Amplification of surface plasmons with quantum dots

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Application Note

Introduction

Optical signals can be squeezed into metallic nano-waveguides where they propagate in a special form consisting of electromagnetic waves coupled with electron oscillations and called surface plasmon-polaritons (SPP). SPPs show unique properties, which are promising for a wide range of scientific fields. However, the propagation loss of SPPs is a challenging problem for potential applications. In order to overcome this drawback, the loss compensation by means of SPP amplification was proposed [1, 2].

In this work, the amplification of a SPP propagating in a metallic nano-waveguide in the presence of quantum dots (QDs) is investigated. The considered metallic nano-waveguide is a nano stripe made of silver embedded in a dielectric. A dielectric-loaded SPP (DLSPP) mode propagating in such a waveguide is strongly confined in the metal and extended in the dielectric. This mode can be amplified by means of QDs located in the dielectric surrounding the metallic core of a nano-waveguide. QDs, which are 4-level quantum system, produce light of a wavelength in the emission band being pumped at a wavelength in the absorption band. This emission can be stimulated by a DLSPP that will lead to the amplification of the mode.

For the investigation of the amplification process, a metallic nano-waveguide with QDs will be coupled to a fiber waveguide using a special taper. A careful characterization of the compound elements of the complete system is required to provide the optimal design. Here we report results on the investigation of the properties of QDs planned to be used in the system.

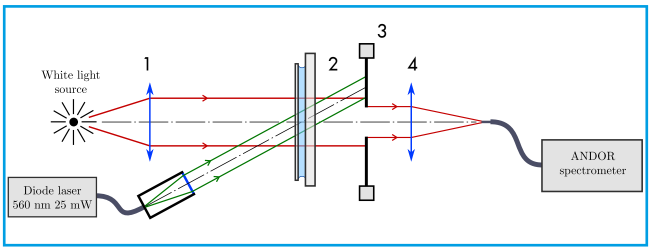

Fig. 1: Setup for the quantum dots emission and crossection spectra acqusition. 1, 4 - focusing lenses, 2 - sample of QDs, 3 - iris diaphragm.

1 Experimental Methods

1.1 Preparation of solution of QDs in agarose

CdTe quantum dots were dissolved in distilled water (3.9 mg/ml). At the same time a solution of hot agarose in water was prepared. Then these two solutions were mixed together. The resulting substance forms a gel after being cooled down. After several hours the water is evaporated and the gel transforms to a solid film with homogeneously distributed QDs.

1.2 Properties of Quantum dots

The absorption and emission spectra of the aforementioned QDs were obtained using an ANDOR model SR-750-B2, serial SR-0416 spectrometer with a CCD camera DU420A-BR-DD, serial CCD-8500 and a 3-core multimode fiber input SR-OPT-8015.

The experimental setup is presented in Fig. 1. A tungsten lamp provides white light, which is used for the measurement of the absorption spectrum of the sample 2. Diaphragm 3 is used to select light that passes through the solution of the QDs only and to block other rays from the lamp. For the measurement of the emission spectrum, sample 2 is pumped with a green laser (wavelength λ = 560 nm). The challenge of this experiment is the enormous intensity of the pumping light compared to the emitted one, which saturates the camera and makes it almost impossible to detect the fluorescence signal. For this reason the pumping ray goes slightly off-axis and hits the diaphragm 3 after passing through the sample 2. Thus, the diaphragm 3 prevents intense pumping light from being reflected or scattered on some surfaces of optical or optomechanical components and going into the spectrometer. As a result, the high sensitivity of the spectrometer can be used for the optimal detection of the weak emission of QDs.

In order to find the absorption spectrum of QDs, a sample of pure agarose solid film was used as a reference. The agarose film was illuminated with a tungsten lamp and the reference spectrum was acquired. The background noise of the cooled to -70 °C camera was measured in complete darkness.

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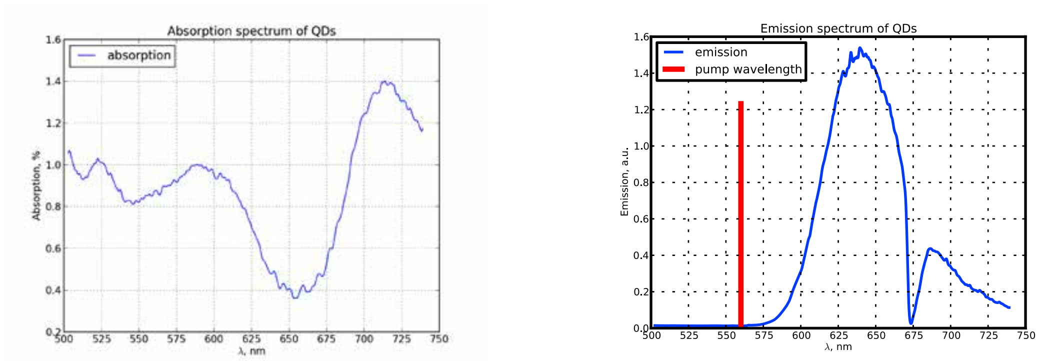

Fig. 1.1: Absorption and emission spectra of CdTe quantum dots for 630 nm. Pumping at 560 nm with 25 mW green diode laser. Concentration is 3.9 mg/ml, 10 µl amount of solution.

Finally, the agarose film was replaced with a sample of QDs and the absorption spectrum of the sample (see Fig. 1.1) was measured. Traces accumulation and long-time exposure were used for all measurements in order to get a smooth, almost noise-free spectrum.

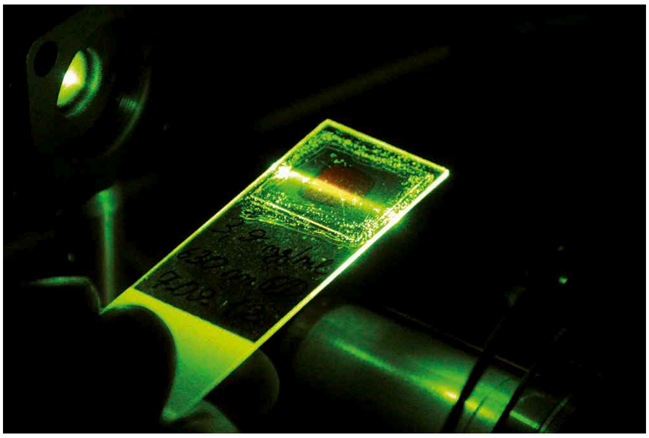

Fig. 1.2: Microscope slide with QDs, illuminated by 560 nm laser. The fluorescent region is clearly seen (orange glowing).

In order to get the emission spectrum of the QDs, the pure agarose solid film was illuminated only by the pump laser (wavelength λ = 560 nm) and the reference spectrum with some stray pump light was acquired. Next, the reference sample was replaced with the sample of QDs and, immediately, the strong fluorescence glowing of orange color was observed (see Fig. 1.2). The spectrum of this emitted light was acquired with the spectrometer in the transmission mode (see Fig. 1.1). Use of the reference spectrum allowed us to exclude the peak caused by the pumping light from the emission spectrum.

From the fluorescence measurement it is clearly seen that QDs can be pumped in a broad range of wavelengths (starting from less than 500 nm and ending at 600 nm). QDs are 4-level quantum system, which will provide spontaneous emission with a peak wavelength about 630 – 640 nm.

According to this results, a metallic nano-waveguide with QDs will be designed to provide the optimal amplification effect of QDs on DLSPP.

References

[1] P. Berini and I. De Leon. “Surface plasmon-polariton ampliers and lasers”. In: Nat Photon 6.1 (Jan. 2012), pp. 16 – 24. issn: 1749-4885.

[2] I. De Leon and P. Berini. “Amplification of long-range surface plasmons by a dipolar gain medium”. In: Nature Photonics 4.6 (2010), pp. 382 – 387.

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