Strong light-matter coupling in dielectric metasurfaces

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Abstract. We demonstrate the strong coupling between excitons in organic molecules and all-dielectric metasurfaces formed by arrays of silicon nanoparticles supporting Mie surface lattice resonances (MSLRs). Compared to Mie resonances in individual nanoparticles, MSLRs have extended mode volumes and much larger quality factors, which enables to achieve collective strong coupling with very large coupling strengths and Rabi energies. Moreover, due to the electric and magnetic character of the MSLR given by the Mie resonance, we show that the hybridization of the exciton with the MSLR results in exciton-polaritons that inherit this character as well. Our results demonstrate the potential of all-dielectric metasurfaces as novel platform to investigate and manipulate exciton-polaritons in low-loss polaritonic devices.

1 Introduction

The use of dielectric metasurfaces supporting Mie resonances as optical cavities to control light-matter interactions has triggered many interesting works in the last years. Due to the low absorption losses and the presence of resonances with both electric and magnetic character, dielectric metasurfaces have an exciting prospect for the development of novel applications. However, such work has been limited to the control of emission, a weak light-matter coupling phenomenon. Achieving the strong coupling regime with Mie resonances has remained challenging due to their moderate field enhancements and large radiative losses.[1, 2] Strong coupling results in the hybridization of light and matter into quasiparticles known as exciton-polaritons, with remarkable properties such as enhanced transport, long-range energy transfer, condensation, and non-linear response.

Here, we demonstrate experimentally the strong coupling between excitons in organic molecules and all-dielectric metasurfaces formed by arrays of polycrystalline silicon nanoparticles supporting Mie surface lattice resonances (MSLRs) with electric and magnetic character.[3] We first discuss the bare MSLRs in the array without molecules and explain the origin of their electric and magnetic character. Next, we deposit an organic dye on the array and show the formation of polaritonic states. Using a coupled oscillator model, we fit these states and extract the values of the Rabi energy. Finally, using simulations we discuss the character of the exciton-polaritons formed in this system.

2 Mie surface lattice resonances (MSLRs)

MSLRs emerge from the enhanced radiative coupling between the Mie resonances of nanoparticles through in-plane diffracted orders known as Rayleigh anomalies (RAs). Because of the low-loss characteristic of diffracted orders, MSLRs have large quality factors. Furthermore, due to the collective nature of the resonance, MSLRs have extended mode volumes that allow interaction with many emitters.

Our array has a periodicity $a=400$ nm and the particles have a diameter $d=120$ nm with height $h=90$ nm. To characterize the optical response of the MSLRs we measure the extinction as function of the incident in-plane moment $k$ ($k = k_x + k_z$) of the metasurface with a deposited layer of poly(methyl methacrylate) (PMMA) with a thickness of $t=290\pm10$ nm (see Figure 1a and 1b). The extinction is defined as $1-T_0$, where $T_0$ is the zero-order transmission. The measurements for TE (Figure 1a) and TM (Figure 1b) polarizations reveal several dispersive modes with Fano lineshapes, which correspond to the bare MSLRs arising from the RAs (indicated by the grey lines).

MSLRs can have an electric or magnetic character that is given by the presence of both electric and magnetic dipole resonances in the individual silicon nanoparticles. The character of the MSLR can be understood with the help of the bottom diagram that shows the preferential coupling between the excited dipoles for a given polarization of the incident light field.

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LP, MP and UP, respectively, which requires $E_\gamma$.

The electric or magnetic character of the MSLRs not only influences the interaction strength with the dye, but it also determines the character of the hybridization. Our simulations (Figures 2c and 2d) of the spatial distribution of the electric field show that due to the extended mode volume of the MSLRs, this electric and magnetic character is inherited as well in the exciton-polariton formed at the strong coupling regime.

These results demonstrate the potential of all-dielectric metasurfaces as a novel platform to investigate and manipulate exciton-polaritons in low-loss polaritonic devices.

References

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