Lab 3 and 4: Single Photon Source

By: Justin Deuro, December 10th, 2009

Abstract

We study methods of single photon emission by exciting single colloidal quantum dot (QD) samples. We prepare the single colloidal quantum dots in cholesteric liquid crystal solution and use a confocal microscope to image their florescence. The antibunching of single-photon emitters is verified with a Hanbury Brown and Twiss setup. We also measured the fluorescence lifetime of DiI dye molecules.

Introduction and Theoretical Background

With almost every aspect of our lives becoming heavily reliant on electronics and technology, the ability to protect information electronically becomes more and more of a challenge. The ability to transmit and receive information in a perfectly secure manner is of the highest importance with things like medical records all turning towards fully electronic storage. Cryptography has always been a matter of importance, and since the breakthrough of quantum science and technology, quantum cryptography has become a growing and interesting field. Using single photon sources in quantum cryptography it will be impossible for information to be intercepted (much less decrypted) would be an incredible boon to people everywhere as far as protecting themselves, information and even their work. The problem with having successful quantum data transfer is the inability to consistently produce single photons.

Light can be explained in one way as particles called photons being emitted from a source. In our case, we have a stream of photons coming from our 40mW pulsed laser (that was being attenuated to 200μW at the microscope input) of 532 nm wavelength and pulse separation of 13.2 ns, pulse duration of 6 ps. In a previous lab, we had attenuated a laser down to a "single-photon level" using filters. This is not the same as having a single-photon emitter; when attenuating the laser, we will not obtain anti-bunched photons, where there are single photons separated by a distance, where as in the attenuated situation at best we will have two or three photons emitted at the same time. In order to produce one single photon at a time, we use colloidal quantum dots. The quantum dots are excited by laser light and return to their ground state by releasing their excited energy as a single photon. The fluorescence lifetime of these quantum dots is the time it takes between the release of a photon and the subsequent emission of another single photon. This lifetime can range from as small as picoseconds, nanoseconds to microseconds.

In order to show that such antibunching is occurring, we implement a Hanbury, Brown and Twiss (HBT) interferometer. To excite the quantum dots, we use a confocal microscope. While it is possible to do so without the confocal microscope, the convenience it offers is helpful: it tightly focuses the laser light onto an extremely small section of our quantum dot sample. The Confocal microscope also enables us to image only what is on our image plane, essentially blocking out other light and noise through pinholes. Using a dichoric mirror, the excitation light is separated from the emitted light from the quantum dots. The emitted light is sent to our HBT setup as shown in Figure 1. The HBT interferometer uses two Avalanche Photo Diodes (APDs). The light is split into two legs, each going to an individual APD. One acts as a "start" signal to our computer and another as a "stop" signal to our single-photon counting board, the Timeharp 2000. These two singles created a histogram of single photon times, which enables us to see the antibunching.

Along with the quantum dots, we also experimented with color centers in nanodiamonds. While we did obtain some small antibunching with the nanodiamonds samples, we were less successful with consistently and successfully producing antibunching, so this report will concentrate solely on our experience with the quantum dots. Both kinds of samples were placed in cholesteric liquid crystal solution in order to improve the emission of the single photons. The cholesteric liquid crystals are structured as a chiral bandgap material, which helps create a much more directional emission of the photons along with improving antibunching. We carried out several measurements of antibunching with single colloidal CdSeTe (Cadmium Selenium Tellurium) quantum dots and succeeded only after using a freshly prepared solution.

Procedure

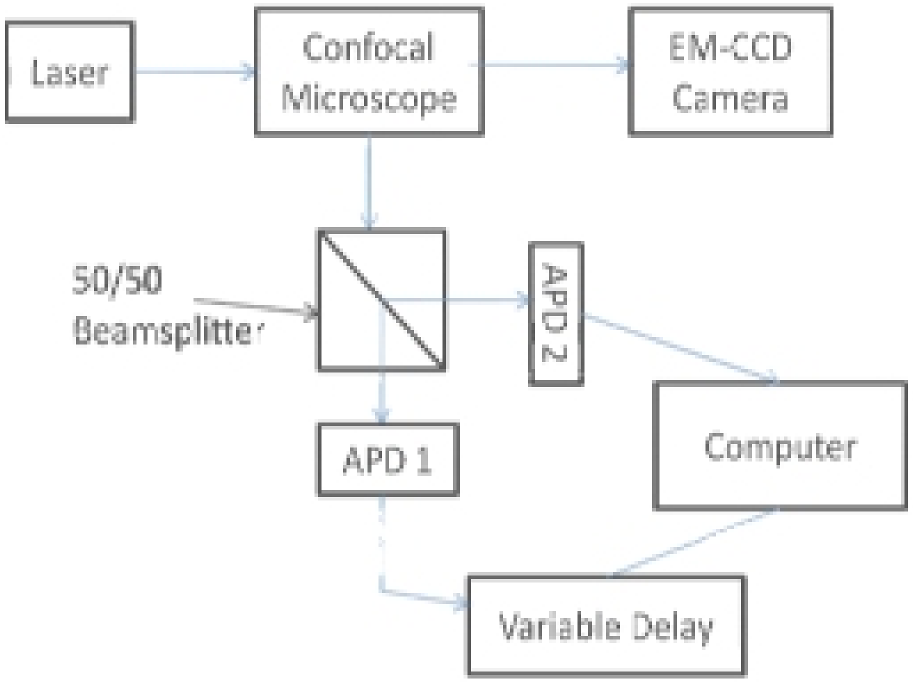

Figure 1: Lab Setup Schematic

1. Samples of the quantum dots were prepared by placing a small concentration of QD on a microscope slide and using a spin-coating machine to make it even. We also made samples of QD in cholesteric liquid crystal by placing small amounts of the liquid crystals on a microscope slide and physically mixing it with QD solution after we had waited to for the solvent to evaporate and placing it under a second microscope slide.