Control of the Light Extraction from a Photonic Crystal Nanocavity by Coupling with a Nanoparticle

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I- Objective :

In this poster, we will present a numerical study of a coupling between a nanoparticle (NP) and a photonic crystal cavity (PCC) in order to control the properties of the light extracted from the PCC. Such an NP is designed to present an electric dipole at the same resonance wavelength of the PCC. This coupling, which is modeled in the near field and as a function of the spatial position of the NP relative to the PCC, shows the possibility of a tunable manipulation of the angular radiation spectrum of the whole structure.

II- Description of the System

The PCC was proposed by Monat et al. [1], such that a 2D hexagonal array (**period a=420 nm**) of air hole cylinders of diameter (**d=210 nm**) are etched into a 300 nm thick InP layer. The latter is deposited on a 1 µm thick silica layer on a silicon substrate. The cavity is thus constituted by the absence of seven aligned holes, as shown in the inset of figure (1.a). Figure (1-b) shows the near-field spectrum calculated above the center of the PCC at a distance of 15 nm in air. The excited mode of the cavity appears at wavelength (**λ_0=1602.92 nm**) with a quality factor of (**Q_f=4035**) as already found in [2].

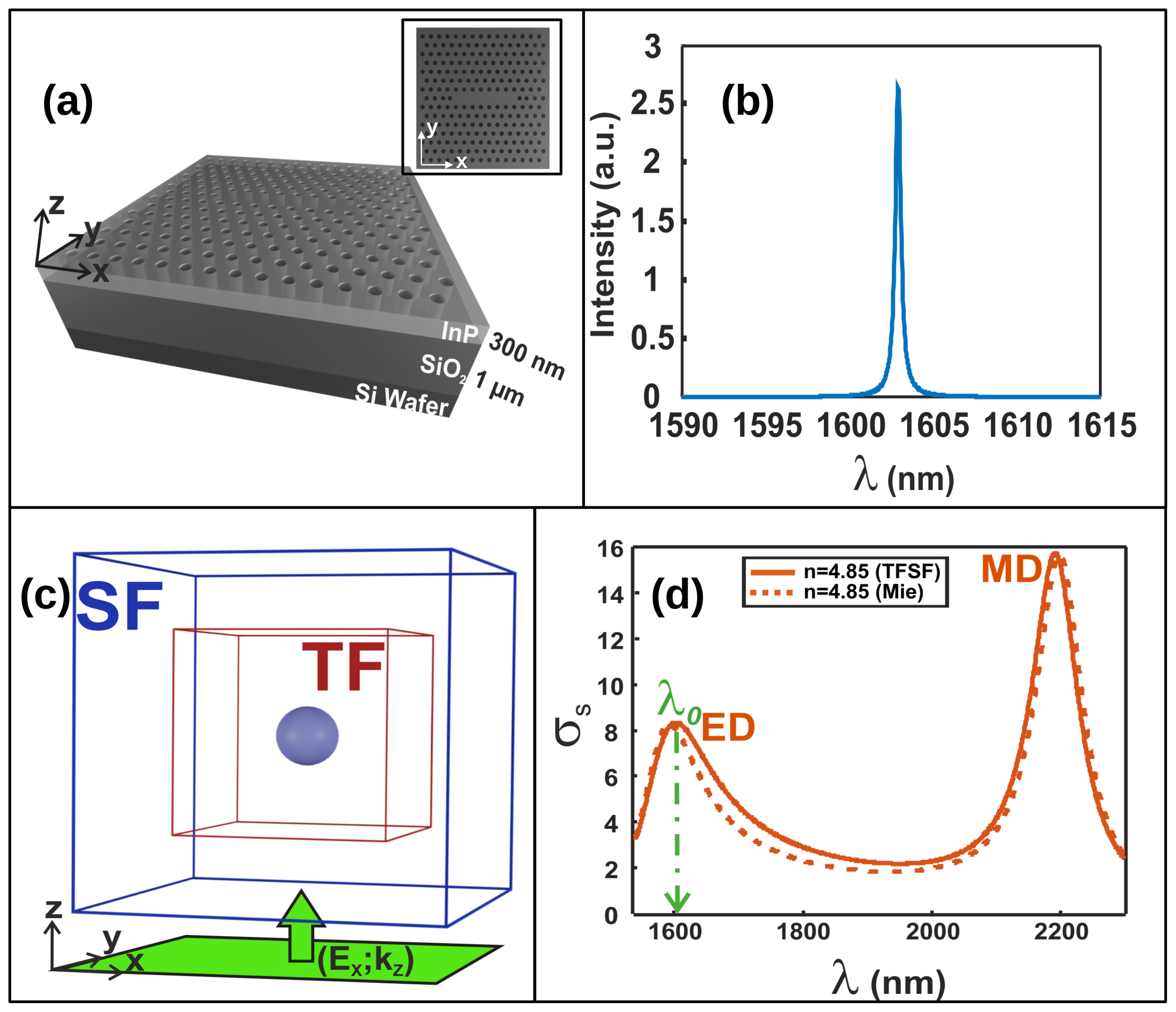

Fig. 1 - (a) Schematic of the considered 3D Photonic crystal with an inset of its schematic in top view. (b) Near-field intensity spectrum calculated at 15 nm in air above the center of the PCC. (c) 3D schematic of the NP surrounded by the 2 boxes (TF and SF) and illuminated by a plane wave polarized along the x axis and propagating along the z axis. (d) Normalized scattering cross section spectra (σ_s) calculated by two calculation methods (TFSF and Mie).

In order to make a local coupling between the above PCC and a spherical dielectric NP which represents an electric dipolar mode at the same resonance wavelength of the PCC, we consider the NP having a radius of (**R=220 nm**) and a refractive index of (**n=4.85**). Numerical simulations are done using a home-made FDTD code using the TFSF (Total Field Scattered Field) technique allowing determination of the scattering cross section of the NP. Figure (1-c) shows the NP surrounded by the two boxes that determine the boundaries of each region [3]. Its is illuminated by a plane wave polarized along the x axis and propagating along the z axis. A good agreement between the spectra of the effective scattering cross section of the NP (σ_s) calculated by the two computational methods (Mie and TFSF-FDTD) [4] is shown in figure (1-d).

III - Coupling Results

Figure 2 summarizes the proposed coupling approach by determining the near-field, transmission, and reflection spectra as a function of NP position :

- Figures (a-c): The NP moves **vertically away** from the center of the PCC,
- Figures (d-f): The NP moves **along the axis of the cavity** at $D_z = 45\ nm$ above the PCC,
- Figures (g-i): The NP moves **along the axis perpendicular to the cavity** at $D_z = 45\ nm$ above the PCC.

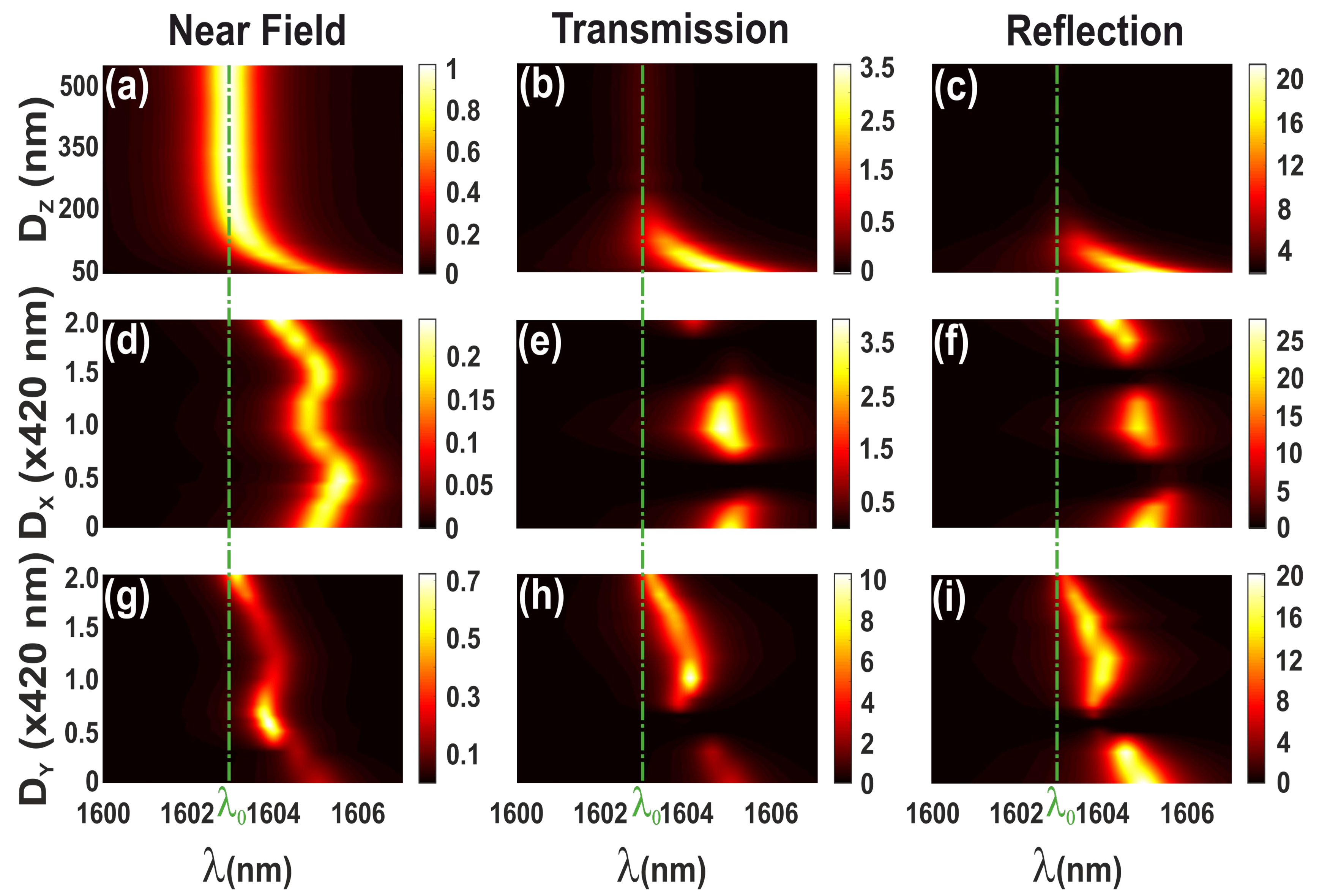

Fig. 2 - The evolution of the near-field, transmission, and reflection spectra of the coupled system (PCC+NP) as a function of NP position. The green dotted line determines the spectral position of the cavity mode indicated by λ_0.

IV – Angular Plane Waves Spectrum [5]

Referring to Figure 2, we decided to examine three specific configurations that correspond to three particular positions of the NP as specified below. Figure (3.a) shows the 3D transmission (z>0) and reflection (z<0) angular radiation spectra of the PCC alone (without coupling). Figures (3.b-d) also show these radiation angular spectra, but in the presence of the NP located at different position over the PCC [position (0, 0, 0) corresponds to the center of the PCC] :

- **A (0, 0, 45nm)** : Most of the extracted light is in the z direction.
- **B (0, 210nm, 45nm)** : The maximum of the extracted light is in the direction ($\varphi = 17.68°$; $\theta = 38.42°$).
- **C (210nm, 0, 45nm)** : The extracted light is quasi-isotropic in "Donate" form with $\theta \approx 42°$.

Note that the light propagated along the z direction is almost completely canceled when the NP is placed at **'B'** and **'C'**.

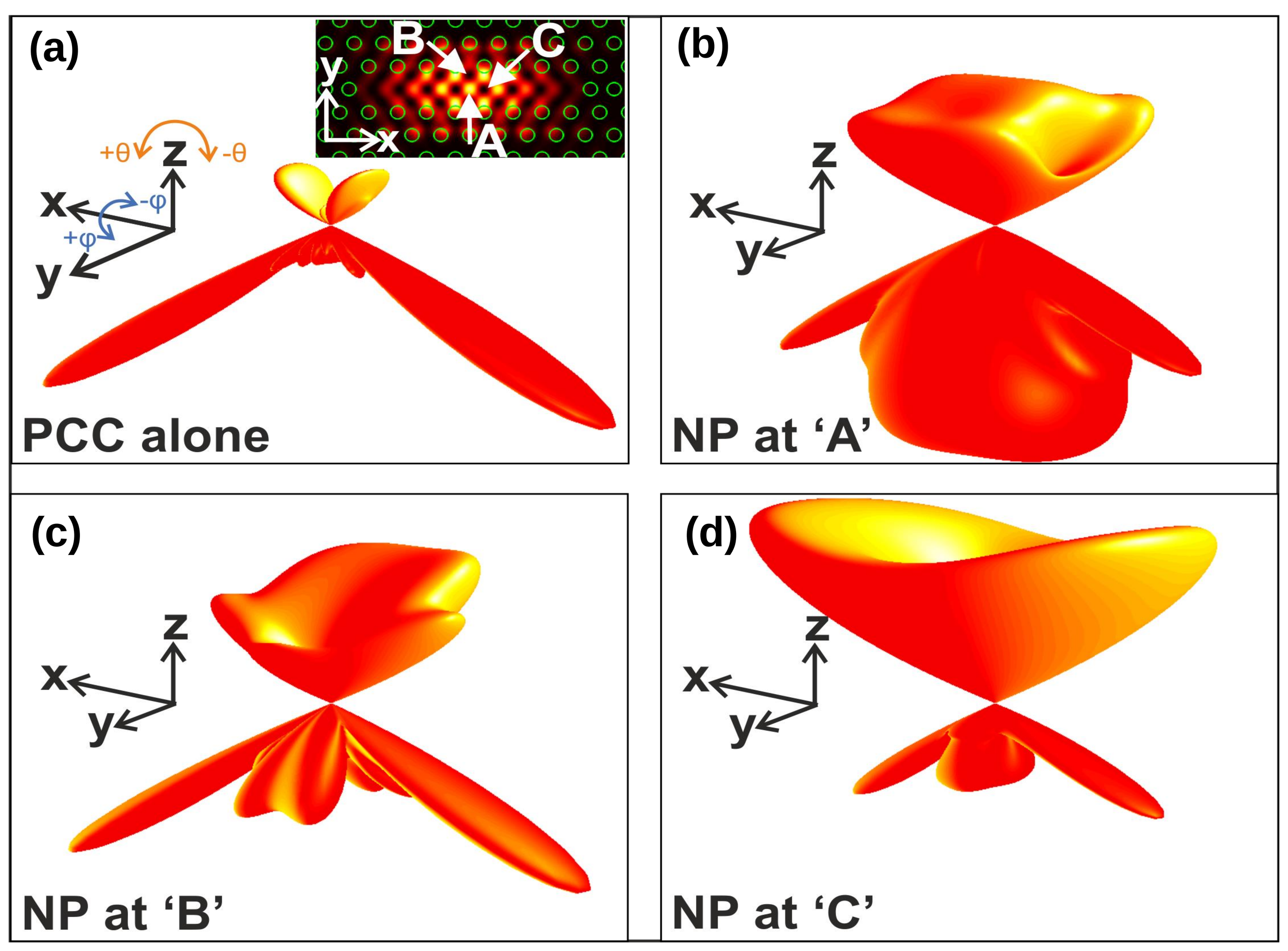

Fig. 3 - The 3D transmission and reflection angular spectrum of PCC alone is shown in (a). The inset shows the electric field intensity distribution at resonance, as well as the lateral position of the NP marked by the letters A, B and C. Figures (b-d) show the 3D transmission and reflection angular spectrum of the system (PCC + NP) when the NP is positioned at A, B and C respectively.

V – Conclusion

In summary, it is possible to control the light extraction confined inside an optical nano-cavity by coupling it with a resonant dielectric NP. The weight and the direction of the emitted light can be tuned as a function of its position relatively to the cavity. In view of experimental demonstration, the NP position can be controlled by gluing it on the apex of a SNOM tip. The numerical tools developed in this work can be easily adapted to the study of any coupling between two optical nano-systems.

References

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