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Weak and strong coupling of a quantum emitter with a meta-surface

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ABSTRACT

Meta-surfaces are the bidimensional analogs of metamaterials. They are made on resonant elements periodically disposed on a surface. They have the ability of controlling the polarization of light and to generalized refraction laws as well. They have also been used to enhance the generation of the second harmonic. It seems however that their near-field properties have not been investigated. In this work, the coupling of an emitter with a meta-surface made of a periodic set of resonant linear dipoles was studied. Bloch surface modes localized on the meta-surface exist due the resonance of the dipoles. The strong coupling regime with a emitter can be reached when the Bohr frequency of the emitter is in resonance with the Bloch modes of the meta-surface.

1. Introduction

Meta-surfaces are the 2D analogs of metamaterials [1]. They are made of basic, resonant, elements disposed on a surface. For electromagnetic waves whose wavelength is larger than the period, the basic elements behave collectively and provide new means of controlling the flow of light [3]. Meta-surfaces are generally seen as devices able to control the far-field behavior of light, such as the polarization state, the directivity, the light-by-light manipulation or the generation of second harmonic signal [2]. Some have made claims that they made possible “generalized laws of diffraction” as compared to Snell–Descartes laws [3]. However, because of their resonant properties, meta-surfaces also have interesting properties in the near-field. In the present work, we aim at initiating the study

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of the quantum electrodynamics of meta-surfaces [4]. In standard cavity quantum electrodynamics, one studies the coupling between an emitter, such as an atom, or quantum dot or a superconducting qubit [5], and the electromagnetic modes. Depending on the ratio between the light-matter coupling and that to the irreversible mechanisms, two regimes can occur: the weak coupling and the strong coupling. In the weak coupling regime the losses dominate and the spontaneous decay rate of the emitter is modified by the structured electromagnetic field. This is essentially the Purcell effect. In the strong coupling regime, the coupling dominates the losses: the quantum emitter and the meta-surface form a quantum system whose behavior cannot be decoupled between two separated objects. Rather, the emitter and the meta-surface can exchange photons periodically in time, which leads to hybrid excited states. From an experimental point of view, this regime leads to the onset of a double peak in the emitted spectrum, due to the anti-crossing of the dispersion curves of the light and matter modes. This situation has been observed in cavity with hybrid states between photons and excitons [6] as well as between photons and plasmons [7]. It was recently predicted theoretically that the strong coupling could be reached between a quantum emitter and Anderson localized modes [8]. In the present work, the coupling of a quantum emitter with the photonic surface modes supported by a meta-surface is investigated. The meta-surface is made of a periodic set of parallel nano wires. From a theoretical point of view, the meta-surface can be described by an effective impedance model, which allows to derive the density of electromagnetic modes due to the meta-surface. Further, it allows to obtain the dressed susceptibility of the quantum emitter and to exhibit the strong coupling regime. An *ab initio* numerical simulation of the meta-surface (containing a finite number of nano wires) is used in order to simulate the various regimes (see Fig. 1).

2. Impedance operator description of the meta-surface

The nano wires are disposed periodically with a period d. They show a resonant behavior at frequency ω_0: they are described by a dipolar susceptibility that has a non-zero component $S_0(\omega)$ [9] along the axis of the wires only. Therefore, the only relevant polarization is $E_{||}$, that is, with the electric field parallel to the axis of the nano wires (Possible experimental realizations are discussed in Section 4). When the collection of nano wires is illuminated by a plane wave $e^{i(kx-Ky)}$, it gives rise to a scattered field that can be written:

$$U^s(\mathbf{r}) = \sum_m s_0^0(\omega, k) e^{ikmd} \varphi_0(\mathbf{r} - mde_x), \tag{1}$$

where $\varphi_0(\mathbf{r}) = H_0^{(1)}(k_0|\mathbf{r}|)$, and $H_0^{(1)}$ is the 0th Hankel function of order 1. From multiple scattering theory [10,11], it can be shown that:

$$s_0^0(\omega, k) = [1 - S_0(\omega)\Sigma_0(\omega, k)]^{-1} S_0(\omega), \tag{2}$$

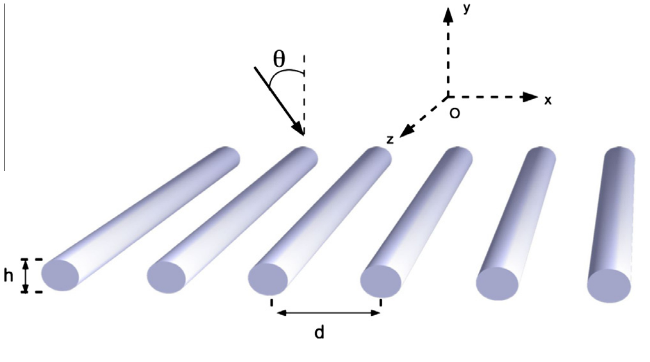

Fig. 1. Sketch of the structure under study.