Optimizing the Deposition of Colloidal Quantum Dots onto GaAs Substrates

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1 Abstract

We examine the photoluminescence signals of quantum dots to determine conditions for minimum laser line scattering to signal ratio. The amount and concentration of quantum dots in a hexane solution are varied in drop-casting deposition onto gallium arsenide substrates. The amount of solution makes no difference, while an undiluted solution results in the best scattering to signal ratio. The cancellation percentage of linear and circular polarizers, used in the photoluminescence measurements, are calculated. The linear polarizers have a cancellation of 95 % while the circular polarizers have a cancellation of only 45 %. The increase of laser line scattering from a bare substrate to a substrate with quantum dots deposited onto it is measured. With linear polarizers cross polarized, the increase in scattering is 10 times, with the linear polarizers co-polarized, the increase is 30 times.

2 Introduction

Quantum dots lie in the range of 10-100 $\AA$ diameter in size. This size range is unique as it lies between the microscopic range of atoms and the macroscopic range of bulk materials. Many material properties, such as electronic and optical properties, vary based on the crystallite size of the material (1). For quantum dots, one of their more remarkable aspects is how much their optical properties change when one alters the size of the quantum dots (2).

The optical properties of quantum dots are of particular interest as it is their optical properties that are most relevant to many applications of

quantum dots. These applications include quantum dot lasers and light-emitting diodes (2).

A very useful technique in analyzing quantum dots is fluorescence line narrowing spectroscopy. Fluorescence line narrowing spectroscopy involves exciting quantum dots of a very specific size with a narrowband laser. This method allows one to study a single nanocrystal size without the usual pains of single nanocrystal spectroscopy (3). In fluorescence line narrowing spectroscopy, we look specifically at the photoluminescence (PL) peak.

To measure a photoluminescence peak, we must first deposit the quantum dots, which are kept in a hexane solution, onto a solid substrate and then shine a laser onto that substrate. The incoming laser line will cause the sample to photoluminesce and will also be scattered. The amount of scattering depends on the size, concentration, and uniformity of the deposition. We are interested in the PL peak, not the intensity of the laser line. Hence, we want to reduce the amount of scattering in the sample to reduce the measured laser line.

To this end, we deposit samples with different amount of quantum dot solution, and also with different concentrations. We use linear and circular polarizers in the data acquisition, and so we also measure the percent cancellation able to be acheived from these linear and circular polarizers. Finally, we measure the increase of laser line scattering due to quantum dots being distributed on the gallium arsenide (GaAs) substrate as opposed to the amount of laser line scattering resulting just from the substrate. This is to determine if the drop-cast method results in samples with acceptably small amounts of additional laser line scattering.

In this study, we determine that the amount of solution does not matter, no dilution of the solution is best, and that a simple drop-cast method for deposition of the quantum dot solutions leads to an irregular film, and hence a large increase in scattering from the laser line. We also determine that the linear polarizers used have a 95 % cancellation, and the circular polarizers have only a 45 % cancellation.

3 Experimental Methods

The PL peaks were examined using a 532 nm 10 mW laser diode as excitation. A beam splitter reduced the power of the laser by a factor of 10, and an attenuator reduced the beam power again by a factor of 100. The set-up

for the experiment can be seen in Figure 1. The optical fiber used in the experiment is 600 $/mu$ m in diameter. The optical fiber leads to a $\frac{1}{2}$ - meter spectrometer with a 300 groove/mm grating.

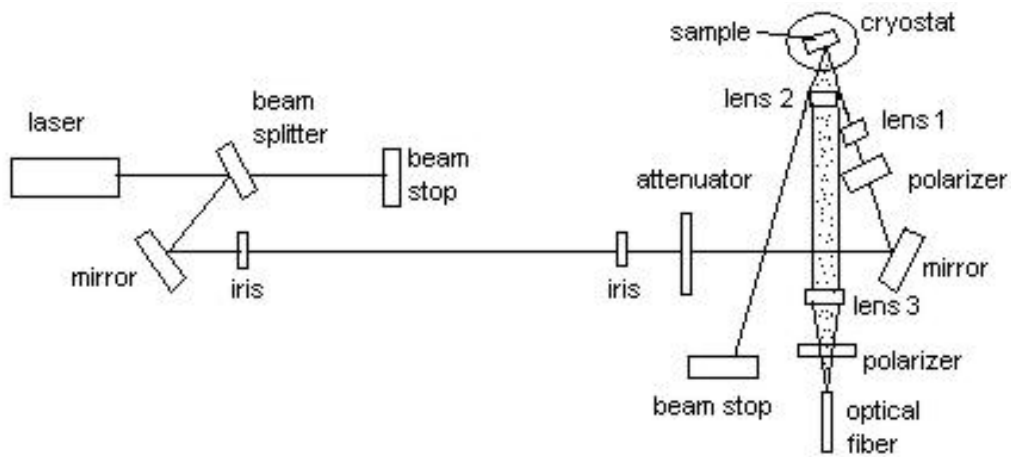

Figure 1: Experimental set up.

For all samples, the solution was deposited onto GaAs substrates using the drop-cast method. Using a pre-made solution of red quantum dots, PL peak 624 nm, different amounts of the solution were deposited onto GaAs substrates. 50 μ L were deposited onto one substrate, 100 μ L onto a second substrate, and 200 μ L onto a third substrate.

Using a pre-made solution of green quantum dots, PL peak 535 nm, different concentrations of the solution were deposited onto GaAs substrates. The solution was dropped undiluted onto one substrate, mixed one part hexane to one part solution and dropped onto a second substrate, mixed two parts hexane to one part solution and dropped onto a third substrate, and mixed four parts hexane to one part solution and dropped onto a fourth substrate.

Data was taken of the PL peaks and laser scattering for both different amounts and concentrations using linear and circular polarizers. To minimize the PL signal to laser scattering ratio the polarizers were crossed and the cryostat, which housed the samples, was rotated at about a 35 degree angle. The incoming laser line, incident upon the sample, was first maximized by rotating the first polarizer. The signal to scattering ratio was reduced by rotating the collecting, second, polarizer.

Data was taken from as close to the center of the substrate, while maintaing a good PL signal, as possible. If the laser was too close to the edge of the sample "edge effects", from the laser scattering on the sharp corner of the sample, caused the laser line scattering to increase. The data was acquired using a CCD camera.

For all samples with linear polarizers crossed, the exposure time of the image was 0.5 sec. For images with linear polarizers co-polarized, the exposure time was 0.005 seconds. Due to the increase in signal with co-polarizers, an exposure time of longer than 0.005 seconds saturated the CCD camera.

4 Results

Figure 2 shows the PL signal and laser line scattering for the samples with different amounts of solution deposited onto the substrate. Crossed linear polarizers were used in acquiring the data in Figure 3. The 100 μ L sample is not shown, as the deposition was bad and resulted in no PL signal. As can be seen from Figure 2, the ratio of PL signal to laser scattering is almost 1:1 in both cases. The amount of solution deposited onto the substrates does not lead to much of a difference in this ratio, and so any amount of solution can be deposited onto the substrate.

Figure 3 shows the PL signal and laser line scattering for the samples with different concentrations of solution. Crossed linear polarizers were used in acquiring the data in Figure 3. The two parts hexane to one part solution sample is not shown as the deposition was bad and led to a weak PL signal. Looking at Figure 3, we see that the concentration does affect the PL signal to laser line scattering ratio, with the undiluted sample having the best signal to scattering ratio.

Figure 4 shows the minimum laser line signal overlaid on the maximum laser line signal from the GaAs substrate. The maximum versus minimum laser line was obtained by maximizing the laser line going through the first polarizer and then rotating the collecting polarizer. The first polarizer was not changed between the measurements of the maximum and the minimum laser lines. The data for both the linear and circular polarizers are shown. Comparing the maximum and minimum peaks, the linear polarizers show a cancellation of 95 %, while the circular polarizers show a cancellation of only 45 %.

Figure 5 shows the laser line signal from the GaAs substrate overlaid

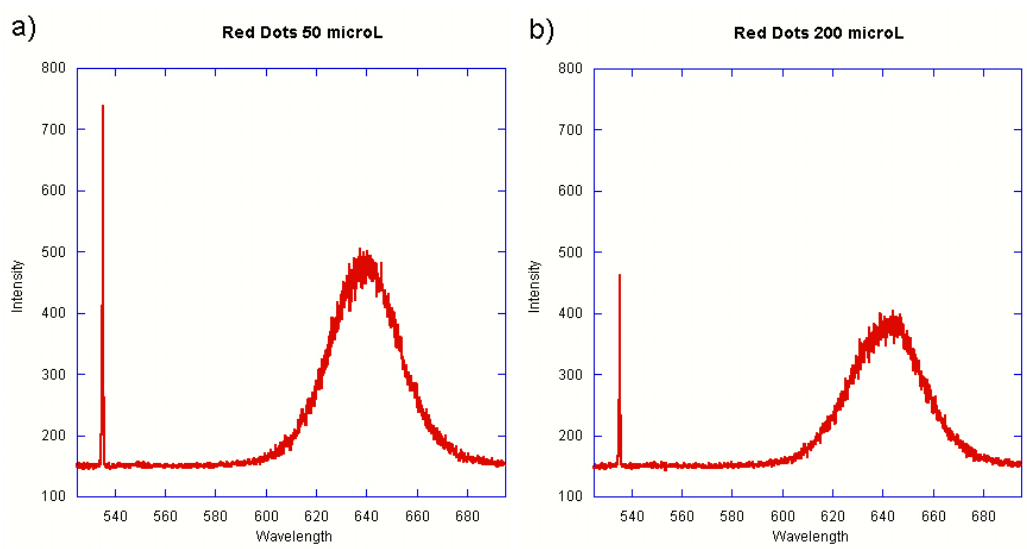

Figure 2: a-b. Signal and scattering peaks of different amounts of red quantum dot solution on GaAs substrate. a) is with 50 μ L of red dots, b) is with 200 μ L of red dots.

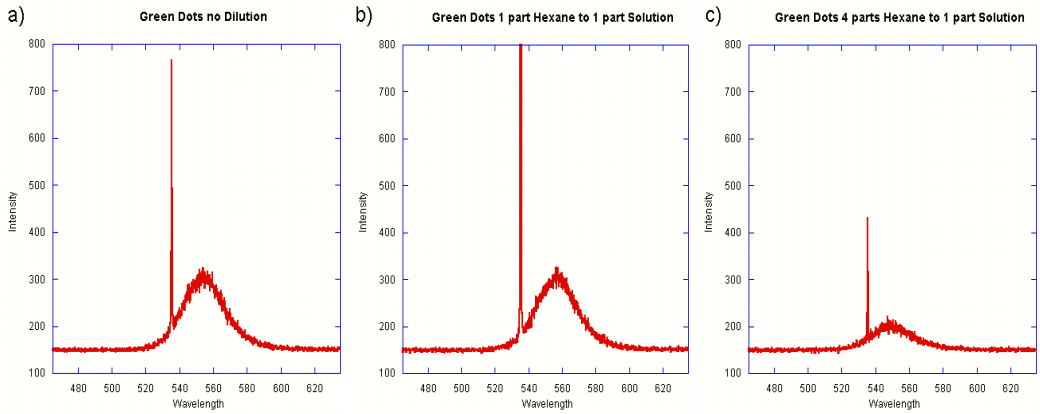

Figure 3: a-c. Signal and scattering peaks of different concentrations of green quantum dot solution on GaAs substrate. a) is with no dilution, b) is with 1 part hexane to 1 part green dot solution, and c) is with 4 parts hexane to 1 part green dot solution.

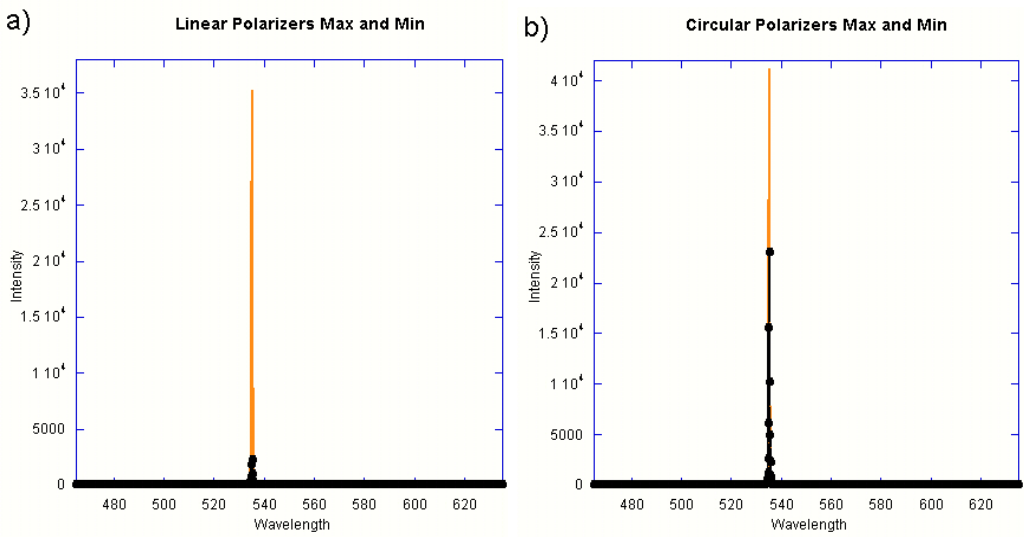

Figure 4: a-b. Comparison of maximum and minimum intensity of scattered laser light from GaAs substrate by rotating second polarizer. a) shows linear polarizer data, while b) shows circular polarizer data.

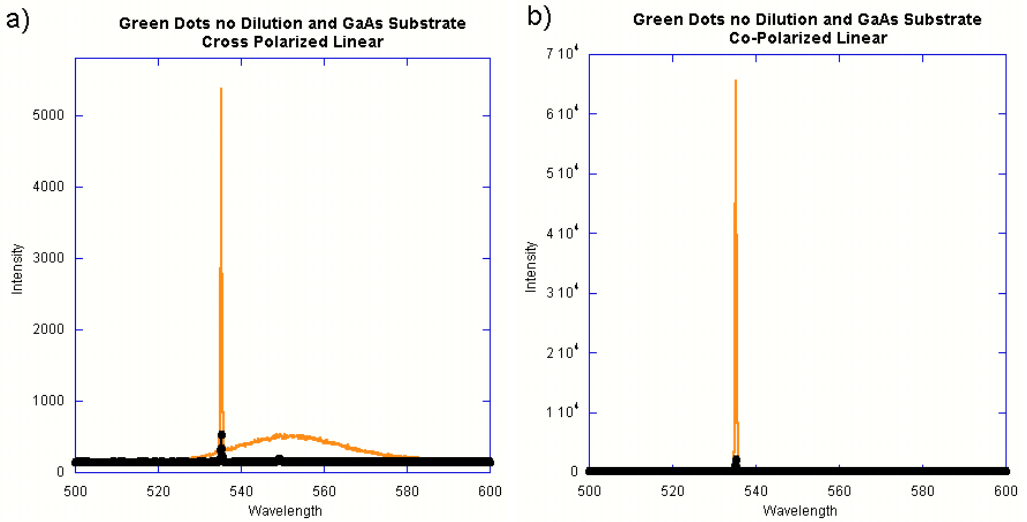

Figure 5: a-b. Comparison of scattered laser light from sample as opposed to GaAs substrate (darker line). a) shows scattering when linear polarizers are crossed, b) shows when they are co-polarized.

on the laser line, and PL signal, from a GaAs substrate with quantum dots deposited onto it. Deposited upon this particular sample was undiluted green quantum dot solution. Note that the PL peak cannot be seen in Figure 5b. This is due in part to the scale of the figure, and also to the reduced exposure time used to acquire the image. However, the PL peak is still present. The increase in scattering with linear polarizers cross polarized and co-polarized are both shown. Comparing the scattering from the sample to that of the substrate, we can see that the presence of quantum dots causes 10 times more scattering with cross polarizers, and 30 times more scattering with co-polarizers.

5 Conclusion

The amount of quantum dot solution deposited onto the GaAs substrate does not affect the signal to scattering ratio. The concentration of the solution does, and the best concentration to go with is undiluted. The linear polarizers used had a 95 % cancellation, while the circular polarizers used had only a 45 % cancellation. The scattering from the sample increases 10 times with the linear polarizers crossed, and 30 times with them copolarized. The drop-cast method is not a very effective method for creating uniform quantum dot samples, and other methods, such as spin coating and sol-gel, should be investigated for deposition of quantum dot solutions.

6 References

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