Lab4 Hanbury Brown and Twiss Setup. Photon Antibunching

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Abstract Antibunching is a purely quantum effect and cannot be realized from the classical theory of light. By observing the antibunching characteristic on the histogram on a Hanbury Brown and Twiss setup, we can prove the source is a single photon source (SPS), which can efficiently produce photons exhibited antibunching is a pivotal hardware element in photonic quantum information technology. Secure quantum communication with single photons will prevent any potential eavesdropper from intercepting the message without the receiver's noticing. SPS also enables quantum computation using linear optical elements and photodetectors.

Introduction

To date, three approaches have been suggested for room temperature SPS’s: single molecules, colloidal semiconductor quantum dots (nanocrystals), and color centers in diamond. The color-center source suffers from the challenge that it is not easy to couple out the photons, that the wavelength is restricted by a specific transition, and random polarization of photons. Both single molecules and colloidal semiconductor nanocrystals dissolved in a proper solvent can be embedded in photonic crystals to circumvent the deficiencies that plague the other system. The primary problems with using fluorescent dyes and colloidal semiconductor nanocrystals in cavities are the emitter’s bleaching and blinking. Using some hosts (e.g., with oxygen depletion) can reduce emitter bleaching. Recently, nonblinking quantum dots were obtained. In our experiment we will work on a room-temperature SPS based on single colloidal quantum dot fluorescence in photonic bandgap host. Photonic bandgap host enhances single-photon emission and provides definite polarization of single photons. To prove a single-photon nature of the light source fluorescence, antibunching measurements will be carried out using a Hanbury Brown and Twiss setup which is located at the one of the output ports of a confocal microscope.

Experimental Setup

One of the important part of the setup is a pulse diode-pumped solid-state laser operating at 76 MHz repetition rate. This laser wavelength is 1064 nm, but KTP-crystal placed inside the resonator converts a fundamental frequency into its second harmonic (532 nm). The 532 nm beam is directed through a light-blue glass filter which eliminates any 1064 nm light emitted by the laser as well as a diode laser radiation. The beam is then reflected by two mirrors, both of which are used for easier beam alignment. Next, the beam is directed through a spatial filter which is used both to clean and widen the beam. In addition, the beam emitted by this particular laser is elliptical, and the spatial filter is used to make the beam circular. Two more mirrors (periscope system) are then used to raise and redirect the beam. These two mirrors are also used for beam alignment when attempting to center the beam entering the microscope.
The beam is then directed through a filter holder which contains neutral density filters. These filters are used to diminish the intensity of the beam illuminating the dye or quantum dot sample since too much intensity causes bleaching of the sample and can greatly diminish fluorescence intensity.

Figure 1. Experimental setup comprising a confocal fluorescent microscope and a Hanbury Brown and Twiss setup.

The beam then enters the confocal microscope, which contains its own system of optics used to redirect the beam. The beam is initially reflected by a specially selected dichroic mirror that reflects, but does not transmit, the 532 nm light entering the microscope. The dichroic mirror does however transmit fluorescent light emitted by dye (579 nm) and/or quantum dot (~ 580 nm or 705 nm). In this manner, laser light entering the microscope at 532 nm is reflected toward the sample, causing it to fluoresce. The light emitted by fluorescence, along with some 532 nm light scattered back into the system, returns to the dichroic mirror where only the fluorescence wavelength is transmitted. Notice also that the light reflected by the dichroic mirror passes through an oil immersion objective. Immersion oil contributes to two characteristics of the image viewed through the microscope: finer resolution and brightness. These characteristics are most critical under high magnification; so it is only the higher power, short focus, objectives that are usually designed for oil immersion.

The fluorescence light transmitted by the dichroic mirror then passes through an orange glass and interference filter which are used to eliminate any remaining 532 nm light. The beam can then be directed toward the avalanche photodiode modules (APD’s) or toward the electron multiplying
(EM), cooled CCD camera depending on the port selected on the microscope. The EM-CCD camera is used before the APD’s to align the system and to assure that the beam is focused. But the main application of this camera is the direct observation in time of single emitter fluorescence when the unfocussed laser beam irradiates the sample. The camera is connected to a computer that displays the image captured by the EM-CCD array. Note that when the EM-CCD camera is being used for alignment, the orange glass filter and the filter on the dichroic mirror must be removed. This is because they reject the 532 nm laser light that is needed to form a bright enough image on the EM-CCD.

When the system is properly aligned and the two filters replaced, the green beam can be directed toward the single photon counting avalanche photodiode modules (APD’s). The APD’s have a size of a detector area of about 170 microns. Each detector area serves as a pinhole for this confocal microscope.

The beam leaving the microscope toward the APD’s is first directed toward a 50:50 non-polarizing beamsplitter. This is an optical part of a Hanbury Brown and Twiss setup for antibunching measurements. This beamsplitter directs about half of the incident photons toward the first APD and half toward the second APD. Two APD’s are used to compensate a deadtime of each detector in measurements of time intervals of two consecutive photons. One is used to provide a “start” signal, and the other, which is on a delay, is used to provide a “stop” signal. By measuring the time between “start” and “stop” signals, can form a histogram of time delay between two photons and the coincidence count (number of second photons which appeared at definite time interval after the first photons). For single-emitter fluorescent imaging the APD’s are connected to a computer which contains two cards (counter/timer and controller board connected to each other with a cable) and runs LabVIEW software. The computer is also used to run a piezo-translation stage, create images of a single-molecule fluorescence, and analyze the data collected.

The APD’s are also connected to a TimeHarp 200 time-correlated single photon counting PCI card. This is an electronic part of a Hanbury Brown and Twiss setup. This card is used in conjunction with the APD’s to create a histogram which displays the time period between detection of successive photons versus number of occurrences. This plot can then be analyzed to determine whether or not photon antibunching has occurred. The occurrence of this phenomenon is an indication that a single emitter has been scanned.

The nanodrive device is connected to the piezo-translation stage on which the sample is mounted. The nanodrive uses a high voltage (~500 V) to move the stage very slightly while scanning and max scan area is 50 um x 50 um). Sample raster scanning occurs like one would read a book from the bottom up: the bottom most horizontal line is scanned from left to right. The next line up is then scanned from left to right, and this cycle continues until the entire sample is scanned. The focusing of the beam onto the sample, selective scanning of only a portion of the sample at a time and the use of a pinhole (the apertures of the APD’s in this case) is what makes this process confocal microscopy.

The same microscope arrangement can be used for a conventional, wide-field microscopy. The fluorescence image of the area with several single emitters under unfocussed laser-beam irradiation can be obtained in a real time using the EM-CCD camera.
Observations and Results

Figure 2. 300 μW, NV-color centers in nano diamonds 25 μm*25 μm scan.

Fig. 2 is a scan on the nano-diamonds sample, it shows the obtained number of incident photons versus location on the sample for one of the APDs, with 25 μm*25 μm area scanned. Fig. 3 is a wire graph of x location versus number of photons detected, for both APDs.

Figure 3. Wire graph of x location versus number of photons detected
Figure 4. 320 μW, NV-color centers in nano-diamonds 15 μm*15 μm scan.

Fig.4. is a scan of nano-diamonds sample with 15 μm*15 μm scanned area.

Figure 5. Scan histogram

Using the data obtained we can construct the histogram by using the TimeHarp software. But we can merely see any antibunching on the graph. Therefore we did not get a single photon source in our experiment. There can be many reasons for it, one main reason may be that the sample we used in the experiment is not good enough.
References

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