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

Selected Research Topic number: **SRT-f18**
Version: 1.0

Title: Single-electron quantum optics for quantum-enhanced measurements

Abstract

Worldwide efforts are directed towards the realisation of a second quantum revolution, using the most advanced aspects of quantum physics in ‘fully-quantum’ applications and the translation of quantum technologies from basic science to applications is a key objective for the next decade. The European metrology infrastructure needs to develop new capacities to leverage the power of quantum enhanced measurement and to provide the metrological infrastructure needed for the development and application of quantum technology in Europe.

Future quantum technologies in the broader application space will also require new metrological tools, for development and validation. Semiconductor quantum devices provide a platform for the manipulation, characterisation and utilisation of single-electron wave-packets. Harnessing the interference of these on-demand quantum states will enable local time-resolved quantum-enhanced sensors for magnetic and electric quantities. This topic should develop such ‘single-electron quantum optics’ techniques for metrology.

Keywords

Electron quantum optics, single-electron wave packet, electron interferometry, quantum state tomography, quantum enhanced sensing, quantum technology, scalable solid state quantum circuits

Background to the Metrological Challenges

Quantum technology offers enhanced measurement capabilities – *quantum-enhanced* sensing of classical quantities – but also creates new requirements for the measurement of quantum mechanical properties. The European metrology infrastructure must therefore develop new capacities to leverage the power of quantum enhanced measurement and to provide the metrological infrastructure needed for the development and application of quantum technology in Europe.

In the past two decades, semiconductor single-electron device technology has moved from simply trapping an electron into a quantum dot to more advanced experiments involving individual electron wave packets emitted ‘on-demand’ from a quantum dot, travelling through a quasi-one-dimensional waveguide. Various types of single-electron sources have been developed and some initial work towards measurement techniques for the characterisation of travelling wave packets has been done.

In a series of experiments, time-controlled electron emission into a quantum hall channel has been achieved using a ‘mesoscopic capacitor’ source and used to test the random partitioning of particles from one source and the interference between particles from two sources, directly analogous to experiments in quantum optics. These experiments were used to study interactions in the edge channel, which were revealed by the incomplete indistinguishability of nominally identical excitations. Due to their low energy the pumped electrons may share – depending on the operating temperature – the same energy band as thermal excitations which can lead to accidental two-particle interference effects. A second approach is the generation of minimal single-particle-like excitations using voltage pulses. Partitioning, indistinguishability and tomography of such ‘levitons’ have been demonstrated.

Dynamic quantum dots have been shown to provide single or few electron wave-packets with precise timing and energy. Their “high energy” (10-100 meV) pumping operation mode enables convenient operation at easily accessible working temperatures (1-4 K). This very much larger energy scale provides isolation from thermal excitations in the leads. It is also expected to give rise to a very different picture of edge state interactions – hot electron transport over long distances can take place in the absence of an electronic reservoir. Existing data reveals some information about the classical projection of the energy and time distributions. Partitioning has been observed in a device with path lengths of several microns with no signature of thermal excitation

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effects, however much more detailed understanding of emitter dynamics and single electron propagation are necessary to realise a single electron interferometer.

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 metrological capacity for single-electron-based metrological tools for quantum technology by investigating electron quantum optics with on-demand sources of single-electron wave packets.

The specific objectives are:

1. To produce semiconductor device components for on-demand single-electron quantum optics based sensing and state tomography, including quantum dot based high-energy on-demand synchronised single-electron sources for time-resolved interferometry, single-charge detectors for electron quantum optics, and correlation measurement techniques and devices for quantum state metrology.
2. To develop the metrological tools for the verification of single-electron sources required for the assessment and optimisation of the emitted electron wave-packet states, including the characterisation of the dynamic electron state within the source quantum dot and the indistinguishability test of the travelling single-electron wave packet.
3. To develop an experimental technique for on-demand single-electron wave-packet interferometry for the sensing of local magnetic and electric fields with high time resolution (~ 1 ns or below) and high spatial resolution (~ 1 µm).
4. To develop concepts and theoretical tools for a full quantum state tomography to enable the realisation of quantum enhanced measurements using electron wave packets.
5. To evaluate the potential of single-electron devices for quantum metrology and to foster the European metrology capabilities for quantum technology by developing the concepts for on-demand single-electron sensing devices and by assessing their potential and practicability (for example, easier accessible working conditions, e.g. temperature > 4 K).

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.

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.