EMRP Call 2012 – Open Excellence, Industry and SI Broader Scope

Selected Research Topic number: **SRT-x05**
Version: 1.0

Title: Quantum optomechanics and quantum enhanced ultra-high precision measurements

Abstract

Basic research in quantum optomechanics is the first step towards the use of mechanical devices as tools for quantum metrology. Initial research in this area should develop mechanical probes into the quantum regime that work at the quantum Heisenberg limits and so facilitate new quantum standards, lead to new applications in medical screening, navigation, communication networks, and facilitate tests of fundamental physics on the feasibility of the preparing, processing and detecting macroscopic quantum-mechanical states.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Industry & Fundamental Metrology on pages 7, 10, and 15.

Keywords

Quantum opto-mechanics; micro/nano-mechanical resonators; Quantum measurement; atto-newton forces; Resonator micro-balances; Ultra-precision displacement and tilt measurements; Quantum-enhanced measurements and its classical analogues; Quantum entangled photon interferometry; Quantum weak value amplification; Dispersion cancellation; Quantum ground state cooling

Background to the Metrological Challenges

Basic research in quantum optomechanics (decoherence and tests of quantum gravity, the wave-function collapse, and the transition between quantum and classical regimes), in addition to providing a glimpse into the quantum behaviour of mesoscopic systems consisting of billions of atoms, is the first step towards the use of mechanical devices as tools for quantum metrology. Mechanical resonators at the micro- and nanometer scales are already used to measure mass and force with extreme sensitivities. Individual atoms and molecules are weighed and the forces between biomolecules, as well as those associated with single spin undergoing magnetic resonance, have been resolved. Whilst the harnessing of quantum probes in the form of atoms, photons, and electrons has enabled advances in many areas of quantum metrology, the thermal noise in the probes' motional degrees of freedom still limits the attainable precision. Optical interactions, combining cooling and trapping, provide a tool that could bring a mechanical system into its ground state without the use of cryogenics. Quantum optomechanics will not only improve the performance of existing mechanical sensors (forces at the sub-attonewton level and displacements at the femtometre level), but it will also enable new measurement techniques (e.g. the quantum non-demolition measurements of photon number).

In the field of the metrology of mechanical quantities, the above concepts (with or without the employment of quantum resources) have yet to be moved on from academic proof-of-principle demonstrations towards "real-world" applicability, let alone commercial implementation. Work towards closing this gap (demonstrations with relevant artefacts for selected application fields) is needed.

Other fields of metrology, such as optical time and frequency standards or quantum information technology, have already advanced in this direction and the concepts developed there could support the necessary work. For example, the development of a very sensitive position transducer in combination with a mechanical resonator capable of approaching the quantum regime would have significant consequences in both fundamental aspects of quantum physics and in applications (detection of nanoforces, entanglement and the decoherence of mechanical resonators, quantum limits in gravitational-wave antennas, etc).

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 theoretical and technological capabilities to realise, to control, to cool, and to perform measurements on micro/nano-mechanical systems operating in the quantum regime.

The specific objectives are:

1. To develop methods for coupling micromechanical systems to optical cavities in order to optically monitor, cool, and control motional degrees of freedom. This work could include fabricating micromechanical resonators (e.g. micromebrane, microspheres) and mechanically compliant, high-reflectivity mirrors. The goal is to bring these systems into the quantum regime, facilitate tests of fundamental physics, and further develop them as candidate next-generation metrological tools.
2. To demonstrate quantum-enhanced measurement of ultra-precision systems at the mesoscopic scale. For example in measurement of dimensional degrees of freedom.
3. To verify the mechanical properties of micromechanical resonators by using traceable local electrical measurements

Proposers shall give priority to work that enables new metrological methods and techniques in the future through excellent science. The project need not address metrology directly.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. Reference may be made to the iMERA-Plus JRP T1.J2.3 “The Quantum Candela"; and JRPs IND06- “Metrology for Industrial Quantum Communications“; and SIB04 "High Accuracy Optical Clocks with Trapped Ions"

The total eligible cost of any proposal received for this SRT is expected to be 1.8 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 84 months of effort.

Potential Impact

The project should be designed to bring together the best scientists in Europe and beyond whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes. Significant non-NMI/DI and international participation in the projects is expected and proposers should make full use of the larger budget for Research Excellence Grants available for this SRT.

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

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 and includes 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 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.