The SIQUST-project – towards single-photon sources as new quantum standards

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In this presentation, the EURAMET joint research project "Single-photon sources as new quantum standards" (SIQUST) [1], funded within the European Union Horizon 2020 research and innovation programme, will be presented.

INTRODUCTION

The aim of this project is to develop new absolute standard radiation sources, which exploit the discrete and quantum nature of photons, and the necessary metrological infrastructure. These sources will be based on single-photon emitters with a calculable photon emission rate and high purity, i.e. with a very low multiple photon emission probability. Such sources hold promise as new quantum standards which will have a large number of applications, e.g. for use in the calibration of single-photon detectors, for the realisation of the SI base unit candela, for quantum random number generation, for quantum key distribution, for subshot noise metrology, for quantum enhanced metrology, and for photon-based quantum computation.

OBJECTIVES AND RESULTS

This project focuses on the development of single-photon sources as new quantum standards. Results obtained within the first half of the project are:

Type-IIa diamond bulk crystals have been implanted with several different ions. Samples implanted with Sn and Pb demonstrated single-photon emission at room temperature under 520 nm and 532 nm laser excitation. The SnV centre exhibited $g^{(2)}(0)$ values down to 0.29 ± 0.02 with a saturation photon rate of approx. 1.4 x 10^6 photons/s. Samples treated differently after the ion-implantation process exhibit enhanced single-photon purities, with $g^{(2)}(0)$ value down to 0.05. Single-photon sources based on InGaAs QDs in micro-structured GaAs were fabricated and for the first time used for a relative calibration of two Silicon single-photon avalanche diode detectors. The photon rate measured for a specific QD was around 3×10^5 photons/s with a $g^{(2)}(0)$-value of 0.23 at a wavelength of (922.37 ± 0.02) nm. The measurement uncertainty for this relative calibration is about 0.7 %. Several single-photon emitters based on a single molecule (dibenzoterrylene in anthracene, DBT:Ac) were designed and fabricated. In order to efficiently collect the emission, a planar antenna design which is simple and cheap to fabricate, and which provides hundreds of source candidates per fabrication run, was developed. A bright single-photon emitters based on a single molecule (dibenzoterrylene in anthracene, DBT:Ac) was metrologically characterized, the parameters are, simultaneously: photon flux up to 1.4×10^6 photons/s at the wavelength of (785.6 ± 0.1) nm with a $g^{(2)}(0)$-value < 0.1 and a spectral bandwidth (FWHM) < 2 nm. The photon flux was measured with a traceable low-noise analogue reference Si detector. This source was used to directly calibrate a Silicon single photon avalanche diode detector against a Silicon photodiode, which is in turn traceable to the cryogenic radiometer.

The impact of different excitation schemes on the quantum optical properties of single-photon sources is investigated for InGaAs QDs (emitting around 930 nm) in GaAs matrix. A strong linewidth decrease is observed from above-band ($\Delta\nu \approx 11$ GHz) via phonon-assisted ($\Delta\nu \approx 7.1$ GHz) to direct resonant excitation ($\Delta\nu \approx 3.1$ GHz). Furthermore, two-photon excitation was applied and high purity ($g^{(2)}(0) = 0.072 \pm 0.104$) and highly indistinguishable ($V = 0.894 \pm 0.109$) single photons were observed.

Indistinguishability of photons emitted by a single molecule has been demonstrated. Setup upgrades to enhance emission purity and spectral filtering, as well to refine indistinguishability measurement are in progress.

The setup for ODMR measurements was upgraded resulting in an increase of magnetic field sensitivity of ODMR-based magnetometry protocols ultimately for applications of sensing in biological systems. Specifically, an optimized diamond sample with a very narrow layer of NV centres is used and the possibility to drive simultaneously all three hyperfine peaks corresponding to one spin orientation was implemented. A new state-of-the-art experimental setup for the implementation of single-photon confocal photoluminescence and ODMR measurements down to 4 K temperature was established.

The new paradigm dubbed the genetic quantum measurement, specifically the possibility to exploit this new approach with quantum dots and colour centres in diamond, has been investigated with respect to understand if there is some peculiar observable of these quantum systems that can take advantage of this novel technique.

A cooled Predictable Quantum Efficient Detector (PQED) in a liquid nitrogen operated cryostat for use in performing SI traceable measurements of low power sources was constructed and characterised. The device uses electronics developed within the project and is capable to detect 1 000 000 photons/s with an uncertainty of < 1 % in the wavelength range between 650 nm and 750 nm.

A portable single-photon source was designed and constructed and currently undergoes compaction to reduce the size to approx. only 40 cm x 27.5 cm x 20 cm. This source delivered with a molecule emitter (terrylene in p-terphenyl) approx. 2 x 10^6 photons/s at room temperature. The $g^{(2)}(0)$ value was approx. 0.2 and the emission covered the spectral region between 550 nm and 700 nm with emission peaks at approx. 580 nm, 630 nm and 680 nm.

First results were achieved using techniques for measuring the $g^{(2)}(0)$ value. A pilot study on the characterisation with respect to the $g^{(2)}(t = 0)$ value of a pulsed-pumped single-photon source, based on a NV centre in nanodiamond, was performed by INRIM, NPL and PTB. The main result of this study was the development of a standardised measurement technique as well as an uncertainty estimation procedure. The validity of the technique (system-independent and unaffected by the non-ideality of the apparatus) was demonstrated by the results which yielded estimated values of $g^{(2)}(0)$ that were compatible within the uncertainty ($k = 2$) for all of the participants. This study will greatly benefit the single-photon metrology community, as well as rapidly growing quantum-technology-related industries.

At the conference, an overview about the project itself as well as on the results obtained until then will be given.

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