Metrological Challenges

Semiconductor chips are the essential building blocks of electronic products. From smartphones and cars to critical applications and infrastructure for healthcare, energy, communications and industrial automation, chips are indispensable to the digital economy. Over the past two years, Europe and other regions of the world have experienced chip supply shortages due to the COVID-19 pandemic. To try and overcome the semiconductor shortage, the European Commission adopted the European Chips Act in February 2022. Although this will help to support Europe's technological leadership in the global semiconductor industry, new emerging technologies are expected from the radiofrequency (RF) and microwave industries in the coming years, which will add further challenges and requirements.

Previous (EMPIR) projects 14IND02 PlanarCal and 18SIB09 TEMMT have developed the foundations for traceable on-wafer metrology for planar transmission lines such as coplanar waveguides (CPWs) on conventional substrate materials. However, the measurement capabilities developed in these projects were mainly used for calibration.

New broadband measurement systems for high accuracy on-wafer measurements are currently being developed commercially. However, these measurement facilities have not yet been implemented at NMIs in Europe, nor has traceability for single-sweep broadband on-wafer measurements been established. Therefore, research into these new hardware solutions is needed to test and verify equipment manufacturers' systems.

To date, traceable on-wafer metrology has only been developed for CPWs on conventional substrate materials, and there is no traceable metrology for industrial semiconductor technologies, including emerging applications. Furthermore, traceability has only been established for passive devices up to 110 GHz. Traceability methods for active devices (i.e. high frequency transistors) still need to be developed. Finally, although commercial material measurement systems were investigated in the previous 18SIB09 TEMMT project using conventional materials, the characterisation of novel 2D, thin film and semiconductor materials has not been done.

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 traceable measurement and characterisation of on-wafer microwave measurements.

The specific objectives are:

1. To develop new hardware and software solutions for on-wafer measurements at millimetre-wave and terahertz frequencies by comparing conventional on-wafer measurement systems with new broadband single-sweep systems. In addition to investigate new on-wafer measurement methods (e.g., Rydberg-atom-based probes, artificial intelligence or machine learning driven probing) as alternatives to traditional on-wafer probing methods.
2. To design, fabricate and characterise improved calibration substrates for industrial semiconductor technologies. This should include developing design guidelines and verification techniques to ensure the metrological traceability of the calibration substrates.
3. To develop reliable and accurate on-wafer characterisation techniques for downscaled millimetre-wave and terahertz transistors (i.e. up to 220 GHz). In addition, to develop verification techniques and determine reliable uncertainties for on-wafer measurements of millimetre-wave and sub-terahertz (0.1 to 0.3 THz) transistors. This should include an evaluation of the small signal characteristics of advanced transistor technologies, e.g. Indium Phosphide (InP) heterojunction bipolar transistors (HBTs), in order to build equivalent circuit models for high frequency InP transistors and to extract figures of merit.
4. To develop accurate methods for the characterisation of semiconductor materials, thin films and novel 2D materials for emerging applications. In addition, to develop new on-wafer-based material characterisation methods and compare them with conventional commercially available material characterisation methods.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (research institutes, calibration laboratories), standards developing organisations (e.g. IEEE Microwave Theory and Techniques Standards Committee (MTT SC)) and end users (e.g. semiconductor and industry sectors).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

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 EMPIR projects 14IND02 and 18SIB09 and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

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,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the semiconductor technology and industrial sectors

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 the Partnership 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.