EMPIR Call 2017 – Industry, Fundamental, Normative and Research Potential

Selected Research Topic number: **SRT-f02**
Version: 1.0

Title: Single-photon sources as new quantum standards

Abstract

The development of new absolute standard radiation sources, exploiting the quantum nature of photons, would have many applications in metrology. Such sources would be based on a single-photon emitter with calculable photon emission rate and a high purity, i.e. very low multiple photon emission probability. Such sources could be used for the calibration of single-photon detectors, realisation of the SI base unit - the candela, quantum random-number generation, quantum key distribution, sub-shot noise metrology, quantum-enhanced metrology, and photon-based quantum computation.

Keywords

Single photon source, photon metrology, quantum standards,

Background to the Metrological Challenges

Single-photon sources are necessary for some types of quantum computing, quantum key distribution and quantum metrology. Although significant progress has been made in the metrological characterisation of these sources, more development is required.

An ideal single-photon source would emit one photon on demand, at a time chosen by the user with the emitted photons being indistinguishable from one another and having an adjustable repetition rate. Currently available single-photon sources are still far from being completely predictable and deterministic, although significant progress was made within the previous project EMRP JRP EXL02 (SIQUTE). Single-photon sources were characterised with a total photon flux up to 260 000 photons per second and with the single-photon emission purity indicated by a $g^{(2)}(0)$-value between 0.10 and 0.23. This is a step towards the realisation of a photon standard-source, but the photon fluxes are still too low and the emission bandwidth too broad for practical use. The emitted photons were also only partially indistinguishable, as indicated by the $g^{(2)}(0)$-values, which means that the impact on quantum technologies is limited.

In order to increase the single photon fluxes, photonic structures for enhancing the photon collection efficiencies are required. Methods employed for enhancing the photon collection efficiency are use of solid immersion lenses and waveguiding structures (e.g. nano-pillars), resulting in typically 30 % collection efficiency. Even larger efficiencies (50 % - 100 %) are expected when coupling to microresonators or planar optical antenna structures.

Photon fluxes up to 4×10^6 photons/s with $g^{(2)}(0) \sim 0.2$ have been demonstrated with 2-D materials such as hexagonal boron nitride (hBN) at room temperature. Single photon emission has also been measured in the transition metal dichalcogenide materials WSe_2 and WS_2. Although requiring cryogenic temperatures, and less bright than hBN, their ability to be electrically pumped could lead to devices of great utility.

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 single-photon sources as new quantum standards.

The specific objectives are

1. To develop single-photon sources as new quantum standards in the visible, near-infrared and telecom wavelength range, based on optically and electrically-driven impurity centres in nano- and bulk

diamonds, quantum dots in semiconductor structures and molecules having, simultaneously, photon rates > 1 × 10^6 photons per second, emission bandwidths < 2 nm and high purity emission indicated by $g^{(2)}(t = 0)$ values < 0.05;

2. To assess new materials and concepts for single-photon sources, such as 2D materials (e.g. hexagonal boron nitride and thin transition-metal dichalcogenides) and coupling designs to optimise the collection efficiency (e.g. microresonators, waveguides, optical antennas). To assess the impact of excitation schemes on the quantum optical properties of single-photon sources;
3. To establish sources of indistinguishable and entangled photons based on near IR (< 1 µm) quantum dot single-photon sources with a visibility > 90 % and novel sensing and measurement techniques based on these sources.
4. To develop metrology infrastructure for traceable single-photon source characterisation, i.e. detectors, amplifiers, single-photon spectroradiometers.
5. To promote the results, to trigger commercialisation of products, and to deliver input to standardisation organisations.

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 EMRP JRP EXL02 'Single-photon sources for quantum technologies' (SIQUTE) 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 to the project.

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,

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.