

In situ monitoring of light generated by quantum dots in integrated photonic devices in the VIS-NIR spectral range

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Optical waveguides are the key component of photonic technology because these structures confine and propagate the light into an integrated optic device of reduced dimensions. Then, it becomes necessary a characterization method able to establish its optical characteristics. In particular, when the structures show active properties it is important monitoring their emitted spectrum under external conditions. In this way, here is proposed a characterization method based on VIS and NIR spectroscopy to analyze active optical waveguides, not only by measuring the photoluminescence spectrum but also by obtaining the gain characteristics and the propagation length of the light along the structure.

Background

Nowadays the industry or research institutions have a great concern in studying the interaction of light beams with different materials and to develop a technology able to generate, control or manipulate a flow of photons [1]. Therefore, during the last two decades it has been produced an important development of photonic circuits able to integrate different passive or active optical functions in a common substrate, in the same way as Microelectronic does with electronic components. Moreover, these "exotic photonic circuits" have additional advantages derived from the high speed ($3 \cdot 10^8$ m/s in the air) and frequency (~ 100 THz) of the light, which allows an improvement of the performances achieved by the traditional electronic technology, e.g. a larger bandwidth, smaller delay time among, miniaturize the size and reduce the power consumption, among others. Then, integrated optics circuits are currently basic in important fields like optical telecommunication systems, radars or high sensitivity sensors.

The key component of integrated optics is the optical waveguide. This structure is based on the confinement and propagation of the light into a material with higher refractive index than that of the surrounding. Unlike electronic devices where silicon is the most used material, optical waveguides have been fabricated using a great variety of technologies, e.g. LiNbO₃, Silicon, III-V semiconductors or polymers. Since each material present different advantages or limitations, they can provide particular functionalities. Then, the study of their optical properties before their application into a certain device becomes necessary. As an example, the generation of light into a waveguide by electrical or optical pumping is of particular interest as it is the basic property in the fabrication of active devices, like amplifiers, diodes or lasers. Therefore it is useful to characterize the emission spectra guided by the structure and to monitor it as a function of external parameters. In this application note it is proposed to use VIS and NIR spectroscopy to characterize the photoluminescence (PL) spectra guided in a waveguide, their gain properties and also the

propagation length of the light travelling along the structure. Those are basic parameters in an active waveguide structure and can be applied to any material with active properties. Therefore, here is proposed to use a nanocomposite consisting of colloidal quantum dots (QD) inside a polymer matrix. This multicomponent material is very promising for photonics because it combines the novel properties of colloidal QDs (highly efficient, temperature-independent emission and band-gap tunable with size or base material) with the technological feasibilities and low cost of polymers [2].

Experimental considerations

QD-PMMA films are patterned on a SiO_2/Si substrate by defining straight lines with different widths (see Figure 1a). Due to the active properties of the nanoparticles, if the waveguides are pumped at an appropriate wavelength the incoming photons can excite the nanoparticles into the waveguide (QDs) providing the emission of new photons at a larger wavelength. This process is called photoluminescence (PL) and is the basis of active devices. Figure 1b shows a photograph of the waveguides patterned on the substrate without (left image) and with (right image) optical pumping. Clearly the straight lines emit red light corresponding to the PL of the QDs inside the matrix (in this case CdSe QDs). Moreover, since the polymer has a refractive index (~ 1.5) higher than that of the substrate (~ 1.45) the nanocomposite can act as a core of a waveguide able to confine and propagate the light coupled at the input edge of the sample (Figure 1c1). Thus, if the light coupled in the waveguide pump the QDs, their PL will be also confined and propagated along the waveguide (Figure 1c2). At the output edge this emission can be analyzed with a spectrometer by collecting the guided PL and focusing into a fiber optics connected to the device (Figure 1c3).

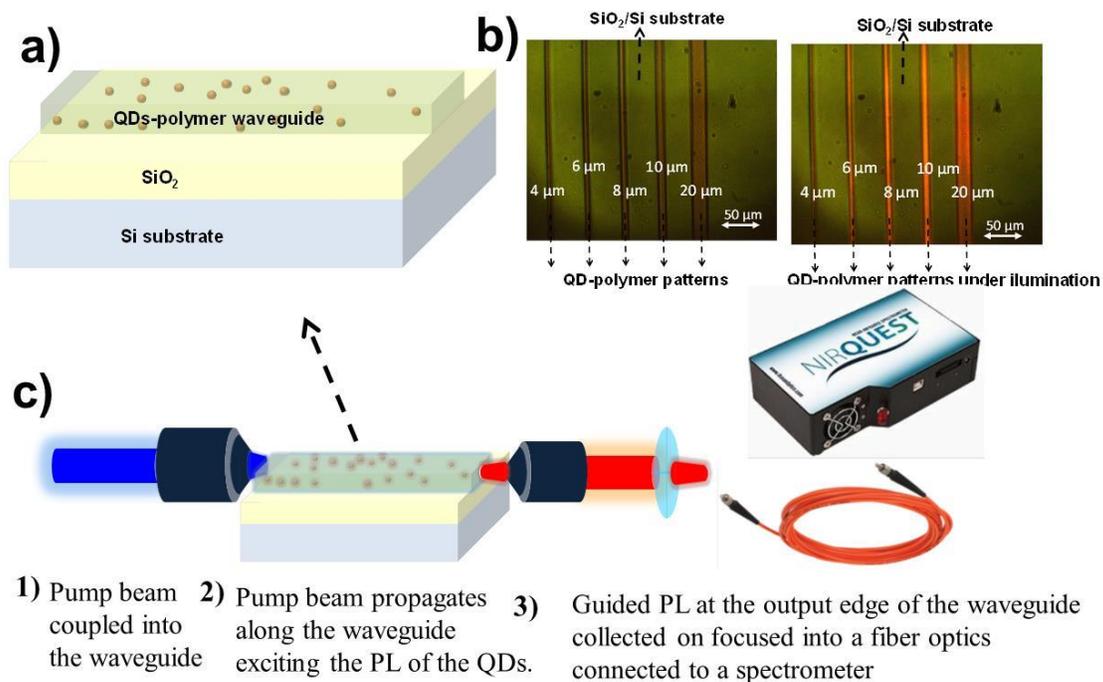


Figure 1. a) Structure of the waveguide. b) Photograph of the patterns without and with illumination. c) Experimental set-up to couple light into the structures.

Results

The experimental set-up explained above can be used to study the guided PL of nanoparticles with emission in the visible (USB-2000 spectrometers) or the near infrared (NIR-Quest spectrometers). Figure 2a and 2b show the guided PL spectra measured at the output of waveguides containing CdSe QDs (emission centered at 600 nm) and PbS QDs (emission at 1100 nm) respectively. The inset photographs correspond to the guided PL signal at the output face of the waveguides of different widths (between 4 and 20 μm). This guided PL can be used for different applications, and thus it is important to characterize its intensity and spectral shape along the structure. For this purpose it is useful to focus the pump beam in a stripe line on the top of the sample and monitoring the guided PL with a spectrometer by using the collection system shown in Figure 1c [3]. In this way, the gain of the material can be estimated by measuring the emission as a function of the length of the stripe (see inset of Figure 3a). As an example, Figure 3a shows the PL spectra for different lengths (z) in a waveguide containing CdSe QDs (emission peak at 600 nm). The inset plots the intensity of PL (I_{PL}) as a function of z . Light intensity increases with the length of the stripe and then it reaches saturation. The behavior can be fitted (red line) by the equation $\frac{dI_{PL}(x)}{dx} = I_{SS} + (g - \alpha) \cdot I_{PL}(x)$, where the gain can be extrapolated. Here I_{SS} is a constant, g the gain and α the losses. In addition, the propagation length (or losses) of the PL spectra can be measured by keeping the length of the stripe constant, analyzing the emission as a function of the distance between the stripe and the edge of the sample (see inset of Figure 3b). Figure 3 b shows the PL spectra for different distances (L) in the same sample (containing CdSe QDs). The dependence of the I_{PL} with L follows an exponential decay $I_{PL}(L) \propto e^{-\alpha \cdot L}$ where losses (α) can be obtained.

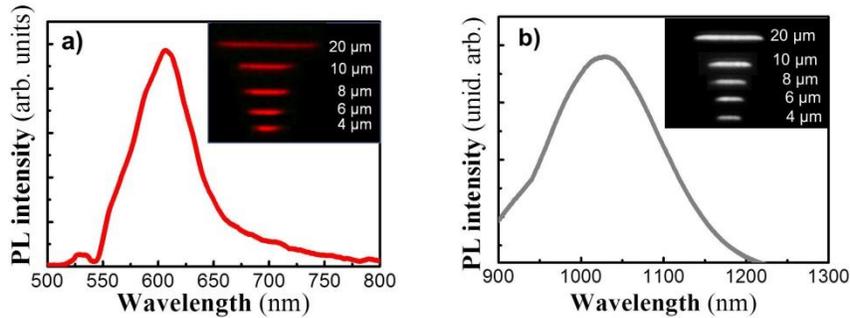


Figure 2. a) Guided PL spectra of nanoparticles emitting at 600 nm (CdSe QDs). b) Guided PL spectra of nanoparticles emitting at 1100 nm (PbS QDs). The inset photographs correspond to the guided PL signal at the output face of the waveguides.

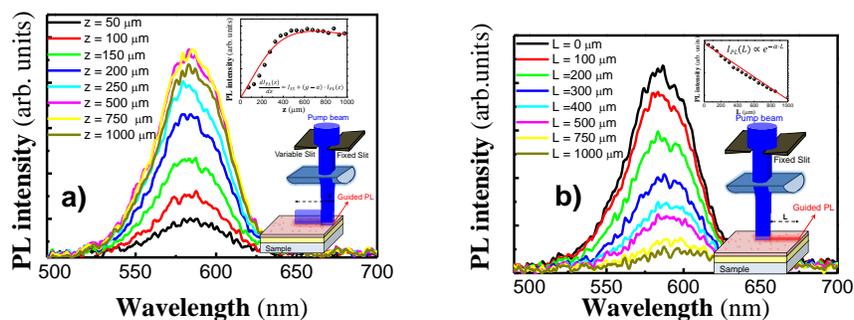


Figure 3. Spectra obtained by focusing the pump beam on a straight line on the top of the sample a) Gain is characterized by measuring the guided PL as a function of the length of the stripe. b) Losses are estimated by measuring the PL as a function of the distance between the line and the edge of the sample.

Conclusions

VIS and NIR spectroscopy is successfully applied in analyzing active waveguides on a broad spectral range (400-1700 nm). When the waveguides are pumped optically the guided photoluminescence spectra can be monitored by using VIS or NIR spectrometers. In this way, the propagation of the light along the structure can be studied obtaining important parameters as the gain or propagation losses. The method can be used in any waveguide material with active properties and here is particularized for quantum dot-polymer waveguides.

References

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