EMPIR Call 2020 – Fundamental, Industry and Normative

Selected Research Topic number: **SRT-f14**
Version: 1.0

Title: Memristive devices as quantum standard for nanometrology

Abstract

The revision of the International System of Units (SI) in 2019 represents a historic change of paradigm for metrology, defining all the SI units in terms of fundamental constants of nature. The development of new experiments and devices are now needed to correlate physical observables to the fixed defining constants. Memristive devices exhibiting quantized conductance levels represent promising platforms for the realisation of quantum-based standards of resistance working in air at room temperature. The scalability down to the nanoscale, the high operational speed in the range of ps and the CMOS compatibility, make memristive devices suitable candidates for on-chip integration of resistance standards for self-calibrating systems with zero-chain traceability. It is therefore important to develop nanometrological characterisation techniques and memristive model systems for investigating quantized effects at the nanoscale underlaying memristive behaviour.

Keywords

Memristive devices, resistive switching, resistance standard, quantized conductance, quantum point contact

Background to the Metrological Challenges

Memristive devices are two-terminal devices where the internal state of resistance depends on the history of applied voltage and current. The working principle is the so-called resistive switching effect, a mechanism based on the atomic reconfiguration that is possible to induce in some materials (such as metal-oxides) under proper electrical stimulation. The involved nanoionic effects underlying resistive switching are related to the formation/rupture of nanosized conductive paths in the active material responsible for the variation of device resistance. Memristive devices are particularly promising for the realisation of a standard of resistance implementable in CMOS technology, with high speed (ps), working in air, in a wide range of temperatures (from 4 K to 600 K) and showing extreme stability against electromagnetic and cosmic waves, high energy particles (avoiding soft errors) and in general harsh environment.

The comprehension of physicochemical processes underlying resistive switching behaviour are hampered by *i)* the coupling of physical phenomena such as electrochemical reactions, mass transport including diffusion and electromigration of ions, electronic transport and Joule heating; *ii)* the difficulty of uncoupling the effects of the numerous driving forces such as electric field, local environment and temperature acting during device operation; *iii)* a poor understanding of the influence of chemical/structural properties of the involved materials on device functionalities. Because the formation/rupture of conductive paths underlying memristive behaviour occurs at nanoscale, properties of the materials require investigation with high spatial resolution at near-atomic-scale. The development of suitable metrology is limited by changes in physical quantities due to quantum confinement and noise. Concerning device characterisation, Conductive Atomic Force Microscopy (C-AFM) turned to be an ideal characterisation tool for correlating local variation of device resistance to morphological changes in memristive materials. However, C-AFM fails in a quantitative evaluation of chemical modifications after atomic rearrangements. Scanning Microwave Microscopy (SMM) can deliver a new perspective on memristive devices by providing frequency sweeps of impedance. The ballistic charge transport is nearly frequency independent, but the surrounding geometry and media determine high frequency impedance. As an alternative, techniques such as *in-situ* Transmission Electron Microscopy (TEM) have been used to investigate the change of the device morphologies and filament formation during resistive switching events. Even if this technique allowed a direct evaluation of chemical/structural changes during operation, it requires the realisation of *ad-hoc* samples where the switching mechanism can differ from conventional memristive devices. There is a need for metrological techniques to allow a quantitative investigation of atomically resolved structural and chemical properties of memristive materials by *in operando* cross-platform measurement techniques, enabling characterisation under electrical bias.

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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 memristive devices.

The specific objectives are

1. To develop well-controlled memristive model systems for establishing a relationship between the involved materials and device functionalities. This should include the manufacturing of memristive cells by combination of deposition functional layers, structuring methods, surface treatment and engineering.
2. To investigate nanoionics processes by advancing reliable nanoelectrical characterisation of memristive devices by using metrological scanning probe microscopies (SPMs) for probing its local electrical properties by means of traceable conductive AFM (C-AFM), SMM, scalpel C-AFM for 3D reconstruction of the memristive cells and Scanning Tunnelling Microscopy (STM).
3. To develop a traceable quantification of chemical, structural and ionic/electronic properties of memristive devices through scanning microscopy (AFM, SEM), atom-probe microscopy, Secondary Ion Mass Spectroscopy (SIMS), X-ray Spectrometry including X-ray diffraction (XRD) and Energy Dispersive X-ray Spectroscopy (EDS) in order to achieve nanodimensional characterisation at near atomic scale of the physical mechanism of the memristive cell.
4. To develop metrological cross-platforms measurement techniques with high resolution in space (< 10 nm) and time (< ms) for investigating device dynamics by correlating the variation of chemical/structural properties to the electrical response of memristive devices in-operando. To also develop quantum-based standard of resistance for nano applications including CMOS compatible and on-chip implementable resistance standards.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (nanometrology), standards developing organisations (IEC TC 113, Polish Committee for Standardisation, Versailles Project on Advanced Materials and Standards (VAMAS) TWA 2 and TWA 21) and end users (nanoelectronics).

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % 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 nanometrology 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.