A bright single-photon source based on a photonic nanowire

The realization of an efficient, single-photon source - that is a device that can produce photons one by one on demand - is an important goal for quantum cryptography and more generally for the future development of photonic quantum information processing. In this context, semiconductor quantum dots (QDs) are very attractive: at low temperature, they can offer a stable single-photon emission with a nearly perfect radiative yield. However, they are generally embedded in a high index semiconductor matrix that prevents the efficient collection of light in the far field. We have overcome this limitation and demonstrated a very bright single-photon source by inserting the quantum dot inside a novel, well controlled electromagnetic environment: a photonic nanowire.

A photonic wire is a monomode optical waveguide that is made of a high index dielectric material. Specifically, we consider here a structure defined in Group III-Arsenide semiconductors which is shown in Fig. 1. The wire is made of GaAs (refractive index n=3.5) and is surrounded by air (n=1). It contains an InAs quantum dot located near the wire axis, with a free space emission wavelength in the near infrared, around 920 nm. The large refractive index contrast between the wire and air has two important consequences. First, the guided mode can be confined very tightly inside a wire having a 200 nm diameter, which guarantees a good coupling to the emitter. In addition, the coupling to the continuum of non-guided modes is strongly inhibited, thanks to a pronounced dielectric screening effect. As a consequence, the spontaneous emission of the QD is nearly completely funnelled into the guided mode. Next, one has to collect the guided photons efficiently with a microscope objective located above the wire. For this goal, the two ends of the wire are carefully engineered. The photons emitted downward are reflected back into the guided mode by an integrated mirror, made of gold and silica. The upper end of the wire features a conical tip, designed to progressively "deconfine" the guided mode into the air, in order to obtain a more directive far-field emission pattern.

The realization of the device starts with the growth, by Molecular Beam Epitaxy, of a planar structure consisting of an array of self-assembled InAs QDs buried in a GaAs layer. After deposition of the SiO_2-Au mirror, the sample is "flip-chip" glued on a host substrate and the growth wafer is removed. Finally, photonic nanowires are defined in a top-down approach, using electron beam lithography and a carefully optimized Reactive Ion Etching step.

The performance of the source was investigated in a micro-photoluminescence setup, with the source at liquid helium temperature. A pulsed laser beam injects electron-hole pairs that are trapped by the QD. The spectrally-filtered fundamental optical transition, which corresponds to the recombination of a single electron-hole pair, then emits a single infrared photon. The source efficiency, defined as the probability to emit a photon into the collecting cone of the microscope objective after an excitation pulse, reaches a maximum when the emitter is saturated. In these conditions, a record value of 72% was obtained. Simultaneously, intensity correlation measurements have provided the unambiguous signature of a very pure emission of single photons.

Beyond a significant progress with respect to the state of the art, this non-resonant approach opens new perspectives for quantum light sources. In particular, it could be applied to spectrally-broad single-photon emitters, to improve the efficiency of room-temperature single-photon sources. A broadband collection will also be a key point for realizing an efficient source of polarization-entangled photon pairs, using the radiative cascade of a quantum dot.

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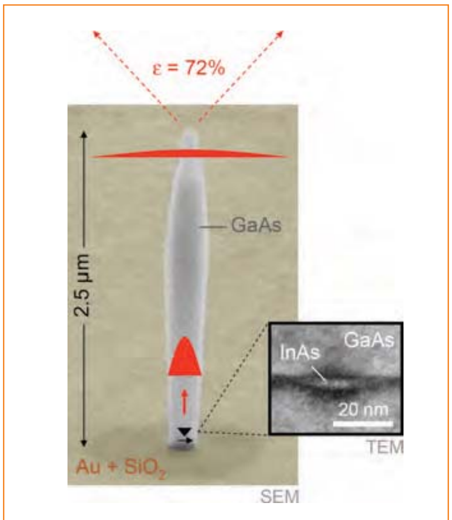

Scanning Electron Microscope view of a tapered GaAs photonic wire, supported by a gold mirror (250 nm-thick) and a silica spacer (11 nm-thick). The wire contains a single photon emitter: an InAs quantum dot (seen in the Transmission Electron Microscopy view at the right). The dot is located 80 nm above the silica layer.

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FURTHER READING

A HIGHLY EFFICIENT SINGLE-PHOTON SOURCE BASED ON A QUANTUM DOT IN A PHOTONIC NANOWIRE"
J. Claudon, J. Bleuse, N. S. Malik, M. Bazin, P. Jaffrennou, N. Gregersen, C. Sauvan, P. Lalanne, and J.-M. Gérard
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J. Bleuse, J. Claudon, M. Creasey, N. S. Malik, J-M. Gérard, I. Maksymov, J-P. Hugonin, and P. Lalanne
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