

Quantum physics as a pillar of metrology: Strategies and approach of a medium-sized NMI

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Overview

Quantum technologies have made it possible to obtain reproducible standards anytime and anywhere, without the need for a traditional traceability chain, revolutionising elemental measurements. The First Quantum Revolution set measurement standards based on the discrete character of physical quantities such as the states or energy levels of atoms. The Second Quantum Revolution, based on the principle of superposition, is transforming metrology by harnessing quantum phenomena to develop advanced tools and methods, redefining measurement techniques.

NMIs have a duty and a responsibility to embrace and implement these advances, ensuring that the potential of quantum technologies is transformed into tangible benefits for science, industry and society. However, this transition is a major challenge for the entire community, but especially for small and medium-sized NMIs. These Institutions should see in this situation an invitation to actively participate in this quantum revolution. By collaborating, investing in knowledge transfer, and adopting scalable quantum solutions, even smaller NMIs can contribute to and benefit from this transformative era of metrology.

CEM as part of Second Quantum Revolution

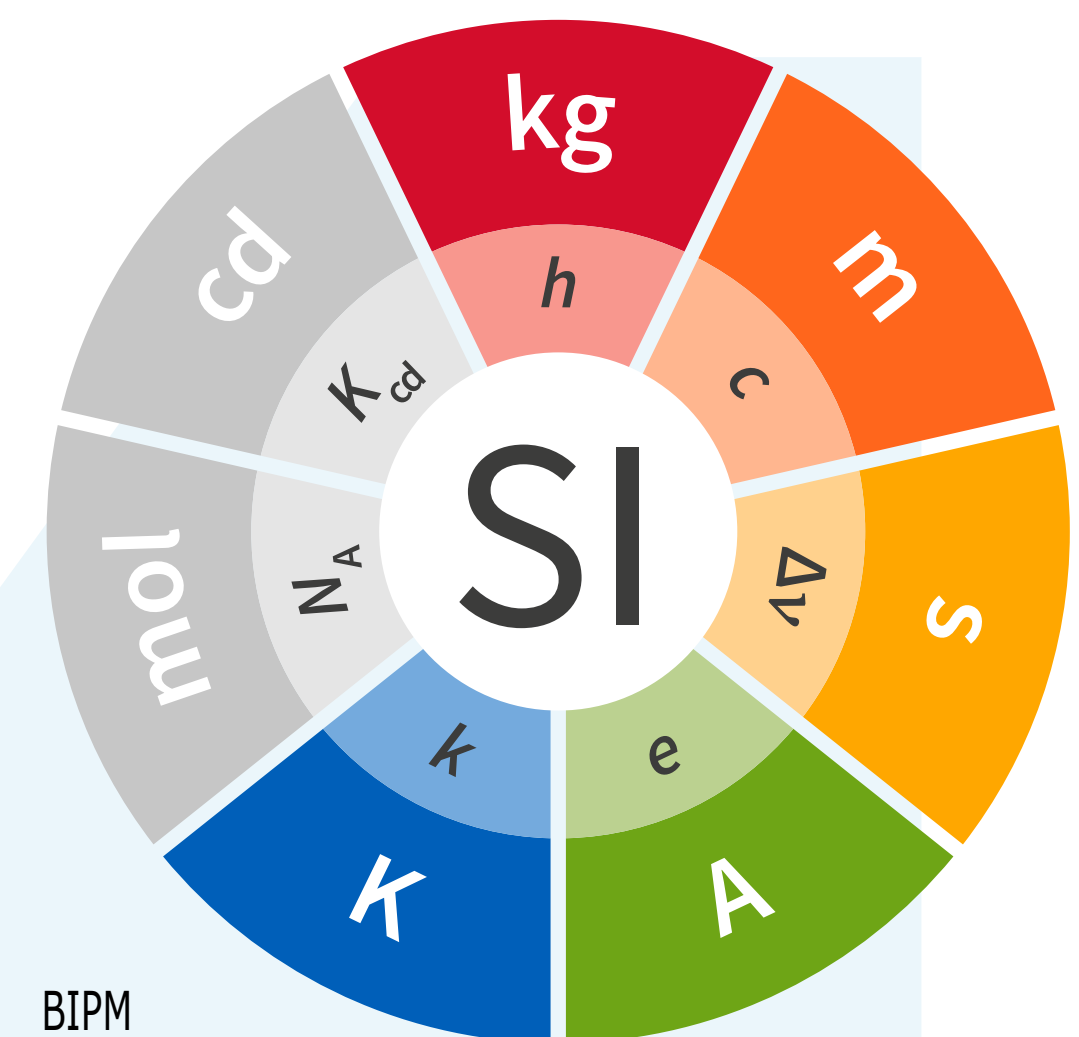
Quantum technologies have enable Centro Español de Metrología (CEM), an institute with just over 100 employees, to establish highly accurate and stable measurement standards. Despite its size, CEM has been integrating quantum technologies since its creation in the 1980s. For almost 40 years CEM has been using quantum principles in the field of length metrology using laser interferometry. In addition, for more than 30 years, CEM has been implementing quantum-based techniques into electrical metrology. In particular, the Josephson effect has been used for the materialization of the Volt, and the quantum Hall effect for the Ohm.

Recognizing the disruptive potential of quantum advances, CEM is committed to fully integrating these technologies into its metrology infrastructure. This has driven a strategic transformation, shifting from classical metrology to quantum developments. Engaged in projects across time and frequency, electricity, thermometry, and mass metrology, CEM aims to lead by example, proving that participation in the Second Quantum Revolution is achievable for all NMIs through vision, proactive engagement, and strong commitment.

Conclusions

By sharing our projects we aspire to encourage collaboration and knowledge exchange, reinforcing the idea that quantum metrology should be an inclusive and global effort. It should not only be an individual effort of each NMI, but the creation of synergies between institutions is a key point for progress to reach the whole community.

This is not just an evolution in measurement science, it is a historic transformation. We are determined to be active contributors and we encourage all NMIs to be part of this great change.



Projects being developed at CEM based on Second Quantum Revolution

Quantum frequency standard based on ⁴⁰Ca⁺



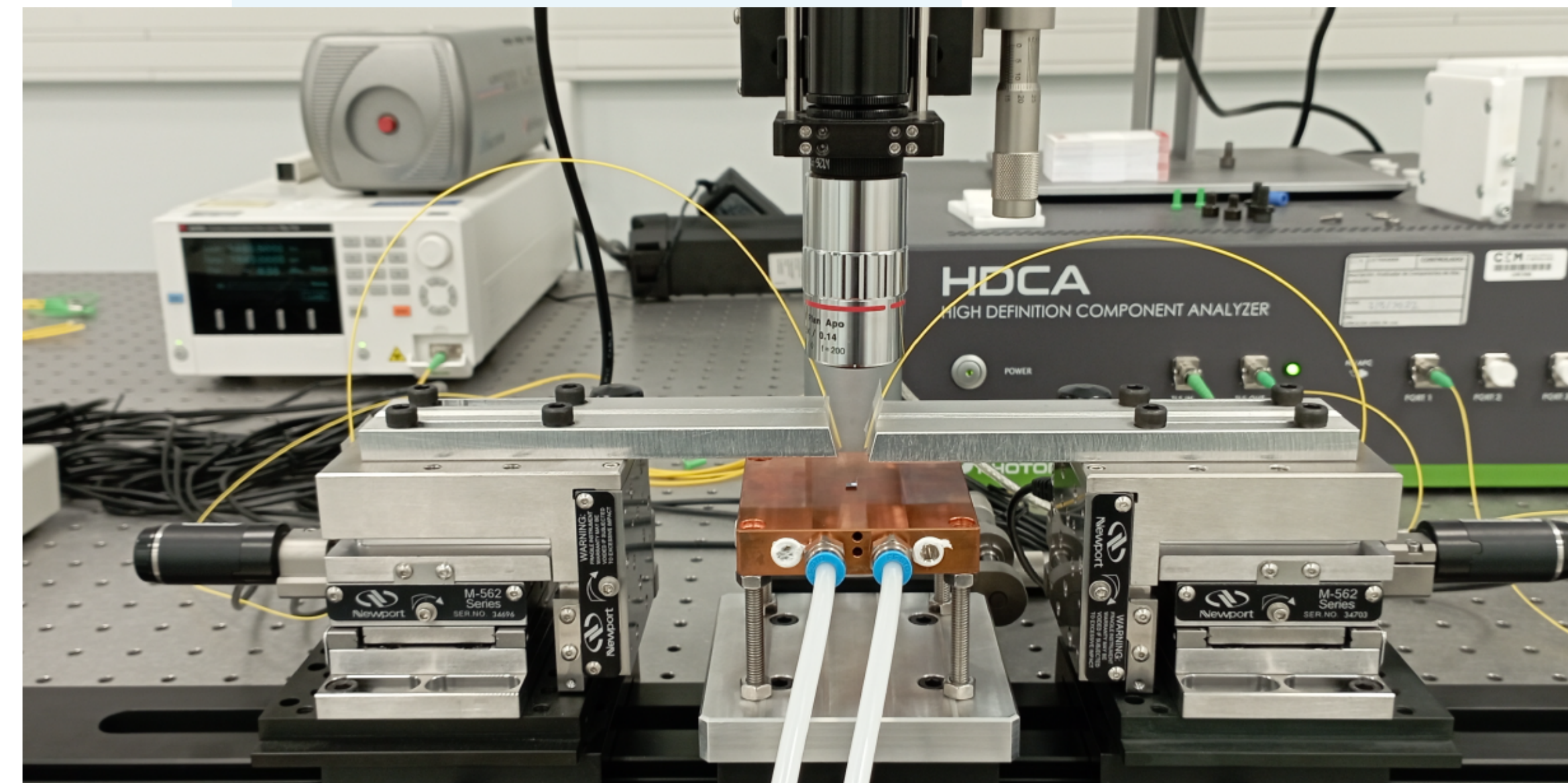
System for a frequency standard at CEM

CEM is implementing an optical clock based on Calcium 40 ions. With this technology, based on a Paul-type ion trap, the aim is to develop a high-precision frequency standard to establish the bases of this technologies for future developments.

Through this project, we also seek to establish collaborations at both, national and international level, adding knowledge to the scientific community, using optical clocks on time scales and dissemination, encouraging the implementation of this systems in small and medium sized NMIs, and contributing to the future redefinition of the second.

At national level, the project is being developed in collaboration with ROA, the institution responsible for time keeping in Spain. In addition, CEM is involved in MADQuantum-CM project. This is a project focused on developing a quantum communication network in Comunidad de Madrid, where CEM will provide the frequency reference for the synchronisation of the nodes, acting also as one of them.

Photonic and optomechanical devices for use as temperature standards



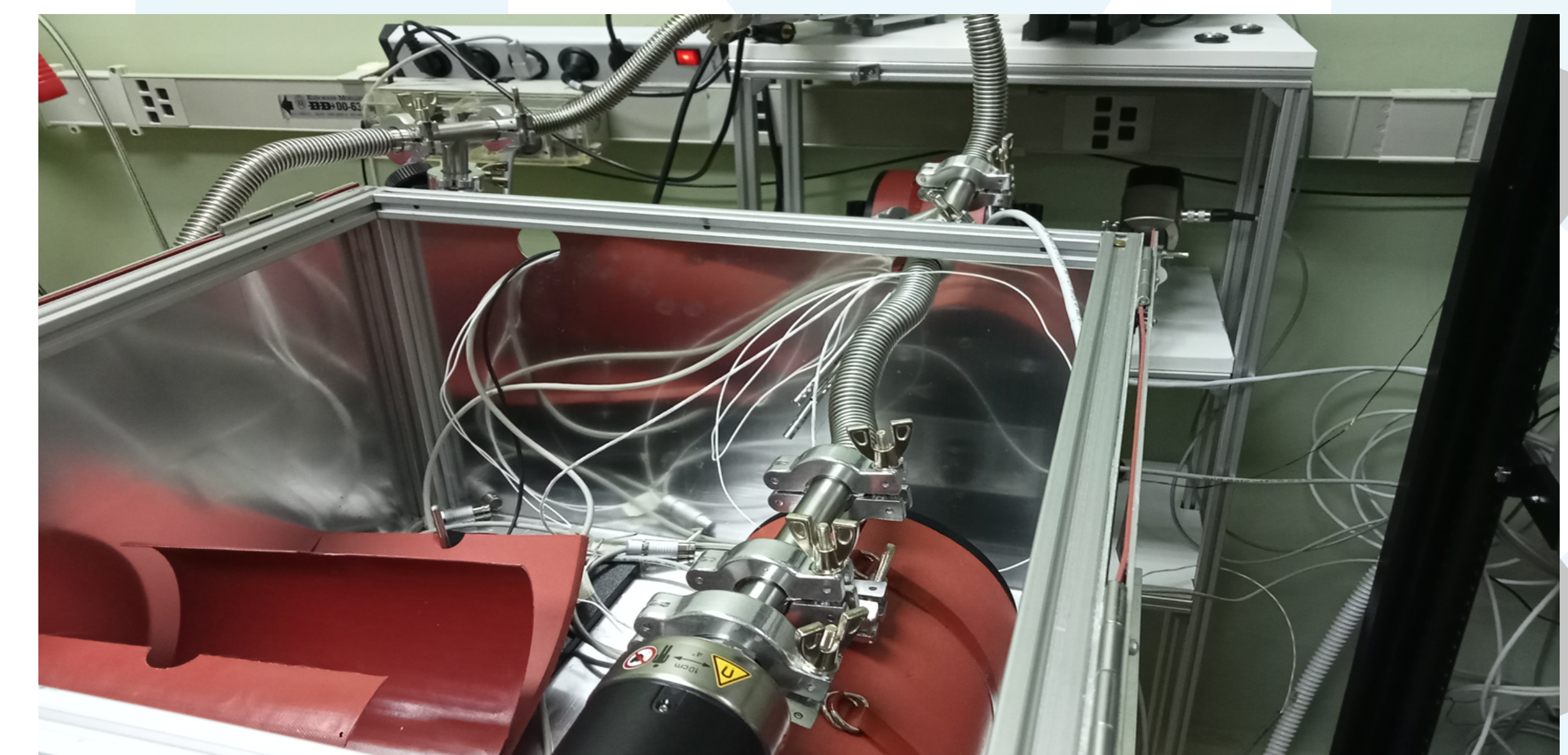
System for PICs study and calibration

Due to the new definition of the basic units of the SI through universal constants, the urgency of developing sensors that provide traceability to the SI at the highest scientific and technological level is evident, so that they can accompany future developments in instrumentation and sensor technology in industry.

One of the sensors proposed by the international Thermometry community is the optomechanical sensor, where the combination of light-matter interaction with the vibrations of the device at the nanometric scale allows the construction of a primary quantum thermometer (using vacuum optical noise to scale the thermal noise).

As a very first step towards this future, CEM has been working in nano-photonic sensors based on photonic crystals in Si. It has developed a free space measuring set-up working at 1550 nm from 10 °C to 80 °C for the calibration of photonic integrated circuits (PICs). This experiment is being developed through the 23FUN01 European Metrology Partnership, building on the work of project 17FUN05.

Quantum techniques in pressure metrology



Equipment for quantum Pascal development

CEM is developing an experiment for the materialization of the pressure unit, Pascal, using quantum-based methods involving refractometry techniques. This experiment has the aim of covering a pressure range from 1 Pa to 20 kPa, ensuring the highest levels of accuracy and stability. The target expanded uncertainty (k=2) is set at 2 mPa + 20 ppm, which represents a significant improvement over classical pressure realisation methods.

This experiment is not an isolated effort but forms part of a broader initiative, currently under development by the European project 22IEM04 MQB-Pascal, that seeks to establish a consistent and quantum-based realization of pressure standards at the international level, in alignment to the previous European project 18SIB04 QuantumPascal.

Besides, this experiment is foreseen as a pillar for primary materialization of other fundamental quantities and the high-precision measurement of gas properties using quantum-based methods.

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