Colloidal QDs/PMMA nanocomposites as material to provide gain in surface plasmon polaritons

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Surface plasmon polaritons (SPPs) are hybrid electromagnetic waves and charge surface states propagating in the boundary between a metal and a dielectric [1]. They receive much interest nowadays because the present unique properties as subwavelength confinement, strong near electromagnetic field enhancement or high sensitivity to the environment [2], leading to a broad range of potential applications, like subwavelength photonics, metamaterials or biosensing. However, although devices based on the propagation of surface plasmon can achieve exceptional properties, SPPs suffer from high attenuation because of the absorption losses in the metal, limiting the application of this technology. Nevertheless, this limitation can be overcome by providing the material adjacent to the metal with optical gain. Under these conditions, the problem of absorption losses is alleviated. Consequently, the propagation length of SPPs [3] is increased or SPPs are even amplified [4]. In the literature different materials like dyes [3], fluorescent polymers [4], rare earths [5] or PbSe quantum dots [6] have been proposed as gain medium for wavelengths between 600 and 1500 nm.

In this work a novel material based on the incorporation of colloidal quantum dots in a polymer matrix is proposed as a dielectric medium to provide gain in plasmonic waveguides. This kind of nanocomposite (polymer+quantum dots) is a useful material because it combines the novel properties of colloidal quantum dots (temperature independent emission and color tuning with the base material) with the technological feasibility of polymers (spin coating, UV and e-beam lithography...). Indeed, the application of CdSe/PMMA in the development of active dielectric waveguides has already been demonstrated at 600 nm [7]. Furthermore, wavelength tunability of the device (from 400 nm to more than 2 µm) can be achieved just by changing the material of the dots and their size [8] without modifying the fabrication conditions. In this manuscript, CdSe-PMMA nanocomposite films are deposited on a gold surface to compensate the losses of the SPP propagating at the interface at 600 nm [9]. First, a suitable design of the amplifier is presented, making a thoroughly study of the propagation of SPP under amplification. The effect of the concentration of CdSe in PMMA nanocomposites on the gain is analyzed. Then, plasmonic waveguides are fabricated by spin coating CdSe-PMMA nanocomposites on gold layers evaporated on a SiO_2/Si substrate. When the structures are optically pumped (see figure 1 a) the photoluminescence (PL) of the CdSe can be coupled to the SPP mode, making it possible to characterize the waveguided PL (figure 1 b) or modes (figure 1 c) by collecting the light at the output of the waveguide. If the pumping laser is focused in the shape of a stripe line the optical gain can be estimated by measuring the photoluminescence as a function of the pumping length [10]. Figure 2a shows the characterization of the gain for three different filling factors of QDs in the polymer. In all cases there is an exponential dependence on saturation for stripe lengths longer than 500 µm. By fitting the curve with an exponential law, net gains of around 25 cm have been estimated for the highest filling factor studied. In the same way propagation losses can be characterized by keeping the length of the stripe constant and moving it away from the edge of the sample. Then, propagation losses can be fitted by approximating the dependence of the output intensity as a function of the distance between the stripe and the edge of the sample with an exponential decrease. In addition, figure 2b shows that propagation losses increase with the concentration of QDs in the PMMA due to reabsorption effects, presenting a compromise between high gain and low reabsorption.

References

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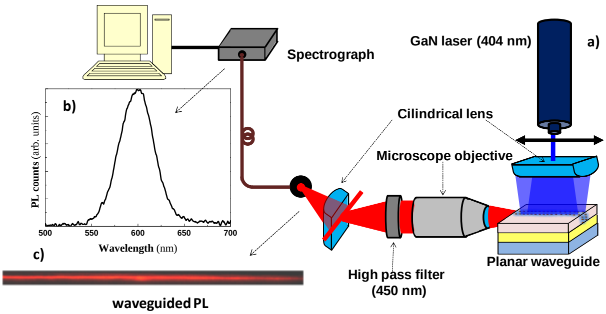

Figure 1

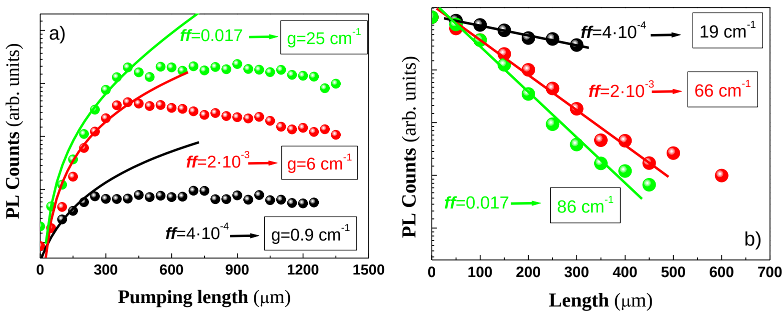

Figure 2