Gold Nanowires: Their Synthesis and Surface Plasmon Resonances

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ABSTRACT

The objective of the project was to fabricate gold nano-rods and study the optical properties of gold nano-particles when coupled to Indium Arsenide quantum dots. The gold nano-rods were synthesized by a seed-mediated growth method using CTAB and BDAC as the surfactants, and the feasibility of changing the aspect ratio of the rods and their Plasmon resonance frequency was studied by varying the concentrations of these two surfactants. Finally, gold nano-rods with longitudinal Plasmon resonance of 940 nm were synthesized. Next, we studied the feasibility of coupling gold nano-wires to indium arsenide quantum dots for investigating their optical properties and studying the spontaneous emission enhancement of InAs QDs in the presence of the plasmon resonances of gold nano-wires. The sample containing nano-wires coupled to quantum dots was excited by red laser, and the emission was passed through a spectrometer and the spectrum was obtained.

I. INTRODUCTION

Nanometer-scale metal or semiconductor particles are under active investigation due to their many size-dependent properties that are distinct from those of the bulk material [1]. Metal nanoparticles have exhibited properties in catalysis, optics, magnetism, and sensors [2]. Optical properties of metal nanoparticles, especially their Plasmon resonances, turned out to be a valuable tool in the development of new optical devices; nanoparticles with resonant plasmonic modes made it possible to create novel artificial materials based on metallic “nano-atoms” and “nano-molecules” with unique optical properties unachievable in natural materials [4]. Extensive research has been devoted to developing synthetic methods and understanding the optoelectronic properties of metal nanoparticles and considerable progress has been made in this area of research, but still there are many unexplored subjects and questions that call for further research in this area [2]. This project was an effort to fabricate gold nano-rods using the most efficient seed-mediated growth method that has been developed so far, and also, to measure optical properties of gold nano-wires and InAs quantum dots.

II. METHODOLOGY AND RESULTS

Different methods of fabrication of gold nanoparticles with different shapes and absorption spectra have been studied in different research projects in the past; in this study, the method of fabricating gold nanoparticles introduced by Smith and Korgel [3] was used, and the method introduced by Nikoobakht and El-Sayed [2] was employed to adjust the aspect ratio (shape) and absorption peak of the particles by changing the concentrations of the surfactants. Gold nano-rods exhibit two Plasmon resonance peaks: a shorter wavelength peak at around 520 nm due to Plasmon oscillations in the shorter transverse direction, and the longer wavelength peak (in the 700-1300 nm range) due to longitudinal oscillations [3]. Two surfactants were used in our fabrication method: CTAB and BDAC. The transverse (shorter wavelength) peak in the spectrum of gold nanoparticles is almost fixed at ~520

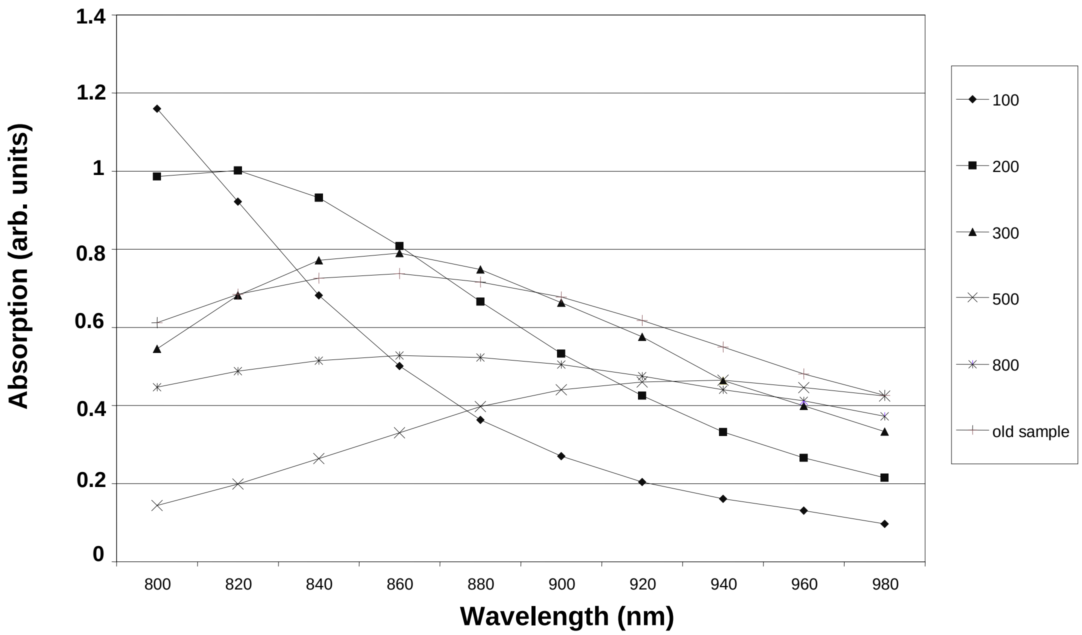

Figure 1. Absorption as a function of wavelength for wavelengths higher than 800 nm.

nm, but we can change the wavelength at which the longitudinal peak occurs by changing the concentrations of these two surfactants; obtaining the longitudinal absorption peak at a wavelength of about 950 nm was the goal of our synthesis of gold nanoparticles because, later, we wanted to couple the gold nano-rods to InAs quantum dots emitting at 950 nm.

In the first step, we used fixed concentrations of BDAC, but various concentrations of CTAB. Six samples of gold nano-rods were synthesized, with the amount of CTAB used varying from 10 mg to 200 mg. The absorption of the samples was measured by spectrometer as a function of wavelength, and the sample with 200 mg CTAB had its longitudinal peak occurring at the longest wavelength (860 nm); therefore, 200 mg was the optimal mass for CTAB. But we were looking for a wavelength of about 950 nm; thus, it was now time to see if we could obtain the desired results by changing the BDAC concentration. In the next step, a fixed amount of CTAB (200 mg, using the results of the previous step) was used, and instead, we used varying amounts of BDAC, from 100 mg to 800 mg. Again, the absorption of the samples was measured by spectrometer as a function of wavelength. Since we were looking for the longitudinal peak, which typically occurs at wavelengths higher than 800 nm, the absorption measured as a function of wavelength has been plotted on the graph shown in Figure I, only for wavelengths higher than 800 nm (this graph also includes the spectroscopy for the sample from the previous step that gave the optimal result).

If we take the longitudinal peak of the samples shown in the graph above, and plot them as a function of the mass of BDAC used, we obtain the plot shown in Figure 2. From this figure, we can conclude that the optimal mass for BDAC is 500 mg, which yields a longitudinal peak at 940 nm; this is very close to our desired wavelength of 950 nm.

We attempted to couple the gold nanorods that were synthesized as discussed above to InAs quantum dots for measurement of their optical properties. However, we had difficulty coupling the sample due to size limitations of the nanorods. Hence, we decided to study the feasibility of coupling gold nano-wires to InAs quantum dots so that we can investigate their optical properties; since the gold nano-wires were longer, coupling them to the QDs was more practicable. The results obtained from nanowires should be very close to the nanorods because they

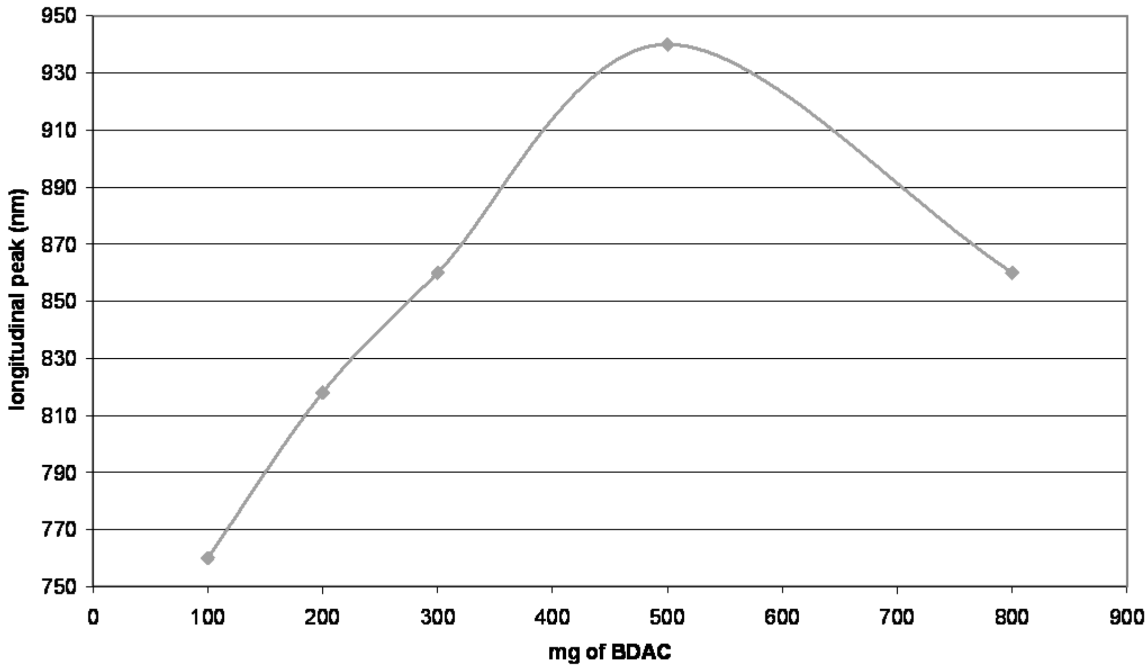

Figure 2. Longitudinal peak of the samples as a function of the mass of BDAC used (varying BDAC, constant 200 mg of CTAB).

exhibit similar Plasmon resonance characteristics. In order to take the measurements, an optical microscope was set up on an optical breadboard bench using lenses, mirrors, an objective, a wave plate, polarizing beam splitters, a CCD camera, an aperture, and an ND filter. A red laser beam was used to excite the sample and a white light source was used to view the sample. After setting up the microscope, we prepared our sample for measurement by spinning a coat of gold nano-wire solution onto the quantum dots. The sample was cooled down to about 6.5 K (using liquid He) in a cryostat for viewing. The sample was excited by red laser, and the QDs that were optically excited within the locally enhanced electromagnetic field of the surface plasmon resonances of gold nanowires, started emitting photons that were guided by the surface plasmons of the nanowires as a highly localized traveling wave. The light was finally scattered when coming out of the ends of the nanowires, and we obtained the spectrum of this light using optical spectroscopy, as shown below.

As shown in Figure 3, almost all of the quantum dots are emitting photons at wavelengths between 900 and 980 nanometers, with the maximum absorption occurring at about 910 nm. This is below our expected value of 950 nm, but it’s reasonable because the gold nanowires, due to their high aspect ratio, do not have a surface Plasmon resonance at 950 nm.

III. CONCLUSION

Gold nano-rods with Plasmon resonance at ~940nm were synthesized using a seed-mediated growth method with CTAB and BDAC as the surfactants; the desired Plasmon resonance wavelength was achieved by varying the aspect ratio of the rods. Then, the spectrum of the light coming out of the end of gold nanowires when coupled to InAs quantum dots was obtained. The spectrum revealed that every quantum dot emits at a different wavelength, which causes the inhomogeneous spread in wavelengths between 900 and 980 nanometers. This behavior was expected because the quantum dots were epitaxially grown, so there is a slight variation in the size and shape of each quantum dot, and hence, every quantum dot is different and emits at a different wavelength. Our desired wavelength of 950 nm falls in the region

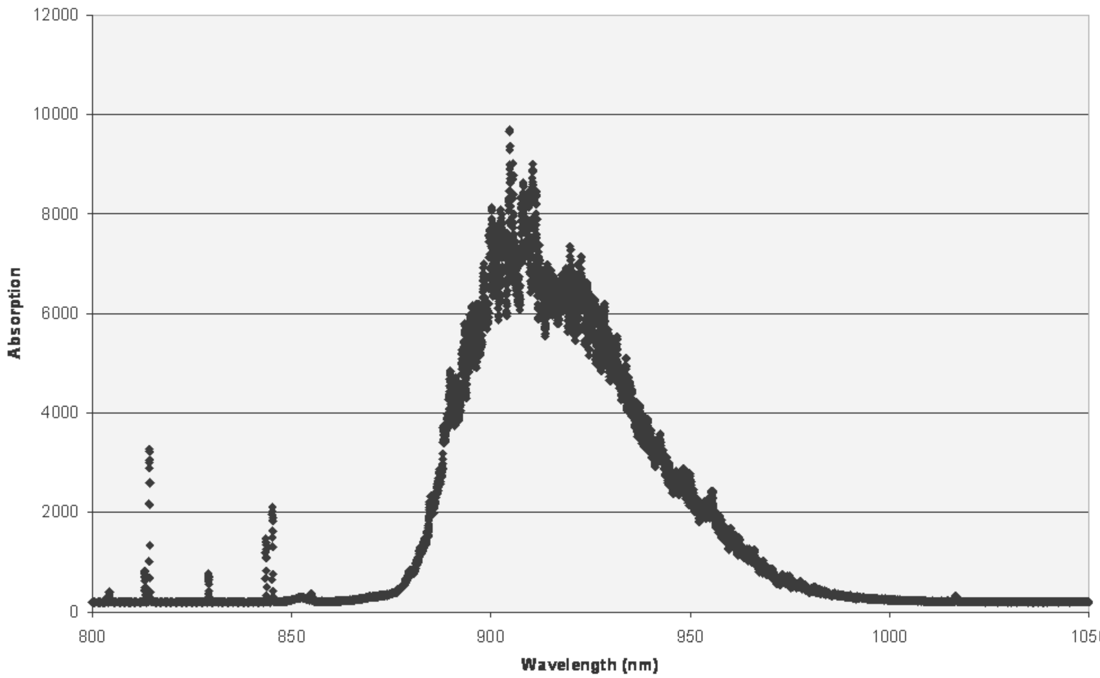

Figure 3. Spectrum of InAs Quantum Dots.

obtained in the spectrum; however, the maximum absorption occurs at 910 nm, which shows that the Plasmon resonance of the nanowires has not occurred at 950 nm, but at some lower wavelength.

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