EMPIR Call 2016 – Energy, Environment, Normative and Research Potential

Selected Research Topic number: **SRT-n07**
Version: 1.0

Title: Developing electrical characterisation methods for future graphene electronics

Abstract

Graphene has been shown to have superlative electronic properties, but its commercialisation and uptake by large-scale end-users is hindered because industrially produced graphene is not yet reliably characterised and thus cannot be compared or developed commercially. For future electronic products based on this material to be developed and commercialised, novel techniques to measure the electronic properties of graphene have to be developed. The required electrical measurement techniques for both high-accuracy and fast throughput and related protocols for graphene must be identified, developed and standardised to overcome the existing gap.

Keywords

Graphene, electrical characterisation, nanodevices, standardisation, contact measurement, non-contact measurement

Background to the Metrological Challenges

The market for graphene is estimated to be worth ~$400 million in 2024, which represents a growth of more than 300 % per year. However, due to its nanoscale nature, the characterisation of graphene offers many challenges that must be addressed before real-world graphene products enter the market.

A business plan for graphene has been initiated within the CENELEC workshop on Specifications for Graphene Related Material (WS SGRM) and six graphene projects have now been approved. In addition, the first international standards related to graphene are under development by international standards committees e.g. IEC/TC 113 and ISO/TC 229, and five activities related to the characterisation of the electrical properties of graphene now under development:

- ISO/TS 80004-13 'Nanotechnologies - Vocabulary - Part 13: Graphene and other two-dimensional materials
- IEC/TS 62565-3-1 Ed. 1.0 "Nanomanufacturing - Material specifications - Part 3-1: Graphene - Blank detail specification"
- IEC/TS 62607-6-1 Ed. 1.0 "Nanomanufacturing - Key control characteristics - Part 6-1: Graphene - Electrical characterization
- IEC/TS 62607-6-4 Ed. 1.0 “Nanomanufacturing - Key control characteristics - Part 6-4: Graphene - Non-contact conductance measurement using resonant cavity"
- IEC/TS 62607-6-5 Ed. 1.0 “Nanomanufacturing - Key control characteristics - Part 6-5: Graphene – Sheet resistance and contact resistance measurement using the transmission line method”

The main requirement in this area is the development of the electrical characterisation of graphene in real-world nanodevices. Current state-of-the-art electrical characterisation tools for graphene include the van der Pauw method, magnetotransport measurements, scanning tunnelling microscopy (STM), scanning Kelvin probe microscopy (SKPM), spread resistance microscopy and microwave resonant cavity methods. These methods have already been extensively used to measure the electrical properties of graphene and a substantial knowledge base has been established over the last decade of graphene research. This capability (both equipment and expertise) typically resides within NMIs and universities, but there are no established measurement standards in this area that allow the cross-comparison of even a few basic properties of graphene. Although industry uses a few of the (typically more affordable) tools, it does not have the level of

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expertise required to develop traceable methodologies that are capable of mutual validation. SMEs, in particular, only have a limited ability to compete in this commercial area until usable and standardised methods are available to industry. Additionally, product specifications of manufacturers are also an issue where a normative action is strongly required.

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 metrology research necessary to support standardisation in electrical characterisation of graphene.

The specific objectives are

1. To develop an accurate and traceable approach for the electrical characterisation of graphene through the development of methodologies for i) contact measurement and ii) non-contact measurement of the electrical properties of graphene, with traceability to electrical SI units. The quantities to be addressed shall include sheet resistance, conductivity, mobility, work function, permittivity, doping level and contact resistance, together with the calibration of the measuring setups and expression of the measurement uncertainty.
2. To develop a high-throughput approach for the electrical characterisation of graphene. This must include the development of novel methodologies for the non-contact electrical characterisation of graphene and comparison of these methodologies with established techniques to validate the measurement uncertainty obtained in the project. The quantities to be addressed shall include sheet resistance, conductivity, mobility, work function, permittivity, doping level and contact resistance.
3. To disseminate the metrology and methodologies established in this project in the form of Good Practice Guides. The dissemination should take place as early as possible to establish a standardised approach in industry.
4. To contribute to the standards development work of the technical committees ISO/TC229, IEC/TC113 and CENELEC WS SGRM to ensure that the outputs of the project are aligned with their needs, communicated quickly to those developing the standards and to those who will use them, and in a form that can be incorporated into the standards at the earliest opportunity.

The proposed research shall be justified by clear reference to the measurement needs within strategic documents published by the relevant Standards Developing Organisation or by a letter signed by the convenor of the respective TC/WG. EURAMET encourages proposals that include representatives from industry, regulators and standardisation bodies actively participating in the projects.

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

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 0.6 M€, and has defined an upper limit of 0.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution to the project.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded 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, in particular IEC/TC 113, CENELEC WS SGRM and ISO/TC 229.
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the nanoelectronics 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.

Additional information

The documents from CENELEC outlining their priorities can be found at

http://msu.euramet.org/current_calls/pre_norm_2016/documents/SRT_related_CEN_priorities/cen_priority_14_2015.zip