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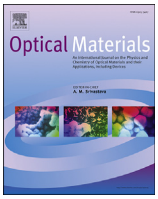

Glass-based 1-D dielectric microcavities

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ABSTRACT

We have developed a reliable RF sputtering techniques allowing to fabricate glass-based one dimensional microcavities, with high quality factor. This property is strongly related to the modification of the density of states due to the confinement of the gain medium in a photonic band gap structure. In this short review we present some of the more recent results obtained by our team exploiting these 1D microcavities. In particular we present: (1) Er^{3+} luminescence enhancement of the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition; (2) broad band filters based on disordered 1-D photonic structures; (3) threshold defect-mode lasing action in a hybrid structure.

1. Introduction

The development of optically confined structure is a major topic in both basic and applied physics not solely ICT oriented but also concerning lighting, laser, sensing, energy, environment, biological and medical sciences, and quantum optics [1–6]. Photonic crystals, photonic structures with a periodically varying refractive index, are of practical importance for photonic devices because they can control the propagation of electromagnetic waves [7]. One-dimensional photonic crystals have been widely investigated and still remain an outstanding tool for new photonics, being the simplest system to exhibit a so-called photonic bandgap and therefore one of the easiest to handle in order to obtain tailored optical devices. RF sputtering has demonstrated to be a viable technique for fabrication of 1-D-photonic crystals allowing management and manipulation of the optical and spectroscopic properties [8,9]. Here we discuss some recent results obtained by our consortium regarding: (i) 1-D photonic crystals allowing Er^{3+} luminescence enhancement concerning the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition; (ii) disordered 1-D photonic structures that are very interesting for the modelization and realization of broad band filters and light harvesting devices; (iii) 1-D microcavities, activated by a layer

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based on poly-laurylmethacrylate matrix containing CdSe@$Cd_{0.5}Zn_{0.5}S$ quantum dots, leading to coherent emission.

2. Experimental

1-D photonic structures were prepared by RF sputtering technique using TiO_2 and SiO_2 as high and low refractive index materials, respectively, and silicon and silica substrates. The substrates have been cleaned inside the rf sputtering deposition chamber by heating at 120 °C for 30′ just before the deposition procedure. Sputtering deposition of the films has been performed by sputtering alternatingly a 15 × 5 cm^2 titania target and a 15 × 5 cm^2 silica target. The residual pressure, before the deposition, was about 8.0×10^{-7} mbar. During the deposition process, the substrates were not heated and the temperature of the sample holder during the deposition was 30 °C. The sputtering has occurred with an Ar gas pressure of 5.4×10^{-3} mbar; the applied rf power was 150 W and 130 W and the reflected powers 0 W for silica and titania targets, respectively. Particular attention has been paid to the reproducibility of the single layers and the monitoring of the deposition rates during the process. To monitor the thickness of the layers during the deposition, two quartz microbalances Inficom thickness monitor model SQM 160, faced on the two targets have been employed. Thickness monitor was calibrated for the two kinds of materials by a long deposition process (24 h of deposition) and by directly measuring the thickness of the deposited layer by an m-line apparatus and SEM imaging. The final resolution on the effective thickness obtained by this quartz microbalance is about 1 Å. More details about the deposition protocols can be found in Ref. [10]. Number of layers as well as the thickness of each layer were defined as a function of the functionalities desired for each microcavity.

3. 1-D photonic crystals allowing Er^{3+} luminescence enhancement

One of the interesting features of the 1-D microcavities is the possibility to enhance the luminescence, resonant with the cavity, when the defect layer is activated by a luminescent species. This is a general and significant property of photonic crystals and it has frequently been used to modulate the emission wavelength and enhance the radiative rate and intensity of luminescent objects [11]. When the cavity dimensions approach the wavelength of the emission the density of electromagnetic states inside the cavity are strongly perturbed and can lead to significant enhancement of the luminescence quantum yield [12]. This enhancement is achieved by increasing the number of the localized modes coupled with the emitter [7,13].

Fig. 1 shows the SEM image of a microcavity with an Er^{3+}-doped SiO_2 active layer inserted between two Bragg reflectors, each one constituted of ten pairs of SiO_2/TiO_2 layers. The dark regions correspond to the SiO_2 layer and the bright regions correspond to the TiO_2 layer. The substrate is located at the bottom of the images and the air on the top.

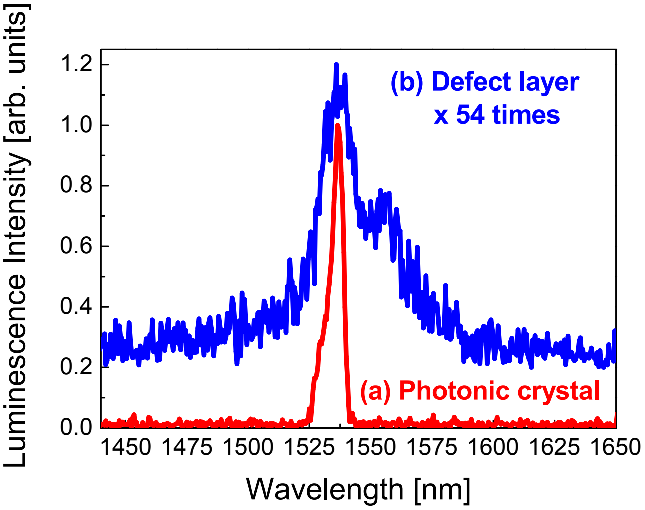

Fig. 2. $^4I_{13/2} \rightarrow {}^4I_{15/2}$ photoluminescence spectra of the Er^{3+}–doped SiO_2 active layer in 1-D photonic crystal (a) and of the Er^{3+}–doped SiO_2 active layer without cavity effect (b). Excitation was at 514.5 nm. The cavity enhances the emission of about a factor 54.

The Er^{3+} content in the active layer is about 0.6 ± 0.1 mol%. The NIR transmittance spectrum, measured at zero degree of incident angle, shows the stop band from 1490 to 1980 nm. A sharp peak in the transmittance spectrum appears at 1749 nm. It corresponds to the cavity resonance wavelength related to the half wave layer inserted between the two Bragg mirrors. The full width at half maximum of the resonance is 1.97 nm, corresponding to a quality factor of the cavity, Q, of about 890.

Fig. 2(a),(b) shows the Er^{3+} $^4I_{13/2} \rightarrow {}^4I_{15/2}$ luminescence from the cavity (a) and from the reference (b), constituted by Er^{3+} - doped SiO_2 layer deposited on a Bragg reflector. In order to get a correct comparison a specific procedure, assuring that the only variation is constituted by the cavity effect, was employed as detailed reported in Ref. [10]. Both the cavity and the reference were excited with the 514.5 nm line of an Ar^+ ion laser with an excitation power of 180 mW. The erbium emission from the reference is centered at 1538 nm with a full width at half maximum of 29 nm and exhibits the characteristic shape of Er^{3+} ion in silica glass [14].

The peak luminescence intensity of Er^{3+} ions inside the microcavity is enhanced by about a factor 54 in respect to that detected for the reference at the corresponding wavelength. The Er^{3+} $^4I_{13/2} \rightarrow {}^4I_{15/2}$ emission line shape is strongly narrowed by the cavity and exhibits a full width at half maximum of 5 ± 0.5 nm. According to Fermi's golden rule, the rate of spontaneous emission at a given frequency is proportional to the density of states at that frequency. The Er^{3+} emission is enhanced when the wavelength corresponds to the cavity resonant mode and weakened for the other emission wavelengths depending on the number of the localized modes coupled with the erbium ion in the defect layer.

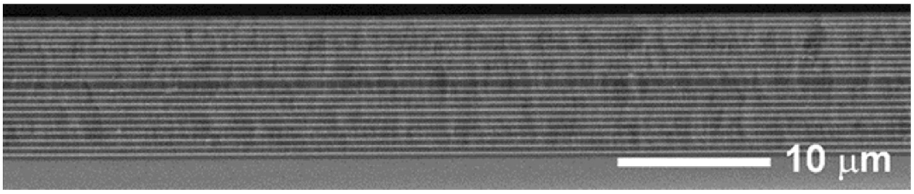

Fig. 1. SEM micrograph of a 1-D microcavity fabricated by RF-sputtering. The Er^{3+}-doped SiO_2 active layer is inserted between two Bragg reflectors, each one constituted of ten pairs of SiO_2/TiO_2 layers. The bright and the dark areas correspond to TiO_2 and SiO_2 layers, respectively. The substrate is located on the bottom of the images and the air on the top.

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