PHYSICS

INRiM - Advanced metrology in physics

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Context of the research activity	This Thematic Grant includes 6 research Topics (listed below), with a specific title and proponent Supervisor/s. The applicants have the possibility to identify the specific topic they are interested in. Topic 1 Heat flux sensors based on Nernst effects Topic 2 Optical quantum technologies applied to quantum measurement and sensing Topic 3 Development and validation of miniaturized sensors for the determination of nanoplastics in food and environmental matrices Topic 4 Advancing Transition-Edge Sensors (TESs) for Quantum Detection Topic 5 Quantum mixtures of ultracold atoms and trapped ions Topic 6 Enhancing Qubit Periphery Metrology for Superior Quantum Computing Performance

	Topic 1 The need to increase the efficiency in processes like thermal cycles, computing and energy storage and transportation has recently increased the focus on heat management, extending the field of interest to the reduced dimensions. In this framework, the design of thermal sensors based on new concepts towards higher versatility and reliability is of great interest for research and industry and has to be supported by metrological traceability. As a heat flux sensor, thermoelectric thermopiles represent an optimal choice in terms of sensitivity. However these devices are plagued but several drawbacks, as for example they are rigid structures, their sensing area has geometrical constrains and the miniaturization of devices is limited. A promising way to overcome these limitations is the realization of active sensing surfaces based on transverse thermoelectric effects, in particular the Nernst effect of metals and the anomalous Nernst effect (ANE) of ferromagnets. Although the Nernst effect is smaller then the Seebeck effect,

its geometry permits the realization of a sensor as a uniform surface, without the need of the two planes of junctions. A further advantage is the use of ANE materials, i.e. ferromagnets with a large remanence and a high coercivity such as MnBi. Moreover, the possibility of using magnetic nano-particles and thin films as active elements allows the realization of flexible sensors, nano-structured devices and heat-sensitive coatings for sensors and energy harvesting devices.
The main objectives of the research on transverse thermoelectric effects are the optimization of the properties of materials for the preparation of devices, the experimental investigation of their transverse thermopower and the development of models related to the experimental findings.

Topic 2
Quantum technologies combine research on fundamental aspects of quantum mechanics with the purpose of overcoming limitations of conventional (classical) techniques in fields like computing, communication, metrology, imaging and sensing. A disruptive impact on both the scientific community and the entire society can be foreseen in terms of fundamental research, communication security, bio-medical diagnostics tools, etc.
In this context, on the one hand the candidate will have the possibility to contribute to modeling and realizing innovative quantum optical schemes and experimental setups for investigating novel quantum measurement paradigms. On the other hand, the candidate may be involved in the design and realization of innovative sensing and imaging schemes that, by exploiting quantum states of light and quantum measurement protocols, allow a more efficient information retrieval with respect to their classical counterpart. These techniques include, for example, optical super-resolution and sub-shot-noise imaging, quantum-enhanced target detection, novel interferometric schemes, etc. The experimental implementations may involve either two-photon (entangled) or single-photon sources (e.g., either heralded or based on color centers in diamond), single-photon detectors, time-tagging electronics, highly sensitive cameras, optical and electronics components.

Topic 3
The need to develop reliable and standardized methods for the identification and quantification of micro- and nanoplastics (pMPs and pNPs respectively) in complex matrices is of extreme importance given the implication of plastic pollution in ecosystems and the food chain, and in the definition of upcoming European regulations that require their detection.
The development of traceable, sensitive and accurate methods is therefore essential to meet the requirements imposed by the EC in the European Green Deal.
The need therefore to develop an integrated system, with a miniaturized analysis chip coupled online to a multi-parametric measurement chain (quantity of particles, size and chemical identity), represents an important challenge to make the determination of these pollutants.
To this end, we intend to create a sensor formed by the coupling of a miniaturized dielectrophoretic (DEP) cell and a Raman spectrometer, capable of locally concentrating the particles in the exposure area of the laser beam, allowing their chemical identification. In a DEP cell, non-uniform electric fields are used which are capable of imparting a force to the particles suspended in a liquid, the movement of which can be controlled via electrical parameters and depends on the chemical-physical characteristics of the particles themselves.
The increase in local concentration also guarantees greater sensitivity of the Raman technique. This system can be further coupled online to a

Objectives	measurement chain formed by a fractionation system (AF4) to separate heterogeneous populations of particles as a function of size, and to a DLS to determine their size. The project intends to build and test microfluidic chips with different gold electrode patterns made by laser photolithography. Different patterns will be studied to maximize the DEP effect, testing polymer particles with different shapes, sizes and chemical composition. Topic 4 Transition-edge sensors (TESs) represent a cutting-edge technology in microcalorimetry, based on the sharp superconductive transition of a metallic film to achieve excellent sensitivity. This sensitivity allows for the detection of single photons across a wide spectral range, spanning from gamma-ray to visible and near-infrared wavelengths. TESs stand out among single photon detectors for their exceptional high-energy resolutions, photon-number resolving capability, and low dark count rates, positioning them at the forefront of quantum detection technologies. At INRIM, we boast extensive expertise in both fabricating and measuring TESs as single-photon detectors, particularly in the visible and near-infrared wavelength regions. The proposed PhD project will center on advancing TES technology by focusing on the development of TESs coupled with single and multimode fibers, enhancing their quantum efficiency and response time. These advancements are crucial for their application across various fields including quantum optics, quantum communications, single photon metrology, as well as rare event search and particle physics. The goal of this PhD position is to push the boundaries of TES performance at INRIM. The candidate will engage in research aimed at optimizing TES design and functionality, with the ultimate aim of achieving groundbreaking advancements in quantum detection capabilities. Key Objectives: 1.Enhance the quantum efficiency and response time of TESs coupled with single and multimode fibers. 2.Explore novel fabrication techniques to improve the performance of TESs. 3.Investigate the application of advanced TES technology in quantum optics, communications, metrology, and particle physics. Benefits: •Work in a dynamic research environment at INRIM with access to state-of-the-art facilities. •Collaborate with leading experts in the field of quantum detection. •Opportunity for professional development and networking within the scientific community. Topic 5 Experimental quantum physics relies on the ability to realize and control quantum systems that can be isolated from the environment. Among the many physical systems that are currently studied, ultracold atoms and trapped ions are probably the most formidable sources of coherent matter available in a laboratory. Neutral atoms brought to ultralow temperatures form ensemble that behave coherently. Trapped ions allow easier single-particle control due to Coulomb repulsion, which makes the ions form ordered crystal-like structure. These systems are some of the most used systems for the implementation of quantum technologies, and in particular of quantum computers. The novel approach of this project is to realize a hybrid system combining ultracold atoms and trapped ions within the same apparatus, offering a fresh

perspective on quantum physics. In this hybrid system atoms and ions interact via an interaction potential that is approx. two orders of magnitude longer ranged than typical atom-atom interactions. The project aims to pioneer a fully controlled atom-ion system of Ba+ ions and fermionic Lithium atoms in which atoms and ions are brought to the lowest energy ever attained. At these energies the atom-ion mixture assumes a quantum behavior, making it possible to perform novel quantum simulations of impurity models – like the Anderson orthogonality catastrophe – and individuate novel quantum information protocols, like creation of a a decoherence-free qubit environment for a trapped ion immersed in an ultracold bath.

Topic 6
This PhD research proposal is centered on the MetSuperQ project's goal to revolutionize metrology for superconducting qubit peripherals, essential components for the advancement of quantum computing technologies. The project seeks to address the complexities involved in the precise control and measurement of superconducting qubits through innovative metrological tools and methods. Key objectives are structured as follows:
Qubit Periphery Development: The primary focus is on developing, fabricating, and testing advanced peripheral devices that directly impact qubit performance. This includes superconducting parametric amplifiers and Josephson pulse generators, which are pivotal for enhancing the fidelity of qubit initialization, manipulation, and readout. Efforts will be directed towards minimizing the added noise and maximizing the signal integrity of these devices, crucial for maintaining coherence in quantum computing operations.
Integration and Standardization of Metrology Practices: Assisting in the development of harmonized metrology routines that allow for precise characterization of single and dual-qubit operations. This includes integrating newly developed peripheral devices into existing qubit systems and standardizing the measurement methodologies to ensure compatibility and reproducibility across various experimental setups.
The proposed research will utilize state-of-the-art facilities at INRiM and collaborate with leading European metrology institutes to ensure that the objectives are met with the highest scientific rigor. By focusing on the development of qubit peripherals, this PhD project aims to provide substantial contributions to the field of quantum computing, particularly in improving the scalability and coherence times necessary for the realization of more advanced quantum computational platforms.

Topic 1
A good attitude for the experimental activities is required for this project, ranging from the preparation of materials to the development of specific measurement systems and code for data analysis. These skills have to contribute to the achievement of independence in the laboratory.
Knowledge in on of the following fields: physics, engineering, material sciences

Topic 2
Previous experience in the (experimental) study of quantum foundations and/or technologies, basic knowledge of optical components/devices and their characteristics, basic skill in mathematical and data elaboration softwares (MATLAB, Mathematica), programming skills.

Topic 3
•Good knowledge of analytical chemistry and/or nanoscience and/or spectroscopic techniques;

Skills and competencies for the development of the activity	•Good capacity to evaluate scientific results/reports and to draft scientific/technical documents; •Good interpersonal communication skills and ability to work in an international environment; •The working language will be English and a good knowledge of oral and written English is necessary. Topic 4 •Strong interest in research activities, especially in quantum technology. •Proficiency in experimental techniques and data analysis. •Knowledge in thin film fabrication, optics, cryogenics, or superconducting devices. •Experience with programming languages such as LabVIEW, MATLAB, Python, or Comsol. Topic 5 Basic knowledge in optics or programming (i.e. Mathematica, Python, etc.) would result in a smoother approach to the project, but this should not be considered a pre-requisite. The thesis work will be carried out in a small team and the student will be supervised and trained in learning all the experimental techniques that are needed. A master thesis in Physics is preferable, although a candidate with a master thesis in Engineering and interest in quantum physics could also be successful. Topic 6 The candidate should possess a strong background in electrical engineering or applied physics, with specific skills in superconducting devices and cryogenic technology. Experience with microfabrication, device design, and quantum measurement methods is valued. Analytical skills for data processing and knowledge of metrological standards are crucial. Additionally, the ability to collaborate effectively in a multi-institutional and interdisciplinary setting is key to succeeding in this role.