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# Enhancement of Quantum Dot Fluorescence by a Metal Nanoparticle/Porous Silicon Microcavity Hybrid System

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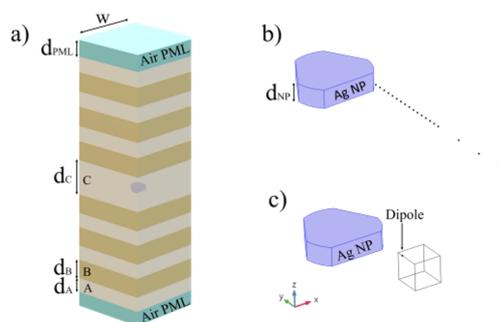
**Abstract.** Enhancement of quantum dot (QD) fluorescence in a hybrid system of a porous silicon microcavity (pSiMC) and silver nanoplatelets (AgNPs) has been estimated using numerical simulation. The system was simulated as a periodic unit cell made of a pSiMC with a resonant wavelength peak at 605 nm, an AgNP with a resonance at 604 nm and a quantum dot (QD) with an emission peak at 605 nm. For comparison, simulations were performed for an AgNP and a QD in a reference single-layered system with a high refractive index. The QD fluorescence was enhanced in the AgNP/pSiMC hybrid system, mainly due to the higher excitation rate.

## 1 Introduction

Combining microcavities and plasmon nanoparticles is a promising approach to obtaining hybrid systems with improved light emission due to strong light-matter coupling. However, the structure of the corresponding photonic devices should be further optimized [1-5].

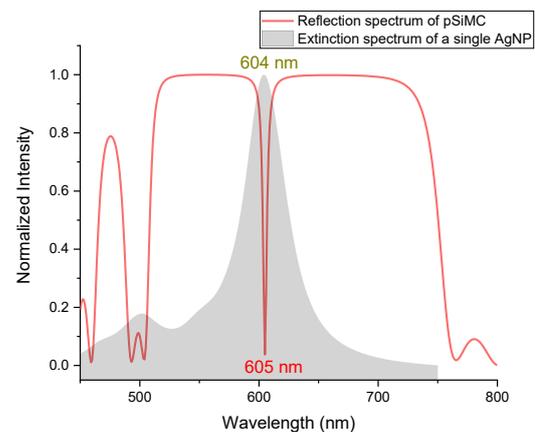
We have numerically simulated a hybrid system of a porous silicon microcavity (pSiMC) containing silver nanoplatelets (AgNPs) and quantum dots (QDs). The fluorescence enhancement was estimated by studying the electromagnetic field (EF) distribution and the QD emission represented as the power of a dipole inside the AgNP/pSiMC hybrid system.

## 2 Numerical simulation



**Fig. 1.** (a) Schematics of the simulated pSiMC unit cell containing an AgNP. The width  $w = 106.5$  nm; the refractive indices are 2.078 (layers A and C) and 1.302 (layers B); the thicknesses  $d_A$ ,  $d_B$ , and  $d_C$  are 72.788, 116.147, and  $2(72.788)$  nm, respectively;  $d_{PML} = 50$  nm. (b) EF evaluation points and the AgNP designed as the intersection of an equilateral triangle with a side of 37.905 nm and a circle ( $r = 14$  nm), both 7 nm thick.

(c) The AgNP with a QD and the monitoring box used to evaluate the dipole power.



**Fig. 2.** Normalized reflection spectrum of the pSiMC consisting of two distributed Bragg reflectors with refractive indices of 2.078 and 1.302. The spacer is  $\lambda/2n$  thick, with a refractive index of 2.078 and a resonance band gap at 605 nm (red line). Normalized AgNP extinction spectrum in water with a resonance at 604 nm (coloured area).

Simulations were performed using the COMSOL Multiphysics 5.5 (Radio Frequency Module). The AgNP extinction spectrum in water (Fig. 2) was calculated using a perfectly matched spherical layer (PML). The pSiMC was simulated as a Floquet-periodic unit cell (Fig. 1) with the (AB)6A2(BA)6 structure, a resonance at 605 nm, and layers with a quarter wave optical thickness with high and low refractive indices. The pSiMC reflection spectrum was calculated using a transfer matrix [6]. PMLs were added at the pSiMC top and bottom to truncate the

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unbounded computational region by absorbing the outgoing waves. We estimated first the EF under excitation and then the dipole emission power. An AgNP and a QD in a single-layer unit cell of the same size with a high refractive index served as a reference.

## 2.1 Simulation of the interaction of the hybrid system with an external light source

Excitation of the hybrid system with 400-nm laser light was simulated using as follows. A port at the pSiMC bottom was configured as the incoming excitation wave with the initial EF amplitude of 1 V/m, another port at the pSiMC top serving as the output. Both ports were domain-backed slit ports of periodic type. Measurements were made at different distances from the AgNP hot spot, in equal steps along the x, y, and z axes, in the presence or absence of the AgNP (Fig. 1).

## 2.2 Interaction of the hybrid system with QDs

A QD was modelled as a dipole with an electric current moment of  $3.33 \times 10^{-14} \text{ A} \cdot \text{m}$  and emission at 605 nm. For calculating the radiated power, the dipole, was enclosed in a box-shaped monitor (side, 10 nm). The dipole power was calculated at different distances from the AgNP hot spot at the same coordinates as the EF (Fig. 1).

## 3 Results

The quantum emitter fluorescence could be enhanced by increasing the (i) excitation rate and/or (ii) quantum yield. The excitation rate is calculated as the ratio of the EF strengths in the presence and absence of the AgNP under excitation. As seen in Fig. 3, the excitation rate near the hot spot (1-2 nm away) is higher in the pSiMC than in the reference system. The quantum yield depends on the radiative and nonradiative emitter relaxation rates. As seen in Fig. 4, the dipole power is about the same in the pSiMC and the reference system, being the highest 1 nm away from the AgNP and rapidly decaying with distance. Since the dipole power is the same in both cases, the AgNP/pSiMC hybrid system enhances the fluorescence mainly by strengthening EF close to the AgNP.

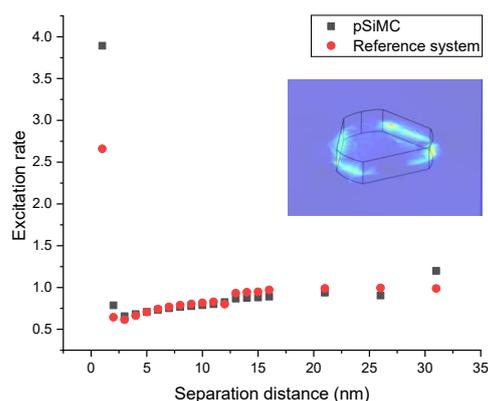


Fig. 3. Excitation rate calculated as the ratio of the EF in the

presence and absence of the AgNP under excitation at 400 nm in (a) the pSiMC and (b) the reference system.

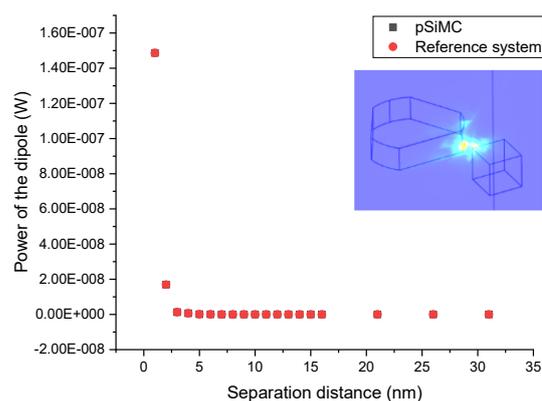


Fig. 4. Power radiated by the dipole in the presence of the AgNP in (a) the pSiMC and (b) the reference system.

## 4 Conclusion

Thus, simulations have shown that combining AgNPs and pSiMC in a hybrid system is a promising approach to QD fluorescence enhancement. Comparative estimations have yielded the optimal conditions for further experiments and laid the basis for future biosensing, photonic, and optoelectronic applications.

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## References

1. N. Abu-Thabit, E. Ratemi, *Front. Chem.* **8**, 454, (2020)
2. D. Dovzhenko, S. Ryabchuk, Y. Rakovich, I. Nabiev, *Nanoscale*, **10**, 3589–3605 (2018)
3. I. Kryukova, D. Dovzhenko, Y. Rakovich, I. Nabiev, *J. Phys.: Conf. Ser.* **1461**, 012076 (2020)
4. D. Dovzhenko, I. Martynov, P. Samokhvalov, E. Osipov, M. Lednev, A. Chistyakov, A. Karaulov, I. Nabiev, *Optics Express*, **28**, 22705–22717 (2020)
5. D. Dovzhenko, V. Krivenkov, I. Kriukova, P. Samokhvalov, A. Karaulov, I. Nabiev, *Optics Lett.* **45**, 5364–5367 (2020)
6. P. Pirasteh, Y. G. Boucher, J. Charrier, Y. Dumeige, *physica status solidi c*, **4**, 1971–1975 (2007)