Title: Photonic and optomechanical sensors for nanoscaled and quantum thermometry

Abstract

Photonics and Quantum Optomechanics are two disruptive technologies which could have a significant effect on present metrology challenges. Photonic sensors can use the light-matter interaction to detect changes in material properties which can indicate a temperature. One possibility is to use nano-photonic devices in combination with nano-mechanical systems (opto-mechanical sensors) to develop quantum primary standards using the scale of quantum correlations determined by fundamental constants, to gauge the size of thermal motion.

Keywords

Photonic sensor, optomechanics, cavity quantum electrodynamics, quantum optics, primary thermometry, primary radiometry, optical flux, temperature, mesoscopic scale

Background to the Metrological Challenges

At present, most temperature measurements are based on artefacts that exploit the thermal properties of materials. These properties are usually probed using voltage/resistance measurements and enable the most sensitive measurement capabilities. The underlying technology has changed little over the last century. The standard platinum resistance thermometer, the temperature sensor most widely used and able to achieve the best measurement uncertainties is more than 100 years old, and many modern temperature sensors still rely on resistance measurements of a thin metal film or a wire. Although resistance thermometers can measure temperature with uncertainties as small as a fraction of a mK, they are sensitive to mechanical shock, thermal stress and environmental variables such as humidity and chemical contaminants that cause drifts and require frequent re-calibrations. These fundamental limitations, as well as the desire to reduce sensor ownership cost is producing considerable interest in the search for new technologies able to produce new sensing devices.

This SRT invites proposals to study new primary methods of temperature measurement using vacuum noise as a quantised standard to scale thermal noise, optical intensity or force at the micrometre or nanometre scale.

As temperature sensors become smaller and more integrated, it becomes more difficult to calibrate them with the usual macroscopic standards. Microscopic measurement devices operating at room temperature and at mesoscopic scale must be calibrated in situ and in real-time during their use. Due to recent improvements in optomechanical quantum sensors, it is now possible to meet this challenge at room temperature. A first step is to use photonic devices with ITS-90 traceability and uncertainties below 1 mK. A quantum primary method becomes a competitive measurement solution at the microscopic scale because, the uncertainty of the calibration grows significantly if the standard is many orders of magnitude bigger than the test device. The direct coupling of the measured quantity to the quantised standard observed with a mesoscopic device would offer new metrological approaches.

Opto-mechanical systems will need to overcome several barriers in order to exploit their quantum properties. Examples of these barriers are cooling of opto-mechanical micro-resonators to the quantum ground state, observation of quantum back-action forces (i.e. radiation pressure from shot noise), the use of squeezed light for sub-shot noise measurements of micromechanical oscillations and even the squeezing of a mechanical quadrature below the ground state fluctuations. Overcoming these barriers will pave the way towards realisation of an ultra-low noise quantum sensor operating at the Heisenberg limit.

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 exploring the potential of high resolution quantum and photonics sensors in terms of sensitivity, accuracy and resolution for realising future quantum and nanoscaled temperature standards.

The specific objectives are

1. To design and fabricate different photonic and opto-mechanical devices dedicated to temperature metrology at the nano- and micro-scale: photonic crystal cavities, micro-rings, micro-disks and membrane resonators with high optical ($>10^8$) and mechanical quality factors.
2. To investigate the optical and mechanical performance (photo-elastic properties) of several materials: III-V semiconductors, Si- based and diamond based, and their influence in the quality factor of the optical and mechanical resonators. To study the viability of these devices in quantum optomechanical resonators.
3. To characterise the metrological repeatability, sensitivity, and stability of both photonic and opto-mechanical devices, and demonstrate quantum-based read-out protocols for opto-mechanical devices as quantum primary temperature standards up to ambient temperature.
4. To develop methods for calibrating the developed mesoscopic sensors traceable to the International Temperature Scale of 1990 (ITS-90) including the evaluation of the uncertainty.
5. To facilitate the take up of the technology, developed in the project, by end users in the field of quantum and nanoscaled technology.

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 to the project.

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,

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.