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Quantum Optics, Nanophotonics IV

Chaired by Romuald Houdré

Time: Tuesday 11:00–12:30 Location: Room F1

20.1 Tue 11:00 Room F1

A bright single-photon source based on a photonic trumpet — Mathieu Munsch[1], Nitin S. Malik[1], Joël Bleuse[1], Emmanuel Dupuy[1], Niels Gregersen[2], Jesper Mork[2], Jean-Michel Gérard[1], and •Julien Claudon[1] — [1]Joint group CEA-CNRS-UJF 'NanoPhysique et SemiConducteurs', CEA, INAC, SP2M, Grenoble, France — [2]DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Fiber-like photonic nanowires, which are optical waveguides made of a high refractive index material n, have recently emerged as non-resonant systems providing an efficient spontaneous emission (SE) control. When they embed a quantum emitter like a quantum dot (QD), they find application to the realization of bright sources of quantum light and, reversibly, provide an efficient interface between propagating photons and the QD. For a wire diameter $\sim \lambda/n$ (λ is the operation wavelength), the fraction of QD SE coupled to the fundamental guided mode exceeds 90%. The collection of the photons can be brought close to unity with a proper engineering of the wire ends. In particular, a tapering of the top wire end is necessary to achieve a directive far-field emission pattern [1].

Recently, we have realized a single-photon source featuring a needle-like taper. The source efficiency, though record-high, was found to be limited by the geometry of the taper [2]. Here, we propose an alternative, high performance, trumpet-like tapering of the wire and demonstrate its implementation in a bright single-photon source. Specifically, we consider a GaAs structure, for which the wire diameter is progressively increased from 220 nm to 1.5 μm, for a total height of 12 μm. Such trumpet-like tapers present a number of key assets: i) a nearly perfect adiabatic expansion (less than 5% losses) of the fundamental mode is achieved for tapering angle as large as 7°. ii) the emitted mode features a Gaussian profile with a divergence controlled by the top-facet diameter: for a top diameter of 1.5 μm, less than 5% of the light is scattered outside the collection cone of a lens with a 0.75 NA. iii) the large top facet also simplifies the implementation of a top electrode, to achieve an electrical driving of the device [3].

Using top-down fabrication techniques, we have fabricated a single photon source based on this geometry. The trumpet lies on an integrated mirror and embeds a single layer of InAs QDs, located 110 nm above the mirror. We obtain collection efficiencies higher than 40% for a bunch of QDs spread over 35 nm in a single wire, with a maximum of 65%. This result, which approaches the state of the art (70%), is also close to the predicted value of 80%, obtained for a perfect emitter [4]. Eventually, we map the field profile at the top facet and evidence its Gaussian profile. This is desirable to achieve a good coupling to a monomode fiber, in view of the long range distribution of single photons. This is also crucial to increase the mode matching when addressing a single QD with an optical Gaussian beam.

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[2] J. Claudon et al., Nature Photon. 4, 174 (2010)
[3] N. Gregersen et al., Optics Express 18, 21204 (2010)
[4] M. Munsch et al., in preparation

20.2 Tue 11:15 Room F1

Bottom-up tailored nanowires for efficient single photon emission and detection — •Michael E. Reimer[1], Gabriele Bulgarini[1], Moira Hocevar[1], Erik P.A.M. Bakkers[1,2], Leo P. Kouwenhoven[1], and Val Zwiller[1] — [1]Delft University of Technology, Delft, The Netherlands — [2]Eindhoven University of Technology, Eindhoven, The Netherlands

Semiconductor nanowires provide a powerful platform for on-chip integration of quantum information circuits since it is possible to tailor both their light emission and detection properties utilizing bottom-up growth. These optical properties can be modified due to the unprecedented material freedom available in nanowire growth and through precise control of the nanowire shape by appropriate choice of the growth conditions. In consequence, many material systems can be combined that are not available during conventional growth, such as integration of III-V materials in a one-dimensional avalanche multiplication channel based on silicon. Additionally, the nanowire shape can be precisely controlled to efficiently extract the light. Very efficient single photon emission and detection at the single photon level is one essential requirement to transfer quantum information over large distances between two remote stationary qubits.

In this work we show very efficient single photon emission and detection by utilizing InAsP quantum dots embedded in tailored InP nanowire geometries. In the first part, we discuss how we can perfectly position single quantum dots on the axis of tapered nanowire waveguides using a bottom-up growth approach [1]. By precisely controlling the quantum dot position and the nanowire shape, we demonstrate excellent coupling of the emitter to the fundamental waveguide mode and a 24-fold enhancement in the single photon flux in comparison to quantum dots in nanowires without waveguide. The single photon flux enhancement that we obtain is accompanied by an increase of the spontaneous emission rate in comparison to no waveguide [2], which is comparable to state-of-the-art photonic crystals and etched photonic nanowires.

In the second part, we combine in the same nanowire device a single quantum dot that is embedded in an avalanche multiplication region of a p-n junction [3]. This novel device concept allows us to spectrally and spatially isolate the absorption region from the avalanche multiplication region. As a result, we reveal a large internal gain of both electrons and holes exceeding 10^4 in the nanowire avalanche region that allows us to detect a single photon resonantly absorbed in the quantum dot. Remarkably, the observed detection efficiency is four orders of magnitude larger than previously reported on self-assembled quantum dots embedded in diode structures and seven orders of magnitude larger with respect to photo-detectors based on a single contacted quantum dot in an intrinsic nanowire.

References

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[3] G. Bulgarini, M.E. Reimer, M. Hocevar, E.P.A.M. Bakkers, L.P. Kouwenhoven, and V. Zwiller. Avalanche amplification of a single exciton in a semiconductor nanowire. Submitted (2012).

20.3 Tue 11:30 Room F1

Full control of spontaneous emission using confined Tamm plasmon modes — Olivier Gazzano[1], Steffen Michaelis de Vasconcellos[1], Karine Gauthron[1], Clémentine Symonds[2], Jacqueline Bloch[1], Paul Voisin[1], Joël Bellessa[2], Aristide Lemaitre[1], and •Pascale Senellart[1] — [1]Laboratoire de Photonique et de Nanostructures,UPR 20, CNRS, Route de Nozay, 91460, Marcoussis, France — [2]Laboratoire de Physique de la Matière Condensée et Nanostructures, Université Lyon 1, Villeurbanne, France

We demonstrate strong three-dimensional confinement of Tamm plasmon modes [1] with a very simple microstructure consisting of a thin gold microdisk on top of a planar GaAs/AlGaAs Distributed Bragg mirror. The Tamm plasmon mode, formed at the interface between the Bragg mirror and the metal, is laterally confined to the dimensions of the gold disk. Discrete modes are evidenced with quality factors up to 1200 for the fundamental mode. These modes exhibit a zero in-plane wave vector, allowing for an excellent coupling to quantum dot excitons and the vertical emission of photons [2].

With a deterministic lithography method [3] we couple single quantum dots to the confined Tamm plasmon mode. An acceleration of the spontaneous emission is observed if the exciton transition is at resonance with the mode, while a remarkably strong inhibition of the spontaneous emission (by a factor up to 40) is measured if the exciton transition is off-resonance [4].

Our study also shows that this structure should allow the fabrication of single photon sources with a brightness as large as 60 %, under electrical control.

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20.4 Tue 11:45 Room F1

Coherent optical control of a single quantum dot hole spin — Tim Godden[1], John Quilter[1], •Andrew Ramsay[1], Yanwen Wu[2], Peter Brereton[2], Stephen Boyle[1], Isaac Luxmoore[1], Jorge Puebla[1], Mark Fox[1], and Maurice Skolnick[1] — [1]University of Sheffield, Sheffield, UK — [2]University of Cambridge, Cambridge, UK

The spin of a heavy-hole confined to an InAs/GaAs quantum dot has potential as a robust qubit, since the contact hyperfine interaction, the main source of dephasing for an electron spin, is suppressed. A key prerequisite for using the hole-spin as a qubit is the ability to perform single qubit rotations.

Here we demonstrate the full coherent optical control of a hole-spin confined to a single InAs/GaAs quantum dot using a photocurrent detection technique [1]. This is achieved by combining rotations about two axes: Larmor precession about an external in-plane magnetic field; and a rotation about the optical axis induced by the geometric phase-shift imparted by a picosecond laser pulse resonant with the hole-trion transition.

In the experiments, a circularly polarized laser pulse prepares a spin-polarized electron-hole pair. Under an applied electric-field, the electron tunnels from the dot, leaving a hole with a Larmor precession that is synchronized with the preparation pulse. The hole spin is detected using a circularly polarized detection pulse that is tuned to the hole-trion transition, where a trion is created conditional on the spin of the hole and detected as a change in photocurrent. Up to 40 periods of the Larmor precession are observed, and an extrinsic coherence time of approximately 15 ns is deduced.

To demonstrate optical control, a third control pulse is applied between the preparation and detection pulses. A geometric phase approach is used. The control pulse has a Gaussian shape, similar to a hyperbolic secant, circular polarization and a pulse-area of 2π. The polarization selects the spin-up component of the hole-spin and drives the trion transition through an angle of 2π. After the pulse, neglecting decoherence, the dot has returned to the hole-spin sub-space,