Plasmon-Exciton Coupling in Nanoparticle on Mirror Structures

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Motivation

The continous miniaturization trends in electronics in accordance with the Moore's law, have confronted a roadblock now, because of scaling, approaching its fundamental physical limits. A viable alternative is to use light rather than electrons because one can send a lot more information, much faster and efficiently using photonic integrated circuits. So, there is a big push to bring photonics down to the single chip scale. This project gives a fundamental understanding in realizing ultrafast, ultrasmall and low power optical modulator using a coupled metal-emitter nanostructure.

Background

- **Plasmon:** collective oscillation of conduction electrons on a metal nanoparticle.
- Plasmon resonance frequency depends on the size, shape and the surrounding medium of the metal nanoparticle.
- **Exciton:** Electron-hole bound pair.
- **Quantom dots (QDs):** semiconducting nanocrystals with a core-shell structure whose radius is comparable to the exciton radius.
- **Nanoparticle on Mirror (NPoM) geometry:**
  - Strong electric field enhancement within the gap
  - Can be easily fabricated by colloidal synthesis at room temperature.

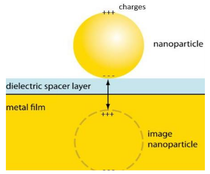


Image courtesy: David R Smith

- **Plasmon-exciton coupling :**
  - Coupling gold nanoparticle with quantum dots.
  - Plasmon gaps despite having very low quality factors, enables us to observe strong plasmon-excition coupling even at room temperatures due to their very small mode volumes.
  - Coupling parameter, $g = \frac{2\vec{\mu_{em}}.\vec{E_{loc}}}{\hbar}$

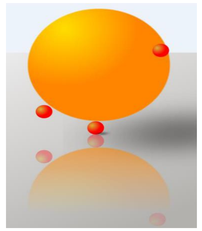
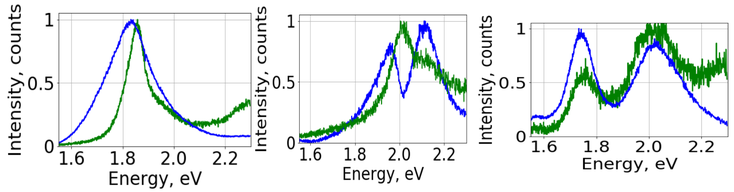


Photo from Dr Kyound-Duck Park

- **Different coupling regimes:**
  - **Weak Coupling :** Spontaneous emission
  - enhancement known as Purcell effect
  - **Intermediate coupling:** NPoM structure becomes transparent due to the destructive interference between plasmon and emitter dipoles.
  - **Strong coupling :** Rabi splitting due to the formation of dressed states

Objective

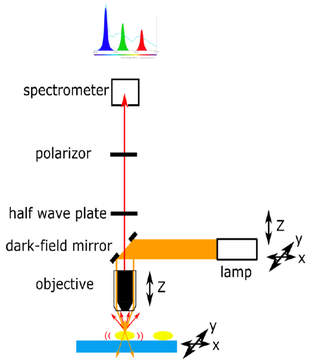
- To reproduce correlated scattering and PL spectra and demonstrate exciton induced transparency.



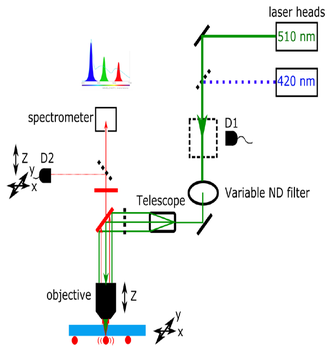
Weak coupling **Intermediate coupling** **Strong coupling**

Haixu leng, Brian Szychowski: Nature communications 9, 4012(2018)

Methods



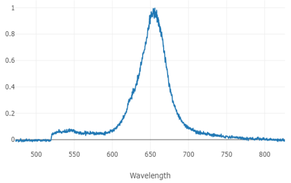
Single particle dark field scattering measurements



Single particle photoluminescence (PL) and time-resolved PL measurements

Image courtesy: Dr Haixu Leng

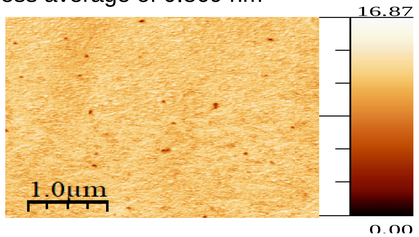
- Halogen lamp is used to get the scattering spectra of single particles.
- Normalised scattering spectra
- of gold nanosphere (AuNS)
- PL spectra is obatained using picoseond pulsed diode laser at 510nm
- Normalised PL spectrum of AuNS-QD particle on Ag film



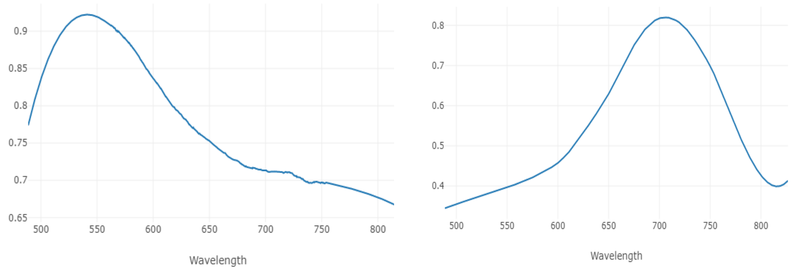
- Template stripping procedure to make ultasmooth gold and silver films
- AuNS-QD assemblies are drop casted on to the film to get the scattering and PL spectra
- Depending on the number of peaks obtained in the spectra the coupling regime is inferred
- The spectra obtained is fitted with coupled oscillator model to get the coupling strength,g.

Preliminary results

- Afm image of the template stripped gold film gives a roughness average of 0.869 nm



- Scattering spectra shows a red-shift in the plasmon resonance of gold nanospheres on Ag film



Conclusion

- Working towards achieving better coupling between AuNS-QD system to observe more nanoassemblies with g> damping rate
- Trying to couple bipyramids with QDs

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