Publishable Summary for 16ENG06 ADVENT
Metrology for advanced energy-saving technology in next-generation electronics applications

Overview
The roll-out of 5th Generation (5G) telecommunications across Europe by the year 2020, and the emergence of the Internet of Things (IoT) with 50 billion connected devices, will strongly increase the demand for energy due to the continuous power consumption of the electronic devices needed to deliver these technologies, leading to an associated demand for more energy-efficient systems. This project establishes the metrology required for this transformational objective for Europe by providing traceable measurements of power, losses and emerging electronic materials properties. Thus this project will enable European industries to optimise device and systems design for 5G and IoT applications requiring ultra-low power and more energy efficient operation.

Need
The ongoing IoT and the future 5G radio access network will have a fundamental impact on the daily life of all European citizens. Sensors (the cornerstone of IoT) will be found everywhere (car, house, industrial health monitoring, etc.) and 5G communication systems will provide greater connectivity (Machine-to-Machine, high data rates with low latency). The high data-rate aspect of 5G at mmWave frequencies makes the power consumption and thermal issues very challenging in wireless devices. By 2020, the Information and Communications Technology (ICT) sector is expected to contribute about 2 % of global CO2 emissions instead of 1.3 % in 2007 (Ericsson report, 2010). Within this, 20 % of the footprint may be attributed to personal mobile networks and mobile devices. Phones and tablets will produce the strongest percentage increase in the ICT's footprint: recent estimations forecast 50 billion devices enhancing the footprint by a factor of 4.

Improvement of the energy efficiency of devices and processes is therefore a key component for sustainable development of European products. Due to restrictions in current scaling strategies and dramatic thermal issues (particularly in wireless systems), semiconductor and electronics manufacturing roadmaps are aimed at the introduction of novel materials, more complete component characterisation and more efficient power management at the system level that will lead to the development of novel ultra-low power devices. To support industry in facing these challenging issues, traceable measurement techniques are required that will establish a robust metrology framework for in-situ, in-operando and multiphysics characterisation of advanced materials and components, and for reliable and accurate data for an efficient power management system.

Objectives
The overall objective is to achieve traceable and accurate measurements of the power consumed by ultra-low power and high frequency energy efficient electronic materials, devices and systems in order to support their development in both industrial and research sectors.

The specific objectives of the project are:

1. To develop nanometrology adapted to the in-situ and in-operando characterisation of advanced new materials proposed for the next generation of ultra-low power energy-efficient devices. These measurements will include impedance measurements (capacitance, resistance and inductance), piezo-electric/piezoresistive stress (200 MPa) and strain (0.02 %) responses to the application of electric (up to 4 MV/cm) and magnetic (up to 2 T) fields, as well as temperature and pressure in the range encountered in electronic devices.

2. To develop frequency and time-domain techniques for the simultaneous measurement of dynamic thermal profiles, electro-magnetic field sensing, DC electrical power consumption and RF operating waveforms for a wide range of RF electronic components (operating in-situ, under realistic conditions).

These techniques to be combined with a multi-physics approach, which will establish rigorous energy budgets, and diagnostic capabilities, for a wide range of electronic components (operating in-situ, under realistic conditions), required for next-generation communications. The uncertainty in the measurement of the power efficiency to be reduced to less than 1 %.

3. To develop embedded sensors and the associated calibration and measurement techniques to accurately measure power consumption of wireless systems (mobile phones, tablets and connected devices) and to improve the effectiveness of analogue and RF tests of components and systems. The power measurement techniques will be able to characterise and calibrate on-chip power sensors with an uncertainty of less than 10 µW.
4. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories), standards developing organisations (ISO) and end users (the semiconductor industry, and the telecommunications sector).

Progress beyond the state of the art

This project will act at three different scales (materials, components and systems) to support European industries in the development of optimised energy devices and systems required for 5G and IoT applications.

Materials

The characterisation of novel materials, such as ferroelectric, multiferroic, and piezoelectric-resistive materials, requires a joint effort in improved impedance, material structure and compositional metrology. Currently, the impedance measurement and structural analysis at nanoscale of such materials suffers from a lack of traceability, insufficient resolution and reliability. This project will develop a broad platform of metrologies to extend the spatial resolution of material structure and compositional measurement down to the nanometre scale, to quantify impedance of novel materials with an uncertainty of 10%, and to extend measurement of stress and strain responses to electric field up to 4 MV/cm and magnetic fields up to 2 T.

RF components

RF electronic components are never single transistors and it is critical to understand design limitations by measuring the electromagnetic fields, temperatures and losses distribution as the device operates. In Europe, no metrology basis exists to measure simultaneously and in-operando the electromagnetic and thermal responses of RF and microwave components under realistic operating conditions and to measure switching losses accurately. This project will combine a range of contacting and non-contacting techniques to reduce the current uncertainty in evaluating the power efficiency of such electronic components from 2% to 1%.

Systems and devices

To optimise the power consumption and system performance of battery-supplied devices, it is necessary to monitor and adjust the transmitted RF power accurately and continuously. On-chip power levels measured in these devices can be as low as the micro watt level. Even if power and thermal measurements are becoming increasingly integrated by many semiconductor suppliers at chip level, the traceability of on-chip power measurements does not exist at NMI levels. This project will develop traceable high frequency power metrology for on-chip power measurements with an uncertainty of less than 10 µW.

Expected Results

Nanometrology for characterisation of new materials

This project will develop new impedance standards and will identify error sources involved in very small capacitance measurements (down to the attofarad range) to improve reliability and establish traceability of Scanning Microwave Measurement (SMM) methods used to characterise high permittivity and losses of nanomaterials. This project will qualify and extend complementary, independent and traceable methodologies (X-ray, TEM and LIMM) for the in-situ characterisation of advanced materials (piezo and ferroelectric materials) under different operational environments (stress, strain, pressure, electric and magnetic fields) and will develop and adapt Focused Ion Beam Milling techniques required for the preparation of samples. The dataset produced by such advanced measurement techniques will be made available to correlate materials structure and device functionality.

Multiphysics characterisation of RF components

The project will develop and combine time- and frequency-domain, electromagnetic field and thermal mapping measurement techniques to establish rigorous energy budgets, and diagnostic capabilities, for a wide range of electronic components (operating in-situ, under realistic conditions), required for next-generation communications. This multidisciplinary approach will produce datasets that will be simultaneously analysed and correlated to evaluate the power efficiency of such electronic components. Detailed error analyses of each measurement system will be made available and the uncertainty of the power efficiency will be established (target value of 1 %). A time-domain method, algorithms and tools will be specifically developed for the losses measurements of high-speed switching devices such as GaN, MOSFET and IGBT transistors.

Power consumption measurement of wireless systems and devices

This project will develop embedded BiCMOS sensors, with an associated calibration method, to establish the traceability of on-chip power measurement with 10 µW uncertainty. This project will develop algorithms and adapt near-field scanner test benches, used so far for electromagnetic compatibility issues, to evaluate the level and location of power losses generated by heat or radiation. Data measurements of the non-contactless measurement technique will be produced to compare energy consumption between electronic boards and improve the design of components and effectiveness of analogue and RF tests. This project will finally provide to industry low cost and traceable sensors and fast scanning measurement data to improve on-chip power traceability.

Impact

Impact on industrial and other user communities

Outputs from the project will directly improve material and component characterisation as well as accuracy of power sensors, which will be used by industry to improve their systems' performance at lower cost: improvements boosting performance and functionality at all levels (device, circuit, system), and, in particular, in relation to the few critical parameters such as: power consumption, operating frequency, switching time, throughput, and device or circuit complexity. This project will enable the increase in performance of power management systems - the cornerstone of wireless mobile devices. Outputs in x-ray spectrometry and related atomic fundamental data will be fed directly into a recent academic and industrial international roadmap at LNE-LNHB (www.nucleide.org/IIFP.htm). Impedance standards fabricated in the framework of the project will be available for end-users of scanning probe instruments.

Impact on the metrological and scientific communities

Scientific communities will benefit from new extended measurement capabilities: (i) a high-level platform in nanometrology (nanoscale impedance, stress and strain, X-ray, LIMM), (ii) a unique test-bench assembling different measurement techniques (electromagnetic measurements in the time-and frequency-domain, thermal mapping); and, traceable on-chip low cost power sensors. Successful outcomes of the project will therefore be submitted for publication in high impact peer-reviewed journals and, as part of the knowledge transfer, two specific workshops (on materials, on characterisation of electronic components and power measurements) will be organised and held. Representatives of industry (both manufacturers and users), academics and NMIs will be invited to these workshops.

Impact on relevant standards

Project progress and engagement will be reported at IEC (TC 47, 49 and 113), ISO (TC46 and TC206), IEEE (P1859/D6), VAMAS (TWA24) and EURAMET TC-EM SC-RF&MW/EMC, SC-LF committees through dissemination of good practice guides and organisation of meetings dedicated to standardisation activities relating to semiconductor devices, piezoelectric and dielectric devices and characterisation of materials at the nanoscale.

The expected impact of these actions will be:

- To provide internationally recognised test methods for the most important properties (piezoelectric coefficient measurement, high stress dielectric property measurement, the measurement of strain at high stresses) that are required for these new advanced materials.
- To enable the technical committees preparing international standards for the design and manufacture of integrated circuits, and industry, to incorporate multiphysics measurement methods that are required to evaluate the dynamic thermal and electromagnetic gradients inside RF semiconductor devices in operation.

Project start date and duration:	1 September 2017, 36 Months

Coordinator: François Ziadé, Dr. SC., LNE Tel: +331 30 69 21 71 E-mail: francois.ziade@lne.fr Project website address: not yet available		
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