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The photonic nanowire: An emerging platform for a highly efficient quantum light source

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Abstract— The single-photon source capable of emitting single indistinguishable photons on demand represents a key component in quantum information applications. The photonic nanowire represents an attractive platform to construct a source with near-unity efficiency.

1. INTRODUCTION

An optically or electrically triggered quantum light emitter, e.g. a semiconductor quantum dot (QD), embedded in a solid-state semiconductor host material appears as an attractive platform for deterministic generation of single photons. However, for a QD in bulk material, the large index contrast at the semiconductor-air interface leads to a collection efficiency of only 1-2 %, and efficient light extraction thus poses a major challenge in single-photon source engineering. [1]

The photonic nanowire is a vertical GaAs cylinder with an embedded InAs QD placed on a substrate with an emission wavelength of $\approx$ 950 nm. By choosing a proper nanowire radius, the spontaneous emission into radiation modes can be strongly suppressed, and the probability for an on-axis QD of emitting photons into the fundamental HE_{11} mode can be close to unity. The design features no cavity and does not rely on resonant cQED effects, meaning that efficient coupling from the QD to the guided mode is obtained over a broad spectral range. No spectral alignment between the emitter line and a narrow cavity line is required, which represents a huge practical advantage in the fabrication.

To control the light emission and ensure a high collection efficiency, two additional elements must be included. While photons are efficiently funneled into the nanowire fundamental mode, half of the light will propagate towards the substrate due to the nanowire mirror symmetry. It is thus necessary to implement a bottom metal mirror to reflect this light back towards the top. Furthermore, the optimum nanowire diameter is only $\approx \lambda/4$ leading to a narrow mode waist and a highly divergent far field emission pattern of the truncated nanowire. A conical tapering strategy is thus required allowing for an adiabatic expansion of the fundamental mode and narrow output beam waist.

The original optically pumped photonic nanowire design implements regular conical taper, and its first experimental demonstration featured an efficiency of 0.72. However, for applications, electrical contacting is desired, and a novel photonic trumpet design based on an inverted conical tapering compatible with the implementation of a top metal contact has recently been proposed. The trumpet features a strongly Gaussian far-field emission, and a first implementation of this strategy [2] has very recently lead to an ultra-bright single-photon source with a first-lens external efficiency of 0.75 and a predicted coupling to a Gaussian beam of 0.61.

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