Detection of Single Photon Emission by Hanbury-Brown Twiss Interferometry

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Abstract

We prepare a solution of nano-diamond particles on a glass microscope slide with a target concentration of 1×10^{-9} M. Using a confocal microscope, we observe photons emitted from the particles via excitation from a pulsed 532 nm solid state laser at 840 μW. A Hanbury Brown and Twiss interferometer is used to probe these photons for evidence of antibunching. At this time, we did not observe antibunching.

Introduction

The rise of quantum information science has prompted a need for single photons on demand. Such 'photon pistols' provide significant practical value for quantum communication and quantum computing. Furthermore, they allow in-depth experimental study of fundamental aspects of quantum mechanics.

One potential single photon source is spontaneous emission from a single emitter, such as an atom, molecule, or quantum dot. In this case, it is often difficult to ascertain whether true single photon states have been created and detected. Fortunately, a Hanbury-Brown Twiss interferometer can be used to distinguish classical from non-classical states of light. We use a confocal microscope to image single emitters onto such an interferometer in an attempt to detect non-classical single photon states.

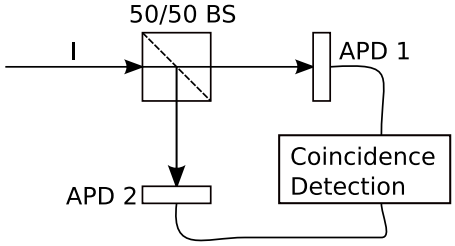

Figure 1: Hanbury-Brown Twiss Interferometer

Theory

The Hanbury Brown and Twiss interferometer (HBT) consists of an input beam, I, incident on a 50/50 beamsplitter with two avalanche photodiode (APD) detectors situated at the two outports of the beamsplitter, as shown in Fig.1. The HBT measures correlations of the intensities, I_1 and I_2, of the two outports of the beamsplitter by the second order coherence $g^{(2)}_{1,2}(\tau)$:

$$g^{(2)}_{1,2}(\tau) = \frac{\langle I_1(t+\tau) I_2(t)\rangle}{\langle I_1(t+\tau)\rangle\langle I_2(t)\rangle} \tag{1}$$

where τ is the time delay between the relative intensities.

A classical light field, I, will be split evenly into the outports of the beamsplitter, such that $I_1 = I_2 = I/2$. For simultaneous measurements ($\tau = 0$) the second order coherence is equal to:

$$g^{(2)}_{1,2}(0) = \frac{\langle I(t)^2\rangle}{\langle I(t)\rangle^2} \tag{2}$$

which is the second order coherence of the input field. Using the Cauchy-Schwartz inequality one can show that for a classical field $g^{(2)}_{1,2} \geq 1$.

In quantum mechanical theory, the intensities in Eq. 1 are treated as operators which are proportional to the number operator $\hat{n} = \hat{a}^\dagger \hat{a}$. The $\tau = 0$ second order coherence is given as:

$$g^{(2)}_{1,2}(0) = \frac{\langle \hat{a}^\dagger_1 \hat{a}_1 \hat{a}^\dagger_2 \hat{a}_2\rangle}{\langle \hat{a}^\dagger_1 \hat{a}_1\rangle\langle \hat{a}^\dagger_2 \hat{a}_2\rangle} \tag{3}$$

The operators for the two ports can be rewritten in terms of the input field operator $\hat{a}_I$ and the vacuum field operator $\hat{a}_V$ as:

$$\begin{aligned} \hat{a}_1 &= \frac{1}{\sqrt{2}}(\hat{a}_I - \hat{a}_V) \\ \hat{a}_2 &= \frac{1}{\sqrt{2}}(\hat{a}_I + \hat{a}_V) \end{aligned} \tag{4}$$

The second order coherence becomes:

$$g^{(2)}_{1,2}(0) = \frac{\langle \hat{n}_I(\hat{n}_I - 1)\rangle}{\langle \hat{n}_I\rangle^2} \tag{5}$$

which is the second order coherence of the input field. This is the same result as when the calculation is done with a classical light field.

When the second order coherence is calculated using a coherent state of light, which can be described both classically and quantum mechanically, the same value is found in both cases, $g^{(2)}_{1,2}(0) = 1$. A similar relationship is found for a thermal state of light; $g^{(2)}_{1,2}(0) = 2$. However, if we evaluate Eq. 1 using a state that cannot be described classically, one finds that $g^{(2)}_{1,2}(0) < 1$, which is in violation of the classical inequality $g^{(2)}_{1,2} \geq 1$.

For $g^{(2)}_{1,2} \geq 1$ the photons are considered to exhibit bunching. Bunching occurs when multiple photons "bunch" together as they travel. When these

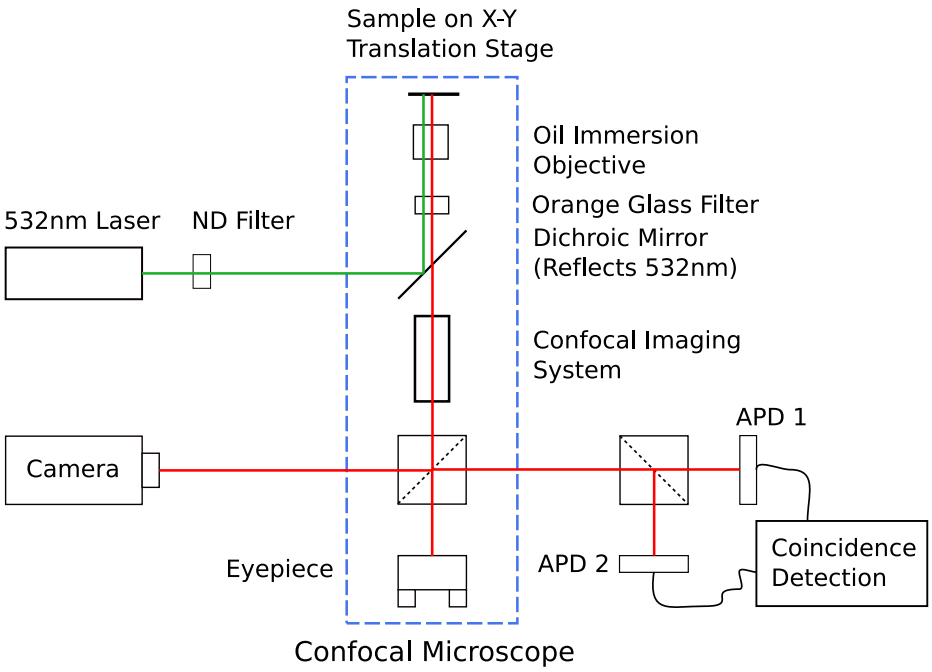

Figure 2: Experimental Setup

"bunches" are incident on a beamsplitter some of the photons are reflected and some are transmitted, leading to an increase in the number of positive correlations. For a purely quantum mechanical state the photons are considered antibunched, which means they are separated equally from each other in time. For the case of a single photon state $g^{(2)}_{1,2} = 0$.

Experimental Setup

A solution of nano-diamond particles was prepared on a glass microscope slide. Approximately 1 μL of solution was deposited on the slide with a pipet. The solution was diluted across the slide with a spin coater rotating at 30,000 RPM for 30 seconds. The target particle concentration was 1×10^{-9} M.

The sample was then placed in the confocal microscopy apparatus presented in Fig. 2. The nano particles are excited by a pulsed 532 nm solid state laser of approximately 1 mW. A confocal imaging system images the sample onto either a Hanbury-Brown Twiss interferometer or an Electron Multipliying Cooled CCD camera. A dichroic mirror prevents contamination from the excitation laser. The microscope can focus on an area of the sample approximately 200 nm in diameter.

The camera can be used to directly view source fluorescence. The sample can also be raster scanned over a 50 μm $\times$ 50 μm area to provide spatial resolution to the signal detected by the APDs in the interferometer. APDs provide both singles and coincidence measurements, and their 170 μm apertures provide the pinhole necessary for the confocal setup.

To detect single-emitter fluorescence, the output is directed to the interferometer. The sample is raster scanned to produce a two-dimensional plot of the sample. A potential single emitter is selected and the sample is translated to the appropriate location. Coincidence detection is then performed using the interferometer for approximately 5 minutes to look for antibunching.

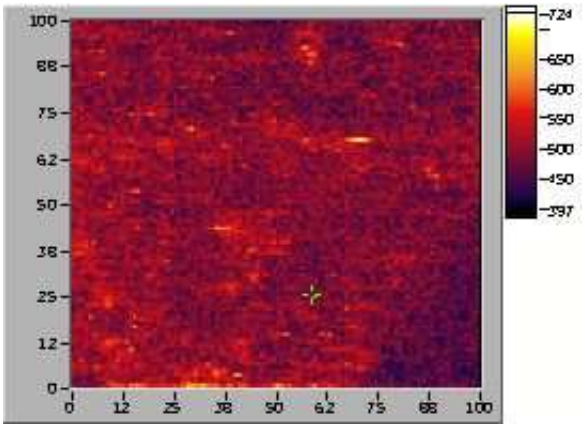

Figure 3: Raster Scan

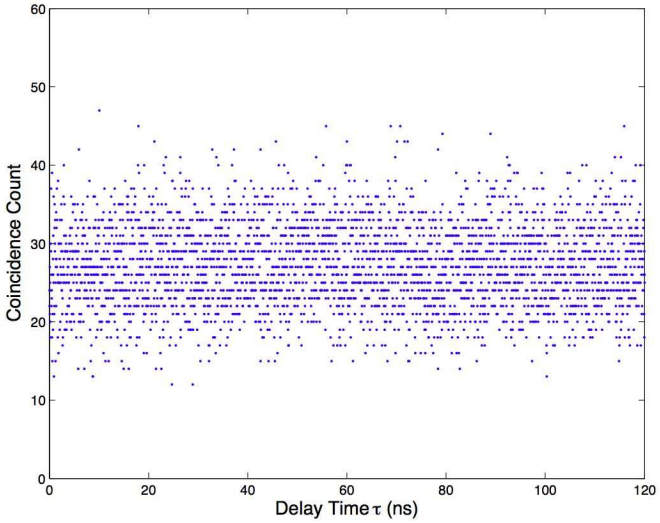

Figure 4: Coincidence Detection

Results

Results are presented in Fig. 3 and 4. . The raster scan (Fig. 3) was taken with excitation laser power of 840 μW. Emitters are characterized by bright

pixel blocks on the scan. The brightest of these are likely multiple emitters clustered together. The location $x = 59$, $y = 25$ (cross-hairs on figure) was probed for antibunching by observing coincidence counts. This measurement is proportional to $g^{(2)}_{1,2}$.

Figure 5: Camera Image

There is no observable dip in the $g^{(2)}_{1,2}(\tau)$ measurement characteristic of antibunching. We were unable to detect non-classical states of light at this location. It is possible we were not observing a single emitter, or a longer integration time may be necessary. The nano-particle density may also be too large on the slide.

An image of the sample taken with the EM-CCD is given in Fig. 5. Single emitters and clusters of single emitters can be clearly seen. It is therefore likely that with further effort antibunching can be observed on this sample.

References

[1] H. Paul, Rev. Mod. Phys. **54**, (1982).

[2] R. Hanbury-Brown and R. Q. Twiss, Nature **177**, (1956).