Title: Metrology with/for NEMS

Abstract

Nano-Electro-Mechanical Systems (NEMS) is a new key technology which will both enable and demand innovative metrology, impacting strongly over a range of sectors. As the dimensions of the devices and structures reduce, new technologies and approaches are required to capitalise on the potential of NEMS. These include the development and metrological characterisation of high frequency high performance nanoscale mechanical resonators and actuators, integrated nanoscale dc and rf power sensors for use in ultra stable and miniaturized voltage references, dynamic cooling techniques to advance beyond classical thermal and sensitivity limits, the selection and characterisation of materials to optimise NEMS performance, and traceable metrology in mass, force, displacement and temperature at the nanoscale.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Health, New Technologies & Fundamental Metrology on pages 9 and 25.

Keywords

Nano-Electro-Mechanical Systems, NEMS, near-field microwaves, dynamic cooling, nanoSQUIDs, nanoscale dc and rf power sensor, ultra-low force and mass detection, nanoscale sensors

Background to the Metrological Challenges

Nano-Electro-Mechanical Systems (NEMS) have been flagged as an emerging disruptive technology in numerous roadmaps (e.g. ITRS Public Conference on Emerging Research Devices, Dec. 2010). The most exciting class of NEMS devices for metrological applications are high Q (low-loss) mechanical resonators since in general they combine the high accuracy of frequency measurement with the excellent sensitivity of nanoscale sensors.

As NEMS devices become smaller their oscillation displacement amplitude scales down rapidly with size so that ultrasensitive transducer techniques and excitation schemes with low dissipation are required. The scaling behaviour and defect dependence of mechanical damping are key issues for the potential development of NEMS based integrated circuits for sensor applications. Metrology methods for validation of dynamic measurements of samples need to be developed.

The selection and optimisation of materials is critical to the achievable performance and the resulting application potential of NEMS structures, with target parameters including high values of Young modulus, high degree of elasticity, low mass etc for exceptional performance and low loss, for specific applications of NEMS sensor and actuators. Potential materials include silicon on insulator (SOI), AlN, low stress polysilicon plus novel materials such as graphene.

As dimensions are reduced ultra stable and ultra miniaturized voltage references for dc and ac current and for rf and microwave power sensors are required together with new system architectures.

Advanced ultra-low temperature research has enabled one US laboratory (University of California, Santa Barbara (UCSB)) to achieve the quantum ground state of a NEMS resonator. Dynamic cooling is one key technological innovation which has the potential to achieve measurement ‘beyond classical’ thermal limits, for example the use of room temperature dynamic cooling with microwaves.

In order to approach the thermal equilibrium quantum limit, operation of NEMS resonators at mK-temperatures is needed. Readout techniques therefore need to be developed that are compatible with this temperature range. SQUIDs are a possibility as they enable ultra-sensitive readout of NEMS resonators whilst offering the potential to minimise heating of the resonator.

Traceable metrology in mass, force, displacement and temperature are currently lacking at the nanoscale but are increasingly needed. In addition improved measurement methods and traceability for dynamical form measurements of MEMS/NEMS are crucial for better understanding of behaviour of components and future quality control needs.

Scientific and Technological 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 JRP-Protocol.

The JRP shall focus on the development of nanoscale mechanical systems as high frequency resonators and actuators for future metrology applications, including single entity and traceable measurements 'beyond classical limits'.

The specific objectives are

1. To develop novel methods for nano-electro-mechanical systems (NEMS) resonator excitation and readout to take account of the reducing size of NEMS devices, including metrology methods for validation of dynamic optical characterisation of samples. Developments for readouts should address piezo-resistive, capacitive and near-field microwave techniques.
2. To select and optimise materials such as AlN, silicon on insulator (SOI), low stress polysilicon, and new materials e.g. graphene for high performance NEMS.
3. To develop architectures for integration/readout of NEMS sensors, references and arrays.
4. To develop dynamic cooling methods to enable measurement 'beyond classical' thermal limits.
5. To fabricate and optimise cryogenic SQUID-NEMS combinations, enabling the operation of NEMS resonators at close to thermal equilibrium quantum limits (mK-temperatures).

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, the involvement of the appropriate user community such as industry, and standardisation and regulatory bodies, is strongly recommended.

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

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the "end user" community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the "end user" community (eg letters of support) is encouraged.

You should detail other impacts of your proposed JRP as detailed in the document "Guide 4: Writing a Joint Research Project"

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the electronics, instrumentation, telecoms, healthcare and security sectors.

In addition proposers should identify real metrological need and applications for this technology and indicate how they plan to engage with the relevant industries and stakeholders to facilitate adoption of the outputs of the proposed research into real-life applications.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. 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 Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.