Broadband Emission Enhancement of the Extraction of Light from Solid-State Emitters by Metallic Nano-rings

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Bright single-photon sources are an essential ingredient for quantum technology applications. Solid-state single-photon emitters are particularly suitable for the integration in on-chip devices [1]. However, they suffer from poor extraction efficiencies due to the high refractive index contrast between the bulk semiconductor and air, resulting in a small fraction of the emitted light being collected in free space. Several approaches to increase the extraction of light from semiconductor emitters have been implemented, including optical cavities (such as micro-pillars, nanowires, and gratings) and solid-immersion lenses [2].

Here we report on a different approach that makes use of metallic nano-rings that act as local lenses that focus the laser excitation and increase the intensity of the collected light. Such an effect is validated by finite-difference time-domain simulations, that we use to optimise the ring dimensions.

The position of the emitters is measured with respect to alignment markers with accuracies of ~25 nm, via a photoluminescence imaging technique [3] (see Fig. 1a). Rings of inner diameter of ~440 nm are deposited on the sample surface (Fig. 1b), by means of electron-beam lithography, Cr/Au deposition and chemical lift off, and centred in correspondence to single epitaxial InAs/GaAs quantum dots (QDs).

The emission intensity collected from the same QD before and after ring deposition is shown in Fig 1c: the ring allows enhancements of up to a factor 25 in the intensity of single QD emission lines [4]. Such ring device is scalable, simple to fabricate and broadband, compatible with any substrate and emitter, including room temperature light sources such as colloidal QDs, defect centres in diamond and in two-dimensional materials.

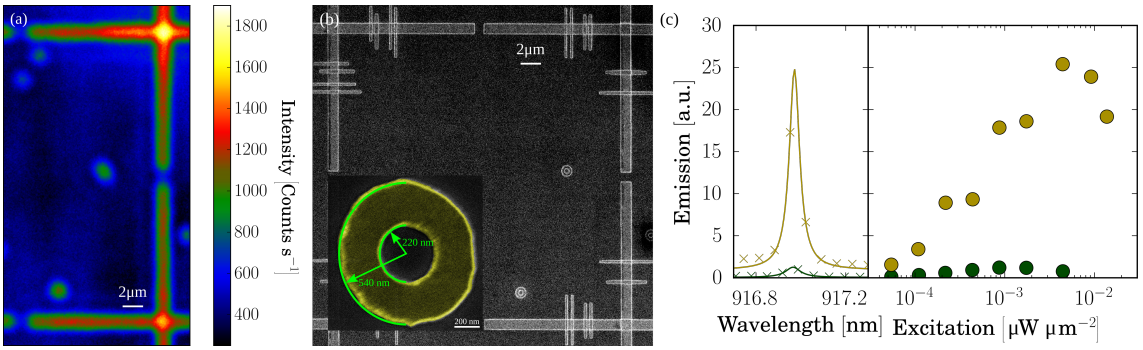

Figure 1: (a) Photoluminescence image showing QD emission and reflected light by alignment markers. (b) Scanning electron microscope (SEM) image of fabricated metallic rings. Inset: False colour SEM of a ring with its dimensions highlighted. (c) Left panel: photoluminescence spectra of the same QD emission line with (yellow) and without (green crosses) the ring measured at saturation excitation power, at a temperature of 10K. The solid lines are Lorentzian fits to the data. Right panel: Emission intensities plotted as a function of excitation power density, normalized to the saturated bulk emission, for the photoluminescence emission line shown in the left panel (with the same colour coding).

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