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Enhancement of Light Matter Interactions in Sensing and Quantum Optics

[1]Shivam Krishna, [2]Nishant Kumar* and [3]Nabin Kumar

Author's Affiliations:
[1]Research Scholar, University Department of Physics, B.N. Mandal University, Madhepura, North Campus, Singheshwar, 852128, Bihar, India
[2]Research Scholar, University Department of Physics, J. P. University, Chapra. 841302, Bihar, India
[3]University Department of Physics, B.N. Mandal University, Madhepura, North Campus, Singheshwar, 852128, Bihar, India
[1]shivampluskrishna@gmail.com,[2]nishant12sep@gmail.comand
[3]naveen.dr9689@gmail.com

***Corresponding author:**
Nishant Kumar
Research Scholar, University Department of Physics, J. P. University, Chapra. 841302, Bihar, India
E-mail: nishant12sep@gmail.com

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ABSTRACT

We have studied the enhancement of light matter interactions leaded to new capabilities in sensing and quantum optics. We have demonstrated a quasi-normal approach for a hybrid transition metal dichalogenides metallic nano-particles system in the strong coupling regime. We have examined the effect of temperature, gap size and detuning to show the characteristics of the coupling between transition metal dichalcogenide and metallic nanoparticles. Large spectral splitting was found for different gap size. The Fano contributions from the individual quasi normal mode expansion of the photonic Green function. The complex mode volume expansion was also used and were found spatially dependent. It was also shown that the results of the Purcell factor as a function of gap size between the metallic nanoparticles and transition metal dicholcogenide. We have shown that the poles of the hybridized modes resulted a small splitting than the Purcell factor spectra. It was also provided the quasi normal mode technique was used to obtain the dipole transmission and was compared the spectral splitting with Purcell factor results. The spectral mode splitting were increased when mode coupling was increased for large detuning. The Rabi splitting was achieved using a microcavity coupled to a transition metal dichalogenide sheet with arrays of gold disks. Normal mode splitting with planar like cavity systems strong coupling phenomena of single dots was found in a number of semiconductor micro cavity systems. The cavity emitter coupling rate was more appropriate because it was describing a single quantum emitter and the light field within a dipole approximation, the single mode approximation is also excellent because cavity system is very low loss and yielded substantial quality factors. The interaction of these emitter cavity systems in the strong coupling regime was clear because the emitter cavity coupling rate was large than any dissipation rates. The obtained results were found in good agreement with previous results.

KEYWORDS

Light Matter Interaction, Sensing, Quantum Optics, Quasi Normal, Hybrid Transition, Dichalogenide, Coupling, Detuning, Purcell Factor, Dipole Transmission, Quantum Emitter.

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INTRODUCTION

Vahala [1] studied the nano optics to create photonic cavity that enhanced light mater interactions. Chikkaraddy et al. [2] presented strongly coupled single molecules and metallic nanoparticles at room temperature for the broad band enhancement of coupling. Xiao et al. [3] and Kormanyos et al. [4] studied the light matter interactions in the case of monolayers of transition metal dichalcogenides for obtaining direct gap semiconductors. Chernikov et al. [5] showed that thin materials leaded to the coulomb bound electron-hole pair excitons and reduced dimensionality. Steinhoff et al. [6] and Katsch et al. [7] studied the excitonic physics and presented that large excitonic binding energies made transition metal dichalcogenides was a platform for suitable result. Zhu et al. [8] presented that spectral mode splitting were increased due to coupling increasing and for larger detuning. Kern et al. [9], Zhen et al. [10] and Wen et al. [11] presented that different types of metallic nano particles have been utilized to verify the strong coupling between metallic nano particles and transition metal dichalcogenides with single metallic nanoparticles nanorods. Bipyramid [12], disks [13], spheroids [14], dimers [15] and arrays of metallic nanoparticles [16-18]. Schneider et al. [19] classically described the splitting of normal mode in the case of cavity and metallic nanoparticles array and Rabi splitting was observed. Reithmaier et al. [20], Yoshie et al. [21] and Peter et al. [22] demonstrated that normal mode splitting with planar cavity systems produced strong coupling of single quantum dots in the case semiconductor micro cavity systems. Several investigators [23-27] presented that quasi normal modes methods were found more accurate for the study of hybrid material systems and successfully modeled a wide range of resonator in nano-optics and plasmonics.

METHOD

Electromagnetic theory and model was used for the study of the required topic on light matter interactions. We have taken the regime of strong coupling in transition metal dichalcogenide metallic nanoparticles systems and hybrid modes. The quasi normal modes were considered for the study. The normal modes are the solutions to source free i.e, no external magnetization or polarization sources. The Maxwells's equations with closed or Periodic boundary conditions for quasi normal modes were the solutions to cavities in open boundary conditions. In cavity system with normal modes, the real eigen frequencies with spatially converging modes and for quasi normal modes the complex eigen frequencies with spatially diverging modes outside the resonator were found. We have developed a quasi-normal mode theory of hybrid systems, which produced full three dimensional demonstration of the mode and light matter interactions and the strong coupling in the semi classical way of quasi normal mode spectral splitting when two hybrid modes were suitably coupled together. The model of coupled harmonic oscillators used to study strong coupling and normal mode splitting in transition metal dichalcogenide metallic nanoparticles systems. The strong coupling regime were characterized the coupled mode splitting of some spectral as the transition spectra which resented the classical oscillations of particles and fields in the time domain. It produced a quantized field theory in order to obtain quantum mechanical case of strong coupling to connect or quantum optics. From first approximation the eigen frequencies of the simplified hybrid systems was found by assuming a harmonic time dependence. In the case of resonance the complex eigen frequencies were found. The coupling constants were determined by observing splitting by using JC type cavity emitter coupling rate through single two level atom or point dipole emitter. The coupling constant were obtained using formula

$$g_{eff} = d\sqrt{\frac{4\pi\hbar N_C}{\in\in_0\ \lambda V_C}}$$

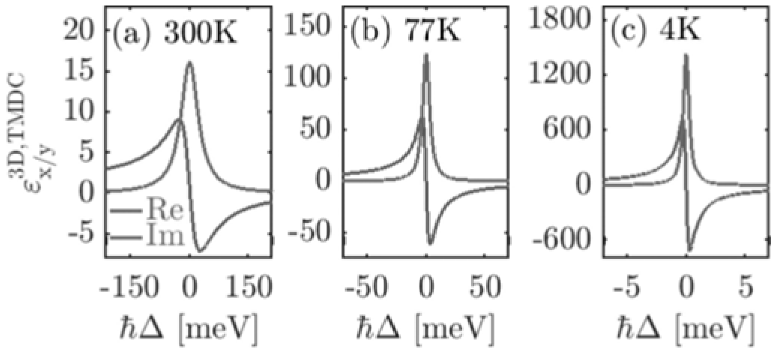
Where d is the excitation dipole moment, N is the number of excitions, C is the speed of light in vacuum, $\in_0$ is the vacuum permittivity λ is the wavelength, V_C is spatially averaged effective mode volume and it is changes as a function of position of *g*. Theory presented the properties of normal modes. Which were not correct modes of open resonators. The use of quasi nano metals allowed the correct position dependent mode volume and coupling constant as functions of the space which was directly involved the excitonic wave function. In transition metal dichalcogenide coupling the hybrid quasi normal modes characterized the classical electromagnetic coupling. These hybrid quasi normal modes are valid modes in the weak or strong coupling regime. We have also applied the Drude model for the study using the relation

$$\in_{Drude}\left(\omega\right)=1-\frac{\omega_p^2}{\omega\left(\omega+iY_p\right)}$$

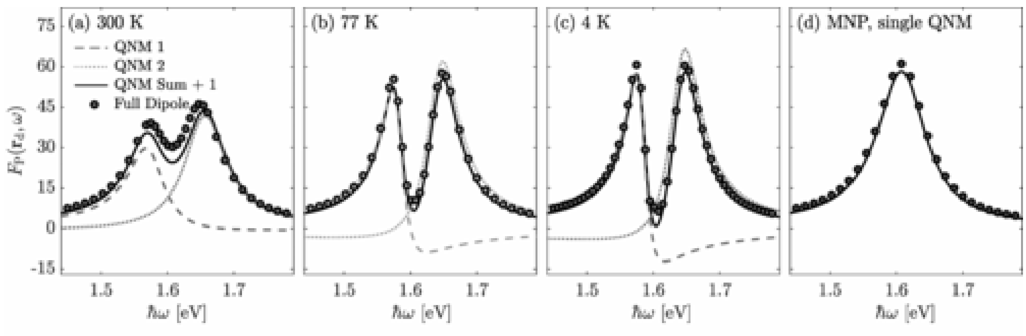
Where ω_p and Y_p are the plasma and collision frequencies. The smallest gap sized was used below 0.5 nm are experimentally feasible and stay within a regime where electronic tunneling effects were negligible. The dipole transmission needed the full two space point Green function and accounted for spatial quenching between the dipole and the depletion point. The Purcell factor is a measure of the projected local density of states at the dipole location which was included within Green function with equal space points. We have made analytical solution to the full two space point Green function through an analytical expansion of the hybrid quasi normal modes which contained the quasi normal mode phase and were applied to a wide range of nano photonics. The obtained results were compared with previous results.

RESULTS AND DISCUSSION

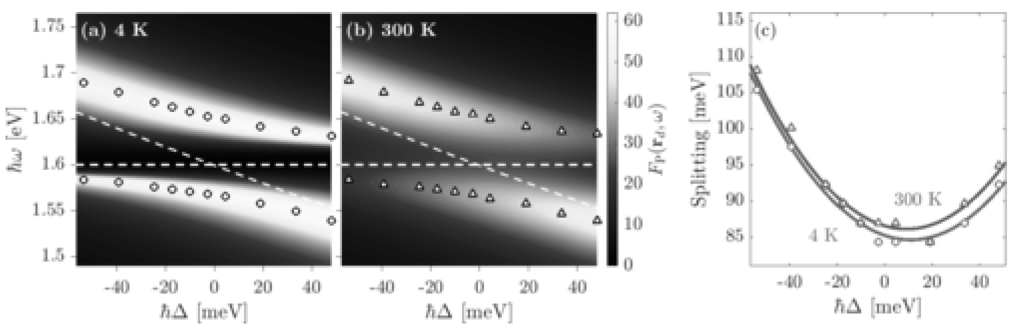
The study of the enhancement of light matter interactions was made. The quasi normal mode approach with hybrid transition metal dichalcogenide metallic nanoparticles system in the strong coupling regime was used. The approach of three dimensional and splitting behavior form hybrid modes were considered with hybrid cavity structure. We have studied the effect of temperatures, size and detuning and characteristics of the coupling between the transition metal dichalcogenide and metallic nanoparticles. The permittivity of transition metal dichalcogenide as function of frequency is shown in Graph (1) at different temperatures. The permittivity is anistropic on circular basis with two dimensional susceptibility. Graph (2) shows the numerical full dipole Purcell factor as the individual hybrid quasi normal modes. This also shows the sum of two quasi normal modes for the hybrid transition metal dichalcogenide-metal nanoparticles system at various temperatures of interaction as well as single metal nanoparticles on hybrid. The calculations of full dipole simulations the computational method was used and obtained quasi normal mode frequencies. The dipole Purcell factor was explained by the two quasi normal mode Green function expansion. We have find the Purcell factor at all locations near the resonator. Using power of the quasi normal mode technique. Graph (3) (c) shows the value of Rabi splitting as function of detuning which was achieved by modifying the length of the metallic nanoparticles. Graph (3) also shows the anticrossing behavior of total Purcell factor calculated for the metallic nanoparticles, transition metal dichalcogenide system with a gap of 2 nm and was found in the presence of strong coupling. Graph (4) shows the effect of gap size between the transition metal dichalcogenide and metallic nano particle at different temperatures. It was found that the Rabi splitting increased as the transition metal dichalcogenide found closer to metallic nano particles because the strength of the electric field due to the plasmonic resonance increased near the metal surface. A classical spectral mode splitting was quantified by computing the full three dimensional hybrid quasi normal modes of the combined structure and allowed the model for light matter interactions. The hybrid quasi normal modes as a function of gap size and temperature and found spectral splitting. The found results were compared with previously obtained results of theoretical and experimental works and were found in good agreement.



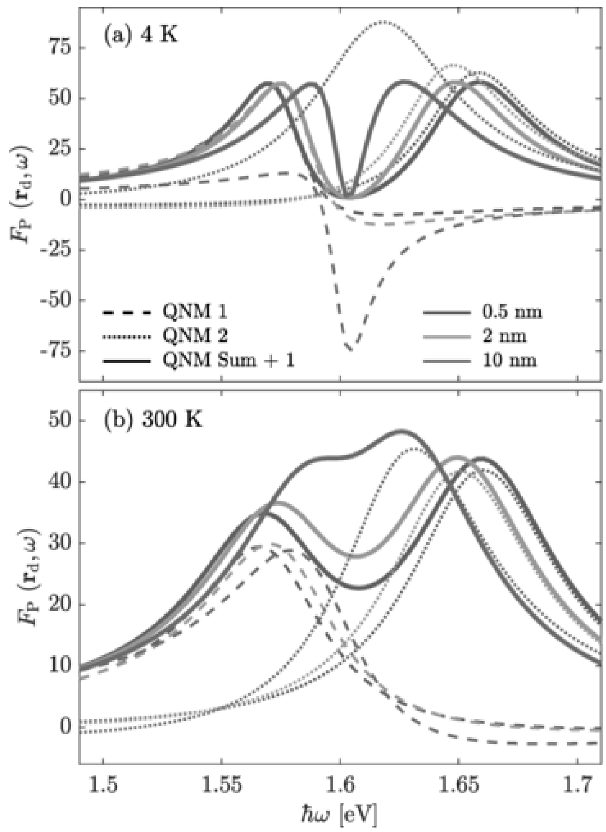
Graph 1: Plot of permittivity as function of frequency at different temperatures.



Graph 2: Plot of full dipole Purcell as function of hybrid quasi normal modes.



Graph 3: Plot of Rabi splitting as function of detuning.



Graph 4: Plot of effect of gap size at different temperatures.

CONCLUSION

We have studied the enhancement of light matter interactions in sensing and quantum optics. The quasi normal approach was adopted for the study of strong coupling behavior between a nano layer and single nano particle. The hybrid quasi normal modes as a function of gap size and temperature and found spectral splitting. The hybrid modes produced Fano resonances and quantified the complex poles of the hybrid modes a well as Purcell factor resonances from embedded dipole emitters. The Rabi splitting was found large at elevated temperatures for very small gap separation between metal nanoparticles and monolayer and found smaller at elevated temperatures for large separations. It was also found that the spectral mode splitting increased as the mode coupling increased and for larger detuning. The results found were in good agreement with previously obtained results.

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