**EMPIR Call 2020 – Fundamental, Industry and Normative**

Selected Research Topic number: **SRT-f01**
Version: 1.0

# Title: Combined photonic and quantum sensors for practical primary thermometry

## Abstract

The redefinition of the international system of units in terms of fundamental constants enables novel approaches to the practical primary thermometry realisation and dissemination of thermodynamic temperature. By integrating photonic and quantum technologies into a chipset, zero drift, temperature sensing to cover the range from 4 K to 500 K could be realised. Proposals addressing this SRT should contribute towards the development of such practical primary thermometry and demonstrate in situ calibration by investigating the combination of photonic sensors with primary techniques providing quantum reference, such as optomechanical resonators or Doppler broadening thermometry.

## Keywords

Practical primary thermometry, chipset, photonic resonator, quantum optomechanics, Doppler broadening

## Background to the Metrological Challenges

Today, there is a clear lack of practical primary thermometers and this is a barrier for the dissemination of the redefined kelvin according to the *mise en pratique* for the definition of the kelvin outside National Metrology Institutes. Optically based primary thermometry techniques combined with high resolution photonic thermometers, all integrated on a chip set, could be used to overcome this problem and to realise a practical quantum primary thermometer.

The use of chipset photonic technologies enables the integration of different optical techniques for primary thermometry onto a single device and thus combining their best performances from cryogenics to 500 K for realisation of a first practical quantum primary thermometer. At cryogenic temperatures (from 1.5 K to 10 K), quantum optomechanics technology enables accurate primary thermometry (uncertainty below 0.05 K). The optical detection must be phase sensitive. Use of optomechanical correlation thermometry is very interesting at cryogenic temperatures as it could be directly compared to Coulomb blockade thermometry technique. In addition, from 10 K and 300 K, thermomechanical noise primary thermometry with optomechanical devices could provide the highest accuracy (below 0.05 K). Following the fluctuation-dissipation theorem, the phase noise power of a probe laser interacting with an optomechanical resonator is proportional to its equilibrium thermodynamic temperature. Last, the range from 300 K to 500 K could be studied by Doppler broadening thermometry, with a target uncertainty of 0.05 K on a nominal mm size metal vapour (or molecular gas) cell integrated on a photonic chipset for the determination of the thermodynamic temperature of the device. The absorption line is broadened by the Doppler effect averaged over the thermal velocity distribution of particles: the linewidth of the absorption spectrum is proportional to the square root of its thermodynamic temperature. The small-scale approach for Doppler broadening thermometry is new and has not been used yet for thermometry purposes.

In addition to the primary thermometry technique, photonic thermometers are needed for high precision and resolution. Photonic thermometry is a chip scale technology based on the thermo-optic effect, the temperature dependence of the refractive index of an optical waveguide that determines temperature from the resonance frequency of an optical resonator, which results in a very high temperature resolution (sub mK). Although photonic thermometry has a very high sensitivity (about 0.07 nm/K) and high reproducibility, it requires in-situ calibration using one of the other types of thermometry because it is an interpolating thermometry technique.

## 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 primary thermometry below 500 K.

The specific objectives are

1. To develop advanced optomechanical quantum thermometry from 4 K to 300 K with target temperature uncertainty of 0.05 K. To enable ultra-high optical detection efficiency (above 80 %) for high signal to noise ratio at high mechanical resonance frequency (GHz range) and high performance phononic shielding.
2. To extend the temperature range for photonic sensors, based on integrated micro optics, from 80 K to 500 K with a target reproducibility of 0.005 K. To solve technical challenges, such as fibre-chip-coupling at high temperatures, design of sufficient nanostructures for the extended temperature range, and exploration of materials besides the established Si (e.g. SiN, Ge, Diamond).
3. To realise on-chip primary temperature sensors based on Doppler broadening, operating from 300 K to 500 K with target uncertainty below 0.05 K for thermodynamic temperature. To study the systematic effects of cell size and vapour or gas pressure on the Doppler broadened optical absorption spectrum for accurate retrieval of the equilibrium thermal velocity distribution.
4. To validate the fabricated chip scale primary sensors (optomechanical and Doppler Broadening Thermometry) and to calibrate the interpolating photonic sensors, with the corresponding uncertainty budgets, including inter-comparisons of different primary sensors in the same temperature ranges. To integrate two chipset temperature sensor technologies into a single packaged system and demonstrate self-validation, large temperature range of operation and performance of hybrid chip-based sensors.
5. To strengthen the European laboratories for quantum and nanoscale metrology by working together with NMIs to facilitate knowledge transfer. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (CCT) and end users in universities, technological centres, national metrology institutes and industrial R&D laboratories.

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. In particular, proposers should outline the achievements of the EMPIR projects 17FUN05 PhotOQuant and 15SIB02 InK 2 and how their proposal will build on those.

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 Quantum Primary Temperature Sensor 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.