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Exciton-plasmon coupling in two-dimensional plexitonic nano grating

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ABSTRACT

The proximity of metal and semiconductor nanostructures leads to the emergence of new optical features for many tunable applications, which affects the electromagnetic modes in metallic nanostructure and electronic states in semiconductor nanostructure in nanometer scales. Thus, it will create some changes in the transition matrix elements and the absorption and emission properties. Therefore, absorption and emission properties can be designed and controlled by exciton-plasmon interaction. In the present study, Rhodamine-B and 6G were used as organic dyes in Polyvinylpyrrolidone as host medium and two-dimensional crystal as plasmonic ones. To this aim, Nano imprint lithography was used to produce two dimensional crystals and its deposit gold was utilized to harvest plasmonic mold in the proximity of excitonic media. Then, the dispersion relation was measured and the polar diagram was plotted for different coupling regime. Based on the results, this system has a poor capability for overcoming the difficulties of obtaining strong coupling although different figures of merit were observed for increasing coupling strength, which is very useful for designing and constructing new generation of plexitonic structures.

1. Introduction

The spontaneous emission and other optical properties can be influenced due to the adjacency of an emitter near a metallic surface [1,2]. Purcell [3] and Kleppner [4] indicated that the radiative properties of an emitter in a cavity are different from those in free space. Thus, the Purcell effect has been experimentally shown in various conditions since that time. Chance et al. [5] reported that spontaneous emission can be strongly influenced by the proximity of metal structures which act as plasmonic optical cavities [6–8]. However, Worthing et al. investigated the modifications of the spontaneous emission rate of erbium ions as light emitters due to silver surface plasmon [9]. However, this exciton-plasmon interaction occurred in weak coupling regime. In addition, Bellessa et al. experimentally demonstrated that a strong coupling regime could be achieved with surface plasmons and organic semiconductors, which reported them for J-aggregates of Cyanine dyes, which were deposited on a silver film [10].

In general, weak coupling regime can be considered as a weak perturbation on the system [11,12] while strong coupling regime usually occurs when the coupling is large, compared to other energies. However, the energy spectrum of the total system was modified in other studies [13,14]. Based on the results, the strength of this coupling can be controlled by tuning the parameters related to the plasmonic and/or excitonic subsystem in order to achieve tunable optical properties. Thus, such systems are hopeful and has attracted a lot of attention for designing and making integrated circuits and other nanophotonics devices. Further, the anticrossing behavior in the dispersion diagram as the Rabi splitting is regarded as the most obvious sign of the strong coupling [15–17]. In this case, the splitting between the two polariton modes of the system should be greater than both linewidths of the subsystem modes which can be obtained by using organic semiconductors (Frenkel excitons) and J-aggregates. The above-mentioned experimental observations of strong exciton-plasmon coupling was reported in different systems such as dye J-aggregates [18], organic dyes [19], quantum dot, quantum well [20–23], excitonic subsystem and metallic film [10], one or two dimensional metallic grating [24], nanorods [25] and other nanoparticles as plasmonic subsystem.

After evaluating the coupling of cavity modes and surface plasmon resonances, Karademir et al. focused on the plasmonic band gap engineering of plasmon-exciton coupling [26]. Furthermore, they studied the resonant coupling between the molecular resonance of a J-aggregate dye and the plasmonic resonance of a textured metal film by using plasmonic bandgap. Based on the results,one-dimensional grating does not show a band gap except for the grating direction (Γ direction). In addition, the coupling takes place when the molecular resonance energy level is outside the bandgap, along Γ direction while the coupling is disappeared inside. Thus, different applications enter the sensing application as the propagation of surface modes is forbidden in plasmonic band gap and propagation is allowed with low group velocities and strong field localization at the band edge [27]. For example,

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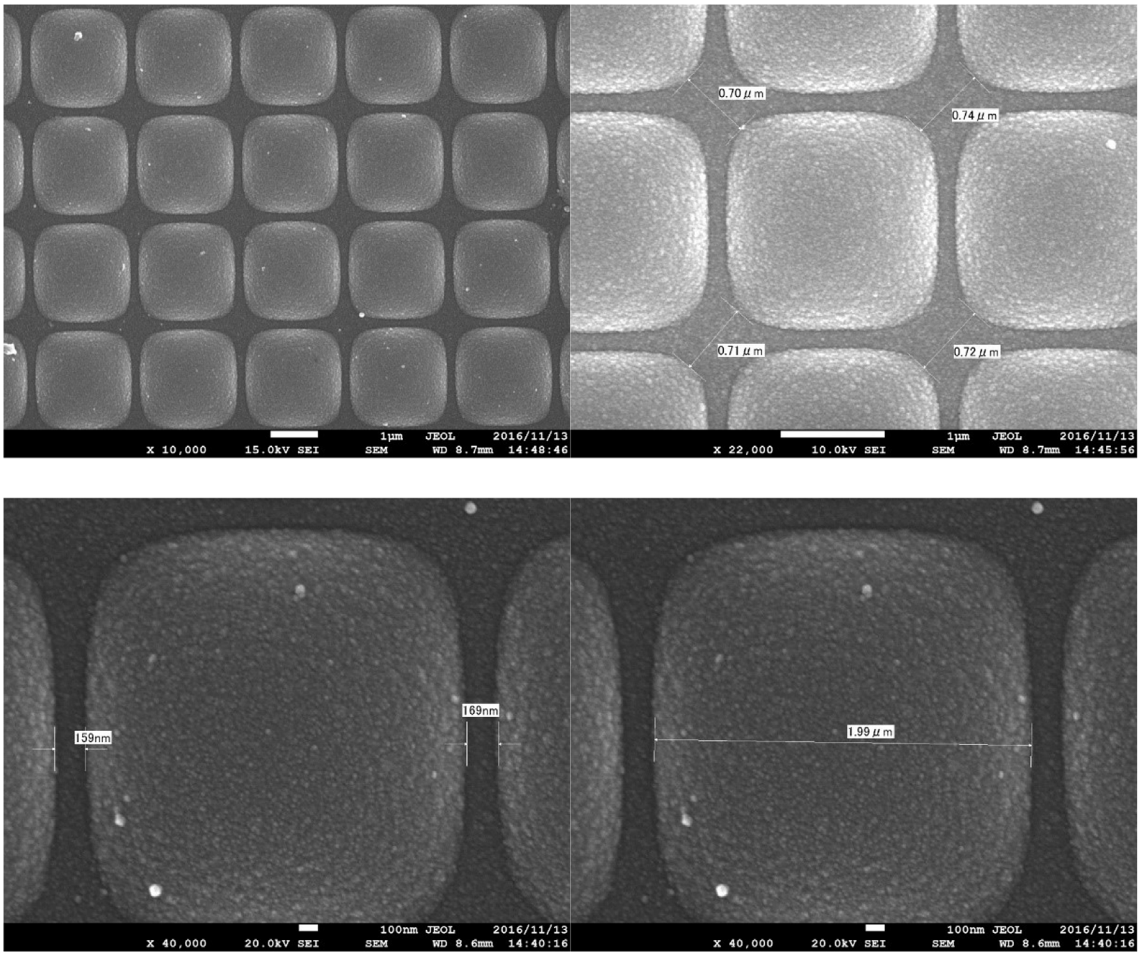

Fig. 1. FE-SEM image of mold in different magnifications.

Fig. 2. Schematic diagram of dye medium preparation.

Grande et al. [28] examined a novel biosensor based on the shift of the leaky surface plasmon mode at the edge of the plasmonic band gap raised from the analyte deposition on the metallic grating.

On the other hand, many lithographic routs were available for reaching the large area nanometric plasmonic structure [29–31] such as Nanoimprint lithography (NIL), as a cost-effective, reliable, and conventional lithographic technique possessing the advantages of nanometer-scale features with high throughput for mass fabrication [31]. In this method, a thin stamp, usually as a composite of hard polydimethylsiloxane (PDMS), is pressed into the curable polymeric material and a thin layer of metal is deposited after curing and removing the stamp. It is worth noting that the PDMS stamp is usually