EMPIR Call 2020 – Fundamental, Industry and Normative

Selected Research Topic number: **SRT-i10**
Version: 1.0

Title: Quantum sensors for metrology based on single-atom-like device technology

Abstract

The commercialisation of quantum devices has been identified as being one of Europe's biggest industrial challenges. This is because new test and validation methods need to be developed for the independent, rigorous testing of new devices in order to be able to bring new quantum technologies to market. However, currently, no European NMI has the metrological capability based on single atom-like quantum sensors (via deterministic ion implantation) to measure quantum devices. Therefore, new single-atom systems need to be developed in order to support, high sensitivity magnetic field or electric field (or temperature) measurements suitable for the characterisation of quantum devices. In particular, the development of single-atom like sensors based on Nitrogen-Vacancy (NV) or novel optically active centres in diamond (or other suitable materials) are needed, as such high sensitivity sensors would be able to fully exploit the unique properties of quantum devices.

Keywords

Quantum technology, single-atom systems, diamond, quantum sensing, deterministic ion implantation

Background to the Metrological Challenges

Despite the potential wide use of quantum technologies in quantum-computing, -communications, and -sensing, its commercialisation is currently limited due to the lack of reliable tools and structured facilities to characterise, test and validate prototype quantum devices. Such characterisation requires certified quantum sensors which are able to perform stable and reproducible measurements at the nanoscale with unprecedented sensitivity at both room and cryogenic temperatures.

Quantum sensing is a promising field, in terms of its practical application and high sensitivity. Traditionally negatively charge NV centres in diamond (or other suitable materials) are used, however more recently novel optically active centres in diamond (or other suitable materials) has been identified as better way to develop nanoscale magnetic field, electric field and temperature sensors by measuring optically detected magnetic resonance, i.e. the possibility to perform spin state manipulation at room temperature with optical readout. For example, for magnetic measurements, sensitivities as low as 15 $pT/Hz^{1/2}$ have been experimentally demonstrated, while in terms of temperature sensitivity values below 1 $mK/Hz^{1/2}$ have been reached.

Recently the number of ions that can be successfully incorporate in diamond lattices to obtain optically active defects has increased and includes Silicon (Si), Germanium (Ge), Helium (He), Tin (Sn) and Lead (Pb). Such novel optically active centres are able to produce deterministic single photon sources, and in some cases demonstrate improved performance compared to NV centres e.g. narrower linewidth in photoluminescence at room temperature.

Currently, NV centres in diamond (or other suitable materials) are the most advanced quantum sensors. They are used for electromagnetic wave characterisation e.g. characterising the field produced by radio frequency (RF) antennas, as they provide information on the spatial distribution of the field. They are also used for the measurement of the frequency spectrum of an RF signal. However, such measurements need to become more quantitative. As at present, in order to quantify the frequency, it has to be calibrated against a reference and the value of the amplitude of the frequency component then evaluated.

Material development is also key for quantum sensing (whether based on NV or novel optically active centres in diamond (or other suitable materials) and for the ability to compare devices produced by different manufacturers. The tools used to develop the materials and their growth processes need to be standardised in order to produce high quality materials and sensors with reproducible performances.

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 the development of quantum sensors for metrology based on single-atom-like device technology.

The specific objectives are

1. To develop single-atom systems in diamond or other suitable materials (e.g. Silicon and 2D materials) using controlled ion implantation with a spatial resolution below 500 nm in a single-ion regime, and to develop the associated metrological capabilities to support this.
2. To develop robust and accurate magnetic field, electric field and temperature quantum sensors using deterministic implantation based on NV defects in diamond (or other suitable materials as per Objective 1). In addition, to metrologically compare the sensitivity of these quantum sensors with state of art NV sensors.
3. To investigate the possibility of developing magnetic field, electric field and temperature quantum sensors via deterministic ion implantation and based on novel defects (e. g. Si, Ge, He, Sn and Pb) in diamond (or other suitable materials as per Objective 1).
4. To develop reliable methods for production and measurement of single-atom-based sensor devices, including modelling their behaviour via tight-binding methods. In addition, to develop the necessary traceability chains for such single-atom-based sensors.
5. To facilitate the take up of the knowledge, technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (ISO, CEN) and end users (quantum computing, communications, and sensing)

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

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 project 19NET02 EMN-Quantum and how their proposal will build on 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 30 % of the total EU Contribution across all selected projects in this TP.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

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 quantum technology sectors.

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.