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The red shift of the semiconductor quantum dots luminescence maximum in the hollow core photonic crystal fibers

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ABSTRACT

Hollow core microstructural optical waveguides (photonic crystal fibers) can affect intensity and spectrum position of luminophores emission located in the hollow core. Most strongly this effects could be in case of luminescence semiconductor nanoparticles – quantum dots (QDs) due to the narrow and symmetrical photoluminescence spectra. Study of the spectral effects arising from the superposition of QDs luminescence band on the photonic band gaps in the fiber transmission spectrum is both of fundamental and applied interest. This paper demonstrates the red shift of photoluminescence maximum of CdSe/ZnS QDs with core-shell structures. Luminescence maximum shift can be more than 10 nm, depending on the position of the photonic band gaps in the fiber transmission spectrum.

1. Introduction

Hollow core photonic crystal fibers (HC PCF) are the promising material for various applications such as optical data transmission [1–5], sensor devices [1,4,6,7], optical coherence tomography [1,8,9] due to a combination of high bandwidth, long length interaction and special spectral properties [10,11].

HC PCF are glass (or polymer) fibers with cylindrical holes propagating along the fiber axis for its entire length [1,11,12]. In HC PCF radiation is localized in the central hole (air defect) due to the reflection from the structural shell [13]. Generally, HC PCF are characterized by a comb-like transmission spectrum containing several distinct photonic permitted bands (PPB) and photonic band gaps (PBG) of width up to 50 nm [14]. The mechanism of PPB and PBG formation in HC PCF is similar to the mechanism of formation of the reflection spectrum of the Fabry-Perot model [15–17].

The number and the location of PBG in HC PCF transmission spectrum depend on the ratio of the refractive indices of the material fiber and the medium filling the holes in the fiber structure and also thickness of the resonant layer. Terms of excitation of cladding modes, identical to modes of a Fabry-Perot model, which correspond to peaks in the fibers transmission spectrum, and in that case they can be represented as [17]:

$$\lambda_j = \frac{4d}{2j+1}\left(n_2^2 - n_1^2\right)^{1/2}, \quad (1)$$

where d - wall thickness of capillaries in the structural shell, n_2 – the refractive index of the material from which the fiber is made, n_1 – the refractive index of the medium filling the holes in the fiber structure. The strong core mode attenuation undergoes when the condition (1) is satisfied, as it is resonantly coupled to the shell mode.[14]

The above described HC PCF spectral features make them an extremely attractive platform for sensory systems creation in which HC PCF combines the functions of micro volume reactor and analytical signal transducer [7,14,18].

Quantum dots (QDs) are unique analytical labels due to high photo stability, an abnormally narrow emission band and broad excitation band that allows simultaneous excitation of several types of QDs [19]. QDs emission band can vary and is primarily related to the size of QDs core, to the thickness of the QDs shells, and to the system temperature. Generally increasing size and thickness layer

Abbreviations: HC-PCF, hollow core photonic crystal fibers; PPB, photonic permitted bands; PBG, photonic band gaps; QDs, quantum dots; TZ, transition zone; MC, micro capillaries.

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Table 1
Spectral properties of QDs.

QD	Structure	λ_{em}, nm[a]	QY, %	C, M*10^5	Photoluminescence color
QD^{630}	CdSe/CdS/ZnS	630	36 ± 4	1.5	Red
QD^{587}	CdSe/CdS/CdZnS/ZnS	587	53 ± 6	1.5	Orange
QD^{538}	CdSe/ZnS	538	50 ± 5	0.1	Green

[a] λ_{ex} = 405 nm.

of QDs, and rise of temperature induce red shift of QDs emission band [20,21] QDs are widely applies as label for single or multiple analyte detection in variety of assay formats [22,23].

The application of the QDs integrated to sensory systems based on the HC PCF with various architectures is presented by Refs. [24–29]. The most complete transmission of QDs signal would be in the case of QDs photoluminescence maximum location in HC PCF PPB, while their location in PBG would results to signal suppression. The significant dependence of photoluminescence for systems based on HC PCF with integrated QDs on temperature allows developing optical temperature sensors [30,31]. Analytical lab-on-chip platforms using HC PCF are especially interesting for multi sensors development [32,33]. Simultaneous detection of multiple analytes in HC PCF based systems is related to possibility of effective spectral separation of analytical signals from the QDs array. The number of HC PCF PPB defines of QDs array size. Thus the falling of two or more QDs in one and the same HC PCF PPB is attractive. To avoid overlaps and distortion of the analytical signals, QDs emission bands maximum should be as far apart as possible in order.

The multidimensionality of systems based on HC PCF with integrated QDs assumes the possibility of QDs emission maximum

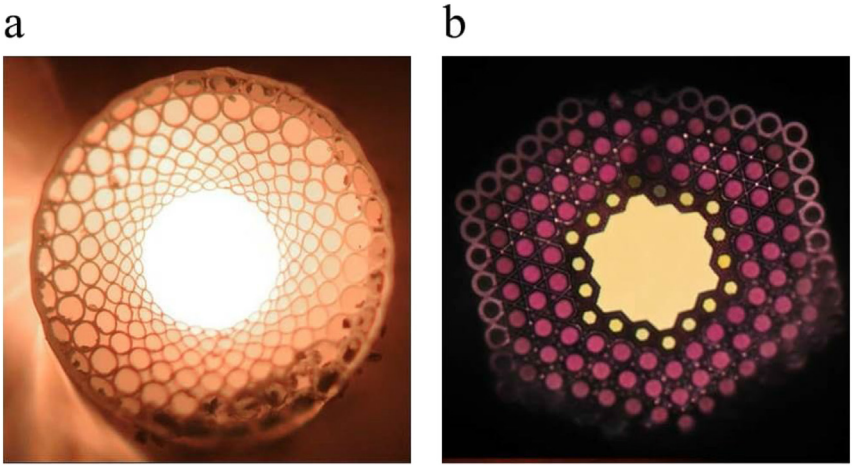

Fig. 1. Cross section of HC PCF with (a) round and (b) hexagonal structure.

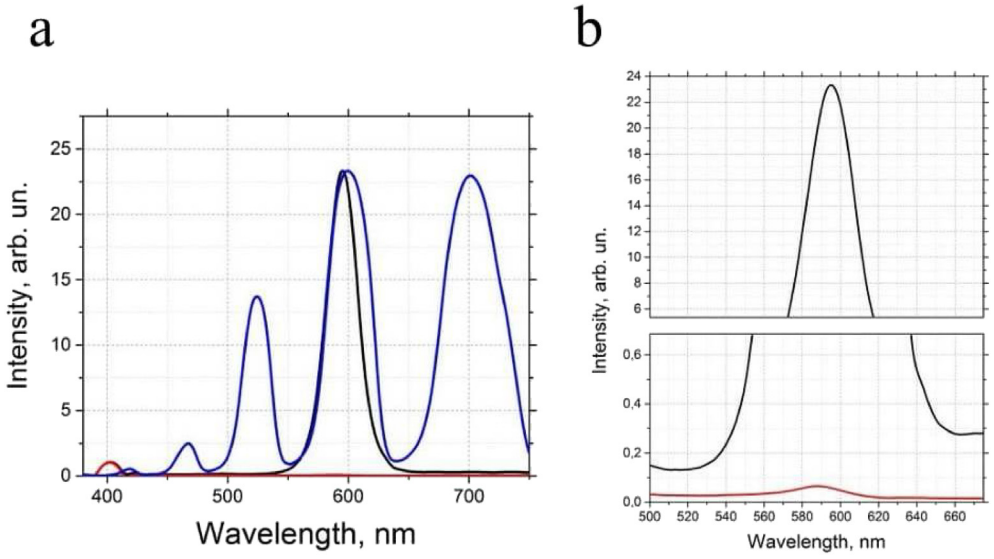

Fig. 2. (a) The transmission spectrum of HC PCF type I (blue), luminescence spectra of QD^{587} in MC (red) and in HC PCF (black), and (b) an enlarged fragment of the graph. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)