Enhanced emission and tunability in self-assembled photonic crystals by hybrid photonic-plasmonic modes

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Tunability is challenging in photonics. The possibility to either passively or actively modify the optical properties of photonic devices opens new applications especially in sensing and light emitting devices. Among all the structures suitable to be implemented as tuning devices, photonic and plasmonic crystals have become two of the most powerful techniques. Recently, coupling between both kinds of structures has shown to provide exceptional properties especially concerning light emission control at visible and near infrared range [1]. From this point of view, more affordable implentations compared to usual lithographic techniques has been proposed making use of the high quality self-assembled photonic crystals fabrication methods. By growing a monolayer of polystyrene spheres (diameter size similar to working wavelength) on a gold substrate it is possible to obtain hybrid photonic-plasmonic resonances coupling [2]. Modal distribution of those hybrid modes is largely dependent on the lattice parameter as well as on the filling fraction of the monolayer of spheres. In addition, if an emitter is placed in the field confinement region for one given mode, emission can be enhanced as well as tuned to the required frequency by choosing the appropriate sphere diameter.

In this work we present an easy implementation method to tune the modal distribution of that system by homogeneously reduce sphere diameter while lattice parameter is kept constant. Applying oxygen plasma etching for a very accurate controlled time we have obtained control over filling fraction (ff) of the photonic crystal. Reductions were performed from the as-grown close packed (ff = 0.52) to largely reduced sphere size (ff < 10) while quality of the photonic lattice was shown to keep very high. Both experimental and theoretical study of the optical response was performed in normal incidence reflectance. Modes of the system (shown as large dips in reflectance) largely blueshift with sphere reduction, especially those with waveguided character. Sensibility of mode spectral position to filling fraction variations was investigated for 1 µm diameter polystyrene spheres by reflectance measurements in diameter reduction steps as low as 10 nm. Almost linear blueshift was observed for every mode. Numerical simulations for reflectance have shown good agreement with experimental results. Field profile into the structure was studied in order to evaluate how changes on sphere diameter affect mode shape. Larger changes were found for waveguided-like modes compared to plasmonic ones as would be expected from studies reported in bibliography for these structures.

As a step forward, changes on emission distribution with filling fraction was studied. To do that, red dye doped PS 520 nm diameter spheres (emission maxima at aprox. 590 nm) were grown on gold substrate. Several steps on sphere reduction were performed and changes for emission maxima were measured typically happening at the same spectral position were a dip in reflectance is shown. It was found that, as expected, emission spectrum was blueshift in the same amount that was is monitorize for reflectance. This provides a proof of principle of tuning of the emission peaks to the required spectral position while the structural modification is very accurately monitorize by normal reflectance measurements.

This results demonstrate that this fine tuning process could be used for passive or active devices leading to high performance but low cost structures as for example biosensors or OLED.

References

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Figures

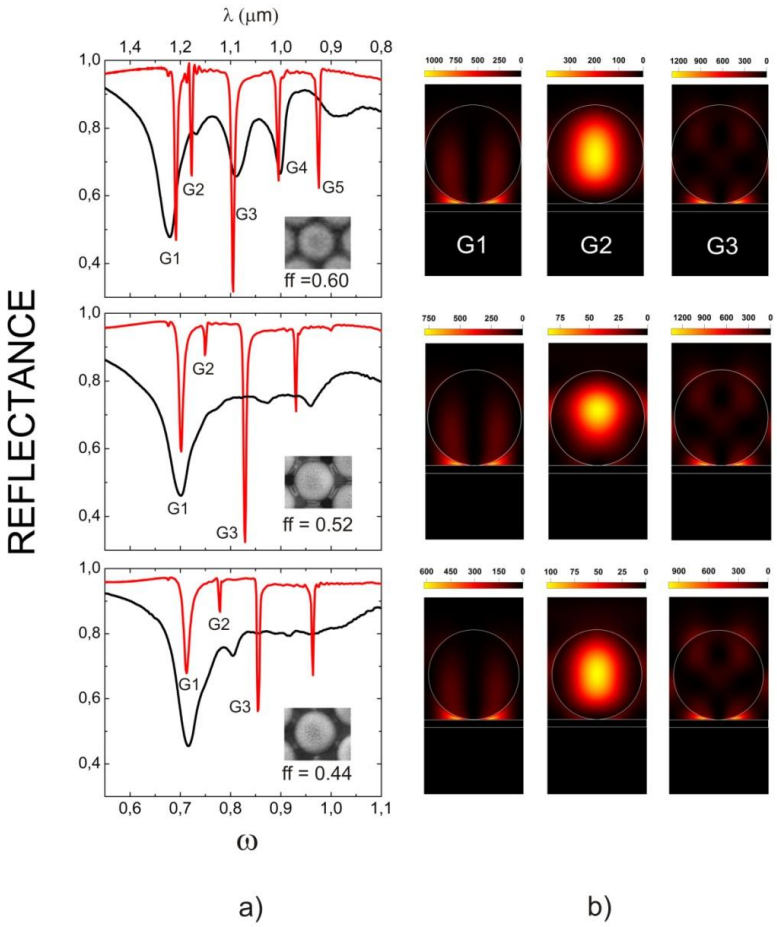

Figure 2. a) Normal incidence reflectance for three different filling fractions. Top to bottom: ff=0.6, ff=0.52, ff=0.44 corresponding to γ=1, γ=0.95 and γ=0.9 respectively. Experimental (black) and theoretical spectra (red) are presented. b) Total field intensity distribution and its evolution with sphere resizing for the first three modes in the left panel.

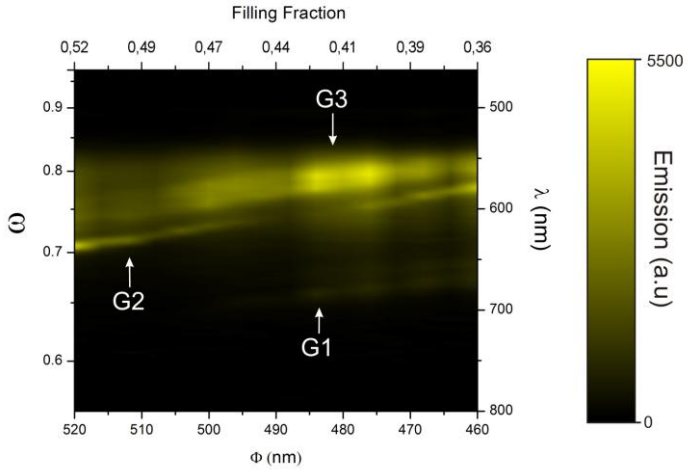

Figure 2. *Emission (in arbitrary units) contour plot for a monolayer of 520 nm dye doped PS spheres in a continuous filling fraction reduction process. Oxigen plasma etching was carried out from the close packed scenario (ff = 0.52) to a final filling fraction of ff = 0.36.*