Metallic nano-rings to improve light extraction from single quantum dots

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We report on a broadband, scalable device based on metallic nano-rings deposited on the sample surface in correspondence to single quantum emitters (see Fig.1a). These allow increasing the extraction of light from single InAs/GaAs quantum dots (QDs) of up to a factor 20 [1]. By combining the nano-ring with a deterministically placed super-solid immersion lens (super-SIL) (see Fig.1b), a further increase of up to a factor 10 in the brightness is measured [2]. The combined nano-ring-super-SIL device allows to reach single-photon fluxes as high as ~1MHz from a quantum dot in bulk (see Fig.1c). The device that we have developed is scalable and relatively easy to fabricate: the positioning of single QDs can be carried out in an automated system, the dimensions of the rings are compatible with photolithography and nano-imprint, and the super-SIL deposition requires only optical microscopy tools. Furthermore, the combined enhancement effect of the nano-ring and the super-SIL is wavelength insensitive, therefore broad-band, and compatible with any kind of solid-state emitter of classical or quantum light, on any substrate.

To control the spontaneous emission via quantum dot-plasmonic coupling, we have also developed a new class of droplet QDs with ultrathin capping layer (~10nm) [3]. Given that the emitters are very close to the sample surface, they can couple to plasmonic fields excited in the metallic nano-rings, thus opening the path to controlling the spontaneous emission rate of deterministically coupled single quantum dots by near field plasmonic fields.

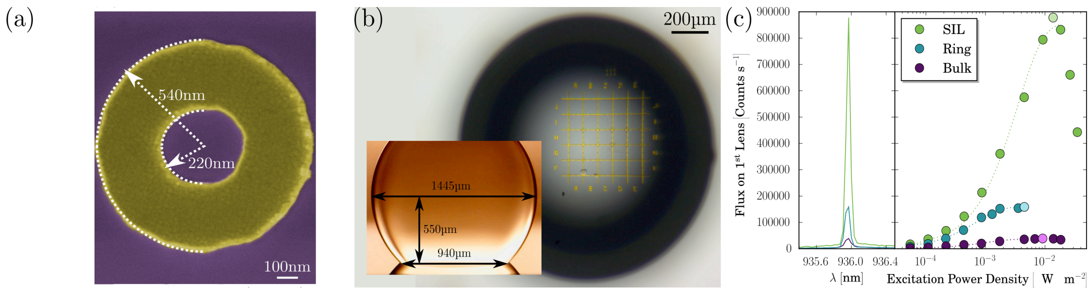

Figure 1: (a) False colour scanning electron micrograph of a gold nano-ring, with dimensions shown. (b) Optical micrograph of a super-SIL deposited on the InAs/GaAs QD sample under study, in correspondence to metallic alignment marks and nano-rings. Inset: side profile of an epoxy super-SIL with critical dimensions shown. (c) Left: Photoluminescence spectra collected at saturation pump power from a QD in bulk (violet line), with a nano-ring placed on the sample surface, centered around the emitter's position (blue line) and with nano-ring and super-SIL deposited on the sample's surface (green line). Right: Intensity of the emission lines shown in the left panel, plotted as a function of laser excitation power density (lighter dots correspond to the peak intensity from the spectra shown in the left panel).

References:

[1] O.J. Trojak, S.I. Park, J.D. Song, L. Sapienza, "Metallic nanorings for broadband, enhanced extraction of light from solid-state emitters", *Applied Physics Letters* **111**, 021109 (2017).

[2] O.J. Trojak, C. Woodhead, S.I. Park, J.D. Song, R.J. Young, L. Sapienza, "Combined metallic nano-rings and solid-immersion lenses for bright emission from single InAs/GaAs quantum dots", arxiv.org/abs/1801.07210 (2018).

[3] S.I. Park, O.J. Trojak, E. Lee, J.D. Song, J. Kyhm, I. Han, J. Kim, G.-C. Yi, L. Sapienza, "GaAs droplet quantum dots with nanometer-thin capping layer for plasmonic applications", *Nanotechnology* **29**, 205602 (2018).