Metallic nano-rings for improved extraction of light from InAs/GaAs quantum dots

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Bright single-photon sources are required for various quantum information technology applications. However, the photon extraction efficiency from solid-state emitters can be severely limited by the high refractive index mismatch between semiconductors (like GaAs) and air, resulting in most of the emitted light being trapped within the high-index material. Several approaches have been implemented in order to increase the extraction efficiency, including photonic nanowires, micropillars, circular gratings[1] and solid-immersion lenses, deposited on the materials surface or 3D printed via in situ lithography[2].

We report on a different approach to control the light emission, based on broadband metallic rings. By implementing a photoluminescence imaging technique[3], we position single InAs/GaAs quantum dots grown by molecular beam epitaxy with accuracies of ~25 nm. We then deposit, by means of electron-beam lithography followed by a lift-off, metallic gold rings with inner diameter of ~440 nm, centered around single emitters (see Fig.1a). A confocal photoluminescence set up is used to excite selected single quantum dots with a continuous wave laser and the intensity of the single-photon emission is measured on a charge-coupled device (CCD), before and after the rings are deposited.

(a) (b)

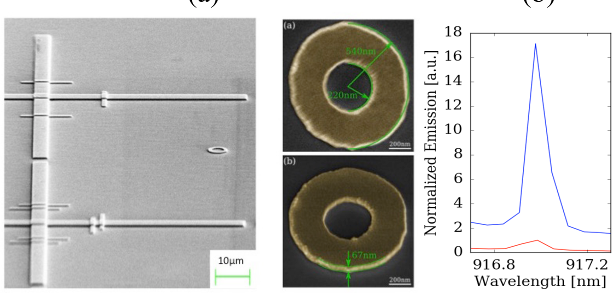

Fig.1: (a) Scanning electron microscope image of a gold ring deposited on a GaAs chip containing InAs quantum dots. (b) Photoluminescence spectra measured from a single quantum dot, before (red) and after (blue) metallic ring deposition (temperature T = 10K, laser excitation wavelength = 780 nm).

We measure enhancements of the emission intensity as high as ~17 (see Fig.1b), due to a lensing effect on the laser excitation and on the emitted light. Compared to optical cavities, our ring devices are intrinsically broadband, since they do not rely on a high-quality factor photonic cavity, and can therefore be implemented with any kind of solid-state emitter. The performances of the rings, obtained with a much easier fabrication technique compared to in situ lithography, also surpass those of 3D printed solid-immersion lenses[2] by almost an order of magnitude. Given the dimensions in play, such metallic rings could also be fabricated using lower resolution techniques such as photolithography and nano-imprinting, thus improving scalability.

REFERENCES

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