

Multicolor wave-guiding in polymer/quantum dot nanocomposite waveguides

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Abstract— Nanocomposites based on colloidal quantum dots incorporated in polymer matrices are proposed. First, CdS, CdTe and CdSe are mixed in PMMA to demonstrate three-color waveguiding. Then, CdSe has embedded in SU8 to implement ridge active waveguides.

Keywords: colloidal quantum dots, polymer, nanocomposite, organic-inorganic hybrid photonics, waveguides, PMMA, SU8

I. INTRODUCTION

Photonics research is evolving toward the development of novel functional materials able to perform more complex and efficient optical functions. In this way, one of the most promising approaches is the incorporation of nanoparticles into a host matrix to form a nanocomposite [1]. These synthetic multicomponent materials combine the novel properties of semiconducting, metallic or magnetic nanoparticles (e.g., quantum confinement, surface plasmon resonance, superparamagnetism, respectively) with those provided by the matrix. For this purpose the choice of polymers as a host matrix is an attractive approach, because they are cheap, flexible and can be easily processed into films on a great variety of substrates. Moreover, some polymers can be micro and nanopatterned by different lithographic techniques such as imprint, electron beam and ultraviolet lithography [2]. Indeed, polymers are especially suitable materials for integrated optics applications because of its high transparency above 400 nm, low propagation losses and easy fabrication. In this sense, polymer-based nanocomposites can be good candidates for active wave-guiding applications by mixing with semiconducting nanocrystals synthesized by colloidal chemistry [3]. These nanocrystals are usually known as quantum dots (QDs), due to the three dimensional size confinements of carriers. In consequence, its effective bandgap, and hence their photoluminescence (PL) can be tuned by either modifying their radius [4] or the base material, being it possible to cover the whole spectra using CdS, CdSe and CdTe in the visible, and PbS, PbSe, and InAs in the near-infrared. Then, these nanostructures are interesting candidates as active materials [5], and have already been incorporated in sol-gel oxide waveguides to develop optical amplification [6], but also in PMMA to amplify the spontaneous emission [7]. Also recently [8], we have demonstrated the optimum conditions for waveguiding in CdSe-PMMA and CdTe-PMMA nanocomposite films; being it possible to obtain

multicolor wave-guiding by dispersing both kinds of QDs into the matrix. In this work, this result is extended to incorporate three families of QDs (CdS, CdSe and CdTe) in a PMMA nanocomposite waveguide; with the intention to show three color wave-guiding as a first step to obtain white light. Also, first results of the dispersion of CdSe QDs in a SU-8 photoresist are presented [9]. As a result, ridge structures able to guide CdSe photoluminescence are implemented.

II. EXPERIMENTAL

Active material used in this work consisted of different sorts of colloidal quantum dots (CdS, CdSe and CdTe) fabricated using the procedure developed by Peng's group [8]. Since each QD family has different chemical nature and size, they will lead to optical transitions at different wavelengths. Exciton absorption peaks are centered at 447, 537 and 580 nm for CdS, CdTe and CdSe, respectively. The PL spectra consist of single Gaussian lines slightly red-shifted with respect to the exciton peak in absorption by about 40 nm.

Nanocomposite solutions have been prepared by mixing colloidal QDs with PMMA or SU8 polymers using a common solvent. The concentration of QDs in the matrix was fixed according to the results found in Ref. 8, where filling factors (ratio of QDs-volume to the total sample volume) between 10^{-4} and 10^{-3} showed optimum waveguiding. The inset of Figs. 1 and 2 depicts the structure of the waveguides. The first one (inset in Fig. 1) consists of QD/PMMA nanocomposite acting as a core of a planar waveguide. The film was processed using the procedure described in [8] and had a thickness of about 0.9 μm . The low refractive index of SiO_2 (1.458 at 600 nm) with respect to the PMMA (1.489 at 600 nm) provides a sufficiently high refractive index contrast to allow waveguiding. In the second structure, SU8 has been chosen as polymer matrix with the intention to implement two-dimensional waveguides with the aid of its photolithographic properties and its high refractive index (1.5108 at 600 nm). The film has a thickness of 2 μm and was patterned into lines of 4, 6, 8, 10 and 20 μm wide using a standard UV lithography procedure [10]. In both cases the SiO_2 was a sol-gel film 650 nm thick processed by the method described in Ref. 8.

III. RESULTS

A. Multicolor wave-guiding in QD/PMMA films

QD-PMMA planar waveguides have been characterized by end-fire coupling at 404 nm (GaN diode laser). It has already been demonstrated that for high filling factors ($>10^{-3}$) of QDs in PMMA, the QDs strongly attenuate the laser beam and waveguiding is not possible [8]. But, if the concentration is low enough, waveguides show small propagation losses and PL can be properly wave-guided. The dispersion of several QD ensembles into the same waveguide enables the observation of guided PL spectra composed by the different "QD colors". Figure 1 shows the guided PL spectra in a waveguide embedding CdS (blue, 452 nm), CdTe (green, 539 nm) and CdSe (red, 601 nm) QDs. It is worth noting that it was critical to adjust the relative amounts of QDs into the matrix in order to avoid (or compensate) reabsorption between QDs families. The PL tail observed at long wavelengths is associated to surface states in CdS QDs. The pictures at the top of Fig. 2 correspond to the three color waveguiding.

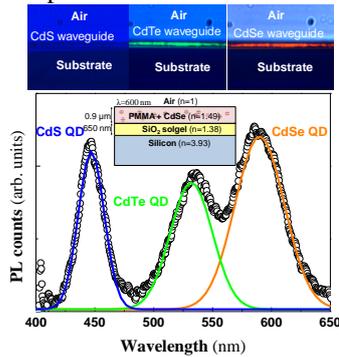


Figure 2. PL waveguided spectra of QD/PMMA thin film with three QD ensembles (CdS, CdTe and CdSe).

B. Ridge CdSe/SU8 waveguides

One of the most interesting characteristics of polymers is the possibility to be patterned by different lithographic techniques. Although PMMA is cheap and allows a trouble-free thin film processing, the patterning by lithographic methods is not possible. In this way SU8 was chosen as the resist matrix to embed QDs, because is easily-patterned by using UV photolithography and has a high refractive index (~ 1.5) [10]. However, the main drawback of SU8 is its chemical incompatibility with as-synthesized QDs. In [10] we proposed the appropriate ligand exchange to disperse QDs in this polymer, making it possible to develop patterns with QD inside. Figure 3 shows a preliminary result of these new patterned structures. The spectra corresponds to the guided-PL of CdSe QDs in an 8 μm SU-8 ridge pumped with a 533 nm DSPP diode laser characterized by end fire coupling. The inset shows a photograph of the guided PL in waveguides with different widths. In all cases the structure is able to confine PL into two dimensions.

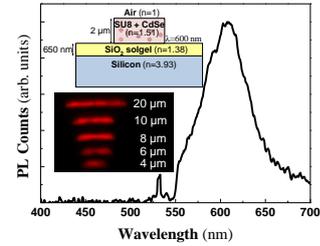


Figure 3. PL waveguided spectra of CdSe QDs into SU8 ridge waveguides.

IV. CONCLUSIONS

The integration of QDs in polymer matrices is an interesting approach for developing active organic photonic devices. In this work, films made by the dispersion of colloidal nanostructures in a PMMA matrix are demonstrated to be a good core for waveguides. Using the appropriate concentrations of QD into the matrix, these films are able to waveguide the PL, and even more than one color when different types of QDs are embedded in the polymer thin film. Finally, these results are extrapolated into a photolithographic polymer (SU8), measuring waveguided PL in ridge structures fabricated by UV lithography.

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