HORIBA

Correlation (g2) Measurement of the Single-Photon Emission from a Quantum Dot

Fluorescence
Technical Note

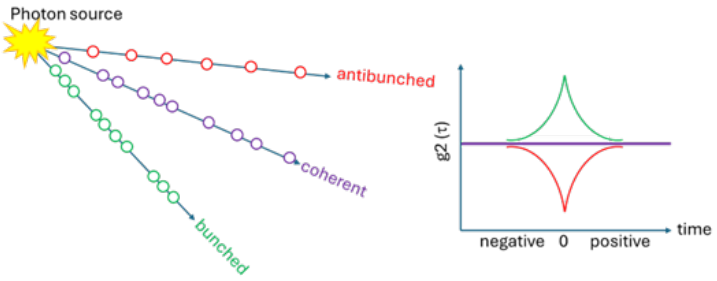
Abstract

Optical studies of quantum phenomena are increasing, requiring the use of bright single-photon emitting (SPE) sources. SPEs can have applications in quantum-enhanced imaging microscopy, as well as in the areas of communication, computing and quantum optical device manufacture. Typical methodology for the determination of whether a source is a single emitter, or not, involves a Hanbury Brown and Twiss (HBT) set up. The signal from the two detectors is correlated and used to provide a second order correlation (g2) function, from which the presence of a single-photon emitter can be discerned. This note provides some background to the experimental set up, and uses the single-photon emission from a quantum dot within a plasmonic nanocavity as an example.

Introduction

The interest in single-photon emitters (SPEs) stems from the fact that SPEs are vital in emerging quantum technology applications. Amongst these quantum areas that can benefit are those of secure communication, optical computing, high precision sensing and enhanced imaging. The SPEs provide one photon at a time, ideally on-demand, which is necessary for advancing the use of quantum-based optical technologies.

The temporal distribution of photons depends on the source. SPEs undergo a defined cycle of excitation and emission, which removes the possibility that two photons can be emitted simultaneously, thus individual photons are emitted. This is termed antibunching, which is in contrast to the light emitted by a coherent or thermal source, which can be random or bunched, respectively. This can be quantified by the use of the second order correlation function, g(2)(τ), or g2 for short. This is a measure of the likelihood of photons arriving together compared to random (Poissonian) light. A key metric is the value of g2 at zero delay (τ = 0). Fig. 1 illustrates this schematically, along with indicative values for the g2 function at zero delay.



light	g2(0)	Comment	Example
Antibunched	<1	Photons arrive separately	SPEs
Coherent	=1	Random arrival	Lasers
Bunched	>1	Photons arrive in bunches	Thermionic emission

Fig. 1. Schematic representation of different light emission and their influence on the g2 function.

The primary method to ascertain antibunching and verify if a luminescent object is a SPE is to use a Hanbury Brown and Twiss (HBT) interferometer [1]. In brief, this uses a 50/50 beam splitter to direct light to one of two single-photon counting detectors. The time difference between photons arriving at each of the detectors can be recorded using timing electronics based on the time-correlated single-photon counting (TCSPC) technique. This can simply involve one detector attached to the “start” input and the other to the “stop” input. A histogram of events representing

the g2 function is then built up. A schematic of a basic HBT set up is illustrated in Fig. 2. There are different types of detectors that can be employed, but typically these tend to be single-photon avalanche diodes (SPAD) or hybrid detectors. The excitation source can be continuous or pulsed, however this has influence on the trace that is built up in the TCSPC histogram.

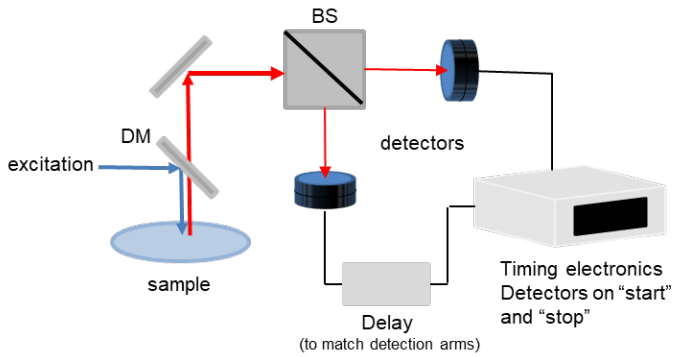


Fig. 2. Schematic representation of a HBT set up. Additional filtering to select the fluorescence emission, and block the excitation laser light, may also be required between the dichroic mirror (DM) and the beam splitter (BS).

The form of the g2 trace, as mentioned, depends on whether a pulse or continuous laser source is employed. Fig. 3 demonstrates the difference in the histogram for a SPE.

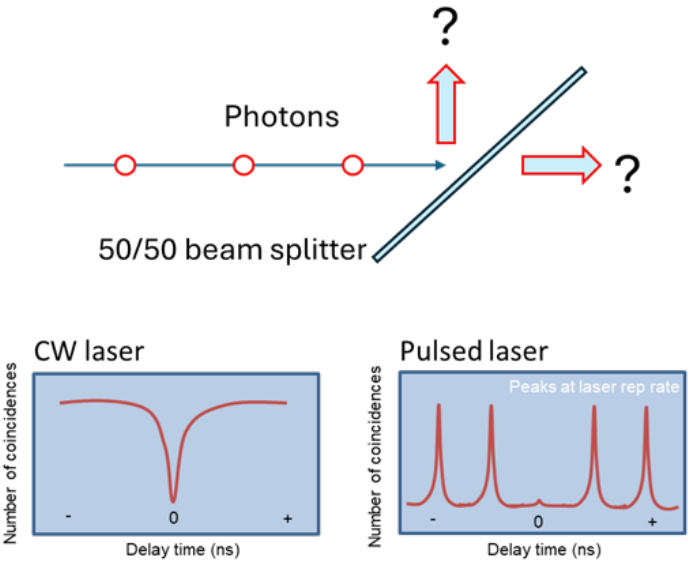


Fig. 3. Schematic of antibunched photons approaching a 50/50 beam splitter (top). Bottom the g2 trace for a SPE in a HBT set up with CW (left) and pulsed (right) laser excitation.

The approaching photon, when it reaches the beam splitter, can be directed to either detector one or detector two. For bunched or random light, multiple photons can arrive together causing both detectors to register. This produces coincidences in the histogram generated by the TCSPC electronics. However, because SPE will not produce two photons at the same time, the coincidence rate at zero delay is supressed. This results in a dip, or reduction in the peak (CW or pulsed excitation, respectively) at zero delay, as measured by the g2 function.

The strength of the g2 signal can be used to determine the quality of the SPE, with a decrease in the signal by 50% or more, providing proof that the emitter is an SPE. In the case of the CW excitation source, the width / shape of the g2 dip is influenced by the fluorescence lifetime of the emitter. Longer lifetimes will produce wider dips. This is also the case when using a pulsed source to obtain the g2 function. Additionally, the peaks seen should be separated by 1/frequency of the laser source. The measurement time to collect the g2 function can take from tens of minutes (bright emitters, such as quantum dots or NV centres) to many hours (dim emitters or inefficient optics) to collect sufficient coincident counts for the desired measurement precision.

For some quantum applications the photons may be required to be indistinguishable, in terms of polarisation, frequency and mode. In this case a Hong-Ou-Mandel (HOM) set up [2] is typically employed. However, this is beyond the scope of this note.

Example measurement from a quantum dot in a plasmonic nanocavity

The advancement of the emerging field of nanophotonic technology, in part, requires the generation of bright, chiral light generated from SPEs. The use of plasmonic nanocavities seems promising in this aspect. It is possible to use them to control the chirality of single photons from single achiral CdSe/ZnS quantum dots [3]. To determine that the quantum dots were indeed SPEs, the g2 function was recorded making use of HORIBA FiPho timing electronics and SPAD detectors. One detector was connected to the FiPho "start" input and the other to the FiPho "stop" input. A delay was used in the stop channel to position the zero point so that both negative and positive delay times would be displayed in the TCSPC histogram. The FiPho was controlled and data acquired using EzTime™ software. The signal was taken from a HORIBA OmegaScope TERS near field microscope. The CW laser used had emission at 594 nm. A schematic of this set up is shown in Fig. 4

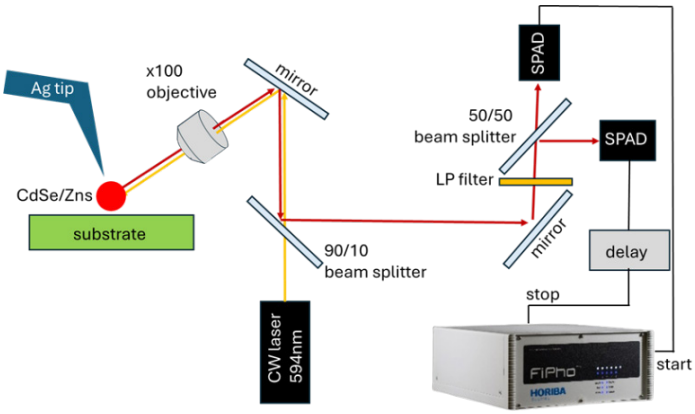


FIg. 4. Simplified schematic of the components used on the microscope for the g2 measurement.

The set up was used to image the quantum dots, making use of an Ag probe. To record the g2 function, the probe was positioned over a specific point on the quantum dot, as shown in Fig. 5.

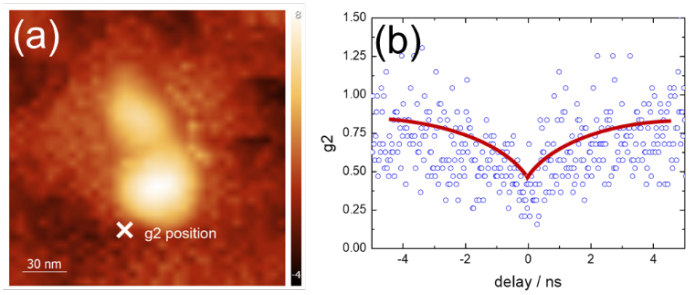


Fig. 5. (a) Position for tapping of the Ag probe for recording the g2 function from the quantum dot. (b) The resultant g2 function. Adapted from [3].

As can be seen in Fig. 5b, the g2 function is built up directly in the histogram in the EzTime software. This shows the “classic” dip, as expected for CW excitation, indicative of a SPE, thus verifying the suitability of this quantum dot / nanocavity system as a source of single photons.

Summary

This work shows the use of a HBT set up incorporated on a near field microscope (Omegascope) with TCSPC timing electronics (FiPho) to provide a HBT set up to check the suitability of a quantum dot / nanocavity system as a source of single photons. This was verified by a dip in the g2 function, as expected for SPEs with CW excitation.

Acknowledgement

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References

1. R. Hanbury Brown and R.Q. Twiss, **1956**, *Nature*, 178, 1046.
2. R.K. Hong et al., **1987**, *Phys. Rev. Lett*., 59, 2044.
3. T. Darlington *et al*., submitted work.

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