Gaussian and directive emission of giant photonic trumpets

Petr Stepanov,[1] **Adrien Delga**,[1] **Emanuel Peinke**,[1] **Niels Gregersen**,[2] **Jean Tessier**,[3] **Mathieu Munsch**,[3] **Joël Bleuse**,[1] **Jean-Michel Gerard**,[1] **and Julien Claudon**[1]

[1] CEA-CNRS-UJF group "Nanophysique et Semiconducteurs," CEA, INAC, SP2M, F-38054 Grenoble, France
[2] DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Building 343, DK-2800 Kongens Lyngby, Denmark
[3] Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
petr.stepanov@cea.fr

Photonic trumpets are broadband dielectric antennas that efficiently funnel the emission of a point like quantum emitter into a Gaussian free space beam. The integration of an isolated quantum dot (QD) in such structures opens appealing prospects for solid-state quantum optics, in particular for the generation of non-classical states of light. Beyond the initial demonstration of bright single-photon sources [1–3], the broad operation bandwidth of these antennas is also a key asset to realize tunable single-photon sources [4] or bright sources of entangled photon pairs [5]. Nanowire antennas exploit the efficient spontaneous emission control provided by a single mode, high index waveguide whose far-field emission is tailored by a top taper. The taper can either assume the shape of a sharp needle or an inverted cone (trumpet taper in the following). So far, appreciable beam directivity have been demonstrated with both approaches, but collection optics with a numerical aperture (NA) on the order of 0.7-0.8 are still mandatory to fully collect the emitted light [3,6].

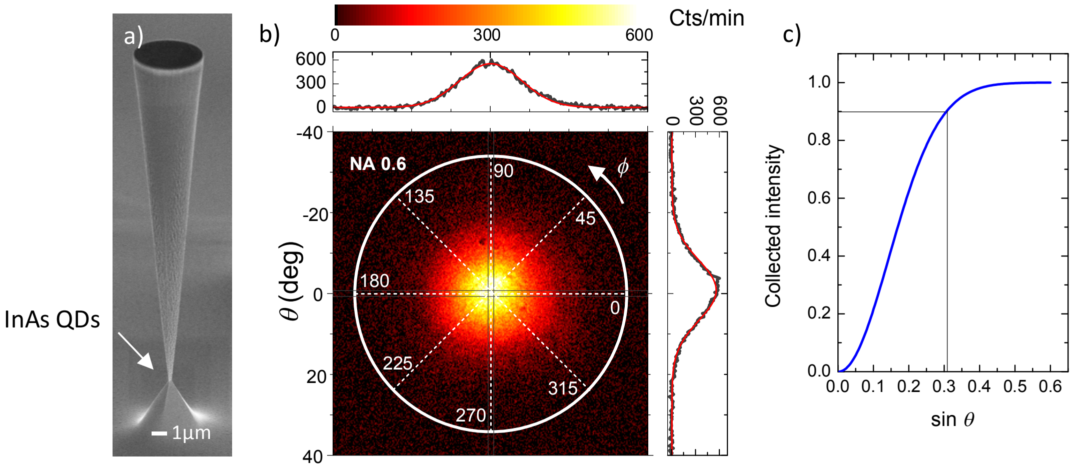

Figure 1: a) Scanning electron microscope image of the 'giant' photonic trumpet (tilted view). b) Giant trumpet's far-field emission pattern with vertical and horizontal cut profiles shown in the top and the right panels. White circle corresponds to the maximum collection angle of the microscope objective (NA 0.6). c) Fraction of the collected beam intensity versus the collection NA.

In this work [7], we demonstrate 'giant' photonic trumpets (~5 µm wide top facet, ~27 µm height, see Fig.1(a)), which emit a very directive, Gaussian output beam. These structures are made of $Al_{0.05}Ga_{0.95}As$ and embed a single layer of self-assembled InAs QDs at their base, where a waveguide diameter about 200 nm ensures single-mode spontaneous emission. We employ Fourier imaging microscopy to map the far-field emission of a single QD embedded in the trumpet (see Fig.1 (b)). As shown in Fig.1(c), a modest NA of 0.31 is sufficient to intercept 90% of the emitted beam. Moreover, vertical and horizontal beam profiles shown in Fig.3 (b) reveal a highly Gaussian structure.

These structures open appealing prospects for the efficient outcoupling to a single-mode fiber using free-space coupling optics, and, reversibly, the incoupling of an external Gaussian laser beam. In particular, the open waveguide configuration (no bottom mirror) investigated here is particularly well suited to explore giant optical nonlinearities through intensity measurements. Interestingly, the broadband nature inherent to a waveguide approach allows exploring ‘multicolor’ nonlinearities based on multilevel emitter scheme.

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