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IGERT Research Plan

Research Motivation and Objectives

My research focuses on studying the quantum dynamics of composite nanostructures using a variety of optical spectroscopy techniques (e.g. micro-photoluminescence). In composite nanostructures, the complex interactions between the individual components can lead to materials with new and unique properties. The purpose of this research is to aid in the understanding of how the components of a nanostructure interact and help guide the design of new materials with particularly desirable properties.

For this project, one major goal is to understand the mechanisms and consequences of exciton-plasmon interactions in metal-semiconductor nanostructures. These nanostructures open the possibility to combine the optical functionality of semiconductor nanoparticles with that of metallic nanostructures.

Specific objectives of the research include: (i) investigation of optical properties of metal-semiconductor nanostructures by performing measurements on both ensembles and single structures; (ii) in particular, investigation of the optical properties of newly developed chemically synthesized bio-conjugated metal-semiconductor nanostructures; and (iii) finally use of numerical simulations to understand the optical properties and guide the design of composite nanostructures.

My adviser, Prof. Xiaoqin Li, has an extensive background in optical spectroscopy techniques. However, in order to meet the objectives outlined above, this project also requires collaboration among groups with expertise in a variety of other disciplines. For the success of this research project, close collaborations are necessary with groups that have chemistry and numerical simulation backgrounds.

Progress

Over the past two years, I have built a versatile optical setup capable of studying optical systems down to the single nanostructure level. This setup allows for imaging and gathering of spectroscopic information from single light emitters. It is also capable of measuring time correlated single photon counting, which can be used to investigate the photo-emission statistics of nanostructures.

In collaboration with Prof. Nicholas Kotov's chemical engineering group from the University of Michigan, I have been investigating the optical properties of CdSe/ZnS nanocrystals bio-conjugated to Au nanoparticles. The bioconjugated structures are particularly convenient for systematic investigations of particle-particle interactions with different geometrical arrangements. In addition, we have placed emphasis on studying the blinking behavior (the on/off switching of photoluminescence) of these structures. It is reasonable to speculate that one may be able to find certain structure configurations of bioconjugated semiconductor-metal composites that exhibit minimal or no luminescence blinking.

One benefit of this collaboration has been the experience I gained about synthesizing and handling the nanostructures. During a visit to Prof. Kotov's lab, I observed the synthesis process of the composite nanostructure and helped with the synthesis of the CdSe/ZnS nanoparticles. This experience was helpful in learning how to handle and prepare the sample for optical studies.

Due to the difficulties associated with sample synthesis, my current research focus has shifted to studying structures constructed with AFM manipulation. Single CdSe/ZnS dots are positioned near gold nanoparticles using the tip of an AFM. The sample is then taken to an optical setup to gather optical information. In this way, optical and structural information of the sample can be correlated.

In order to model and understand these constructed nanostructures, Dr. Stephen Gray from Argonne National Lab has provided me with a Finite-Difference Time-Domain (FDTD) program that runs on the Carbon cluster at Argonne. The FDTD program is capable of giving near field and far field information about the constructed structure. This information aids in the design in the structure and understanding its optical properties. Presently, I am using the program to look at the emission enhancement of a single CdSe/ZnS nanoparticle caused by the presence of gold nanoparticles.

Future Plans

For the future of this project, there will continue to be collaborations with Argonne National Lab. Besides providing the FDTD program, Dr. Gray has been helpful with using the FDTD program. I will continue to work with Dr. Gray in order to use and modify the FDTD program and to understand the results of the calculations.

Prof. Li and I have also been communicating with Dr. Matthew Pelton at Argonne National Lab. We are considering the possibility of using an AFM/confocal setup at Argonne that allows for gathering of structural and optical information from a sample concurrently. Presently, we are constructing our sample on the AFM and then moving it to an optical setup to collect data. However, this process is rather difficult due to the time involved and the problems associated with finding the same structure with the AFM and optical setup. The AFM/confocal setup at Argonne would be an invaluable resource, as it would eliminate these problems.

Within the scope of IGERT program at UT, I would possibly like to work with Prof. David Vanden Bout in the Chemistry department. Prof. Vanden Bout has invaluable expertise in near field scanning optical microscopy (NSOM). One possible way to collaborate with Prof. Vanden Bout is that near field data gathered from an NSOM could be used to compare with calculations from the FDTD programs.

Conclusion

The research purposed here is focused on the optical study of composite nanostructures. This research places strong emphasis collaboration. By using the expertise of groups with diverse backgrounds in synthesis, optics, and numerical simulation, this research hopes to answer fundamental questions that are critical to designing and optimizing the functionalities of composite materials consisting of nanoparticles in general.