PhotOQuanT

Newsletter

January 2020

What is PhotOQuanT?

PhotOQuanT is a European Research project within the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

Why PhotOQuanT?

For a wide range of processes, from consumer electronics to space instrumentation, there is a growing need to make temperature measurements at smaller scales. The range of currently available thermometers, however, cannot meet the challenge. Nanotechnology now offers the possibility of innovative 'optomechanical' sensors capable of measuring temperature on micrometer length scales. Not only could these new temperature sensors replace the standard high-accuracy platinum resistance thermometers but, embedded into production processes, many industrial users could benefit from the technology.

Our objective

This project will design, fabricate, and characterize different optomechanical systems for temperature measurement. Calibration methods will also be developed to make the sensors traceable to the International Temperature Scale of 1990 (ITS-90). Beyond sensing capability on the micro- and nano-scale, other advantages include reduced cost, better portability and robustness, and increased resistance to mechanical shock and electrical interference. Additionally, optomechanical sensors could be developed as a future quantum-based primary standard for temperature measurement.

PhotOQuanT second interim meeting at VSL/TU Delft

Highlights

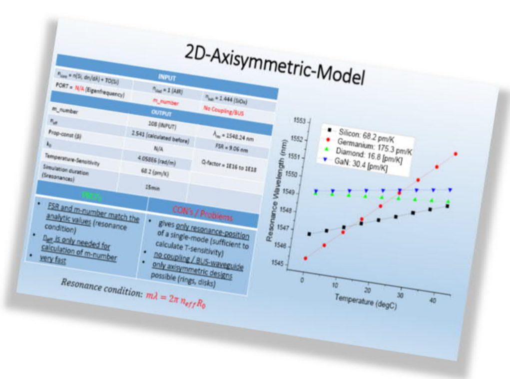
Within this project, different photonic and optomechanical devices dedicated to temperature metrology at the nano- and micro-scale are being designed and fabricated. In the last months, strong efforts have been made to push state of the art photonic and optomechanical sensors following complementary strategies (materials, geometries, mechanical frequencies) for a most effective comparison.

Design and fabrication of novel sensors

PHOTONIC SENSORS:

IHP GmbH, TUBS and PTB have designed photonic resonators made of Si with over 120 individual micro-ring resonators with different ring diameters and coupling efficiencies for their test and optimization. Thanks to highly reliable fabrication techniques, these photonic resonators have been produced with large variety well controlled ring radius as well as coupling efficiency. They are optimized for operation around optical telecom wavelength C-band (1520-1590 nm). The optical tests performed have demonstrated their high quality (Q factor about 160 000) They have also a low residual transmission and a strong optical frequency shift. These high quality resonators will ensure a temperature resolution at the level of a fraction a mK at room temperature.

IMN-CSIC is designing a diamond photonic resonator with different fabrication techniques to be compared.



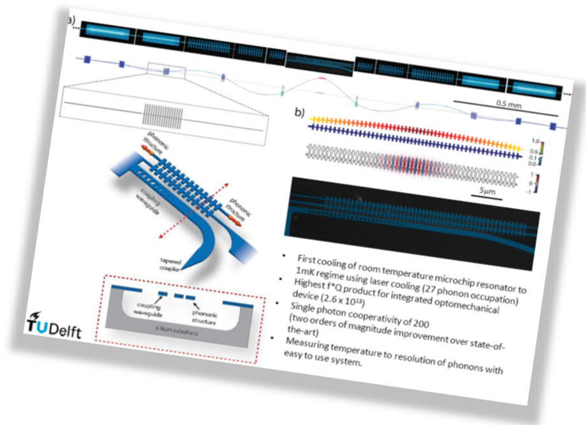
Numerical simulations for diamond base photonic devices

Specific software have been developed for the numerical simulation of some physical properties for microring diamond resonators (temperature sensitivity, self heating). These computations show a sensitivity about 13 pm/K and smaller self heating compared to silicon but also a better stiffness and thermal conductivity, what are very promising results for optomechanical thermometry.

OPTOMECHANICAL RESONATORS, DESIGNED AND FABRICATED WITH THREE COMPLEMENTARY APPROACHES:

The first two optomechanical resonator developed by SU-CNRS are 1D geometry photonic/phononic crystal showing a high optical quality factor (Q= $3\ 10^6$) together with a high value (typ. 7 GHz) of their mechanical resonance radiofrequency. While both sensors monitor the Brownian motion to access the thermal energy, they differ in the choice of calibration protocol. The first one uses a classical phase modulation, providing a device easy to use which works on a large temperature range. The second optomechanical sensor uses a quantum correlation protocol to scale the thermal fluctuation directly in terms of quantum fluctuations yielding a quantum temperature standard. This strategy requires the mechanical oscillator to be close to the quantum ground state and operate at low temperature (<10K).

TU-Delft has designed A Zipper photonic crystal with a very high Q, measured above 1013 Hz, operating at telecom wavelength (C band) to provide a fully integrated device (fiber link). The shielding of the mechanical resonator from spurious external mechanical vibrations is realised with a very efficient phononic shield which provides a very high mechanical Q factor (Q=10^7) above the state-of-the-art published level. The capability of this optomechanical resonator has been demonstrated with the optical cooling of its resonant mechanical mode below 1,5 mK which demonstrates its ability for quantum thermometry, at least below 0.1 K.



TU Delf devices

Sensors characterization and optimization

Some work have to be done to study the photoelastic parameters of the used samples, including effects of its geometry and the mechanical stress applied to the devices. These parameters need to be evaluated with diamond, SiN and silicon

TUBS has designed a setup for the absolute measurement of photoelastic constants of macroscopic samples . Measurements at room temperature on a silicon sample at a wavelength of 1550 nm have been carried out with a relative uncertainty of 0.3% which is one order of magnitude better than other measurement techniques in literature.

An analytical model has been developed for self heating calculation and temperature field induced mechanical stresses, in photonic microrings and microdisk resonators, including material properties, resonator geometry and two photon absorption. Together with photoelastic and mechanical losses measurements on test structures, this model will enable accurate numerical simulation of the resonators performances which should lead to their optimization. Despite its very difficult fabrication technology (etching), diamond seems to have strong potential for optomechanical resonators.

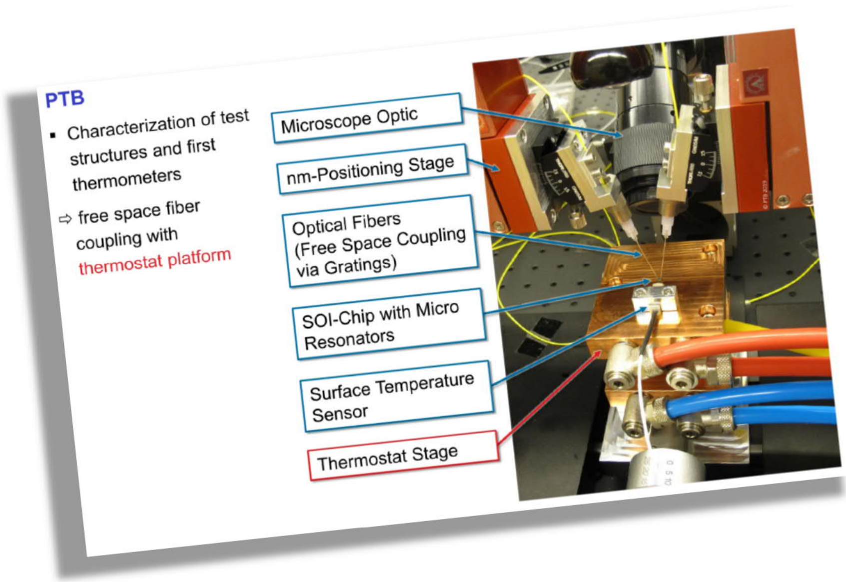
Read-out protocols and calibration systems

PTB has developed and assembled a fiber optic set-up based on a tuneable laser, traceable to an acetylene stabilized laser, together with a nm-positioning system for the read-out of the photonic sensors temperature. The read out protocols developed have showed a very high Q factor of the first generation of optical resonators fabricated. Reproducibility studies are on progress together with the evaluation of laser power effects.

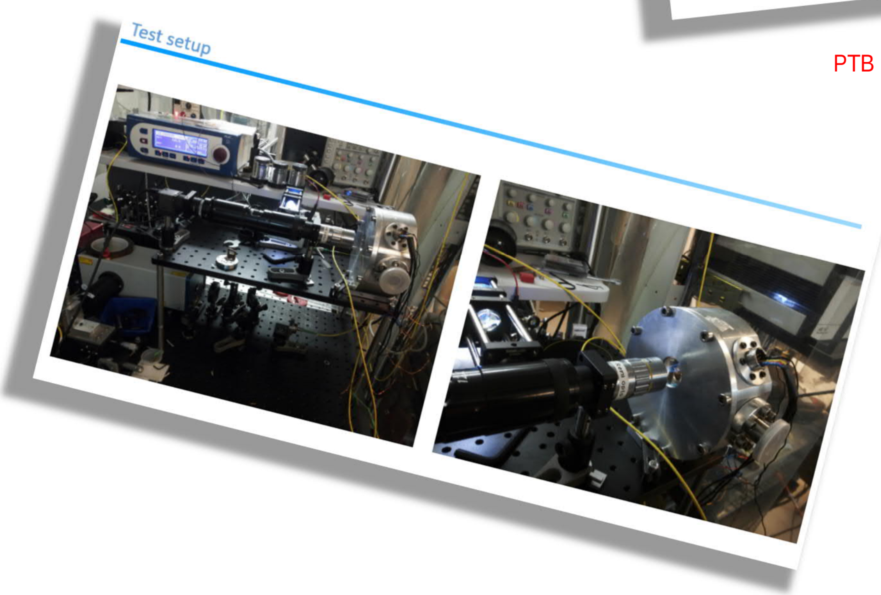
VSL, SU, CNRS and LNE-CNAM have developed the optical read-out of the optomechanical temperature sensor at two different optical wavelengths (1550 nm and around 800 nm) depending on the type of optomechanical resonator used (1D, Zipper). Homodyne and heterodyne techniques are used the measurement of amplitude/phase noise cross correlation, hence allowing the calibration of thermal noise with laser quantum noise.

Of course, traceability to the kelvin has to be demonstrated. PTB, VTT, VSL, LNE-CNAM and CEM are designing and constructing different thermostats for the validation of photonic resonators based on different approaches. Some use water from high stability baths for temperature-control while others use an enclosure inside a temperature-controlled chamber.

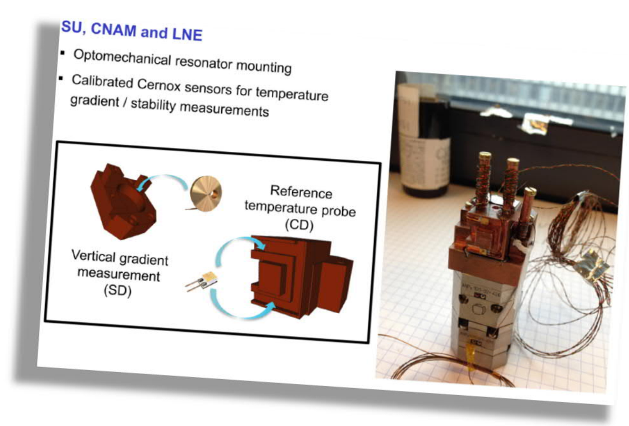
Preliminary tests have shown temperature homogeneity and stability at the mK level around room temperature. The fabrication of these thermostats is on progress and should be delivered soon. They are characterized and modified in parallel, to allow either fiber coupling or free space coupling of the probe laser to the photonic resonator.



PTB thermostat for validation of photonic devices



SU, CNRS, LNE-CNAM read out test setup for optomechanical temperature sensors



SU, LNE-CNAM thermostat

Events

The second PhotOQuanT interim meeting was hosted by VSL/TU Delft in Delft (The Netherlands) the 14-15th November 2019 attended by representatives from all the consortium partners.

The project partners have been disseminating the first results in a wide variety of international conferences such as the International Symposium on Temperature and Thermal Measurements in Industry and Science (TEMPMEKO), the European Conference on Lasers and Electro-Optics (CLEO), the PhotonIcs & Electromagnetics Research Symposium or the international Micro-Nano Conference .

For a detailed list of presentations, visit our web page: www.vtt.fi/sites/photoquant

The consortium is preparing a proposal with the follow-up of this research for the Fundamental EMPIR Call 2020.

The Consortium

PhotOQuanT is coordinated by:

Project partners:

PhotOQuanT is an EMPIR funded project:

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