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An efficient single-photon source based on a metal-embedded nanocone structure incorporating an InAs quantum dot

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Single-photon sources taking advantage of single semiconductor quantum dots (QDs) are of great interest owing to their potential applications in quantum communications and quantum information processing. To achieve high light-extraction efficiency, researchers have directed the efficient QD emission of photons into well-defined microcavities at the cryogenic temperature, photonic nanowires and metal nanoantennas.[1-3] In this work we demonstrate the high light-extraction efficiency of the metal (Ag)-embedded nanocone structure including an InAs QD.

The InAs QDs were grown on GaAs (100) substrate by metal organic molecular beam epitaxy (MOMBE) and capped with another 50-nm-thick layer of GaAs. A nanocone structure was first fabricated by electron-beam lithography and dry etching processes and then deposited with a 60-nm-thick SiO_2 layer and metal Ag film. Sequential polishing followed by dry etching of GaAs was performed to remove the substrate for the formation of the Ag-embedded nanocone structure including InAs QDs. The taper angle and height of the metal-embedded nanocone structure were typically around 23.5° and 500 nm, respectively. And the InAs QDs were located 50 nm above the SiO_2-semiconductor interface.

Figure 1 shows the micro-photoluminescence (PL) spectrum of an InAs QD in a metal-embedded nanocone structure at 4 K under 633 nm CW excitation. The spectrum exhibits a strong emission line originating from the negatively charged exciton (X^-) at 945.9 nm with a FWHM of 152 μeV. Under pulsed optical excitation at 800 nm and 76 MHz, the count rate of the X^- measured by the SPCM was 196,300 cps at saturation. The measured count rate is 8 times brighter than previously reported one.[4] To evaluate the performance of the structure in terms of extraction efficiency, we measured the autocorrelation function $g^{(2)}(\tau)$ with a Hanbury-Brown and Twiss (HBT) setup.[5] Figure 2 shows $g^{(2)}(\tau)$ for the X^- at saturation. The clear antibunching is observed. The measured $g^{(2)}(0)=0.3<0.5$ proves single-photon emission of the metal-embedded nanocone structure including an InAs QD. Taking into account the collection efficiency of the experimental setup and the correction for multiphoton emission events,[2] the photon extraction efficiency was estimated to be ~ 21%, which is higher than previously reported one in a pillar structure.[4]

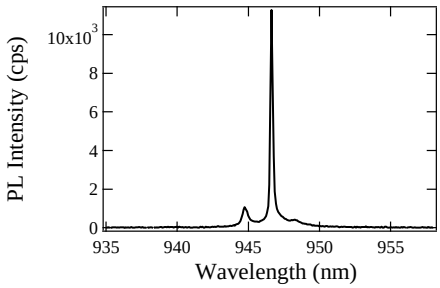

Fig.1. Micro-PL spectrum of the Ag-embedded nanocone structure including an InAs QD.

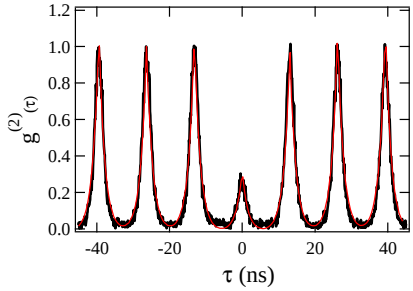

Fig.2. Autocorrelation function $g^{(2)}(\tau)$ of the X^- measured over a 0.5 nm spectral range at saturation.

References

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