Nano-Optics in a Scanning Transmission Microscope, features and applications.

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1. INTRODUCTION

The interest for single photon emitters (SPE) has tremendously grown over the last decades, due to their possible application in quantum information. Well-known SPE are, for example, quantum dots made up of InAs/GaAs or Nitrogen Vacancy (NV) centers in diamond. A SPE emits only one photon at a time, and is a natural candidate for solid quantum bits. The usual way to characterize them is to perform an intensity interferometry experiment (Hanbury Brown and Twiss (HBT)). Such an experiment measures the autocorrelation function $g^{(2)}(\tau)$ of the emitters. The $g^{(2)}(\tau)$ function of a SPE presents a dip at very short delay ($g^{(2)}(0) < 1$), a phenomenon called the anti-bunching ,which is a unique signature of the quantum state of the light generated by the SPE. However, the investigation of SPE is usually performed with photoluminescence (PL), which does not allow accessing information below the diffraction limit (a few nanometers). Alternatives using electron as a way to trigger light emission through cathodoluminescence (CL) sound attractive. Besides the technical *tour de force* which consists in implementing a HBT setup in a CL system, recently performed [1], fundamental differences have arose between electron and photon based methods to excite light emission. In this contribution, we will tackle both the technical and conceptual issues related to performing and interpreting CL HBT experiments.

2. RESULTS

2.1 Experimental conditions

Here, we used a home-made set-up fitting a scanning transmission electron microscope (STEM) coupled to an HBT experiment allowing nanometer resolution. The $g^{(2)}(\tau)$ obtained with our STEM-CL set-up is called hereafter CL−$g^{(2)}(\tau)$. The details of the experiment are explained in [1,2] and in figure 1.

2.2 A new SPE in Boron Nitride

Other than the spatial resolution, one of the main benefits of CL over PL is the ease to study UV emission due to the high energy of incoming electron. At first we will show that CL-$g^{(2)}(\tau)$ had allowed to characterize a new UV-SPE in hexagonal Boron nitride, possibly a new emitter for quantum device.

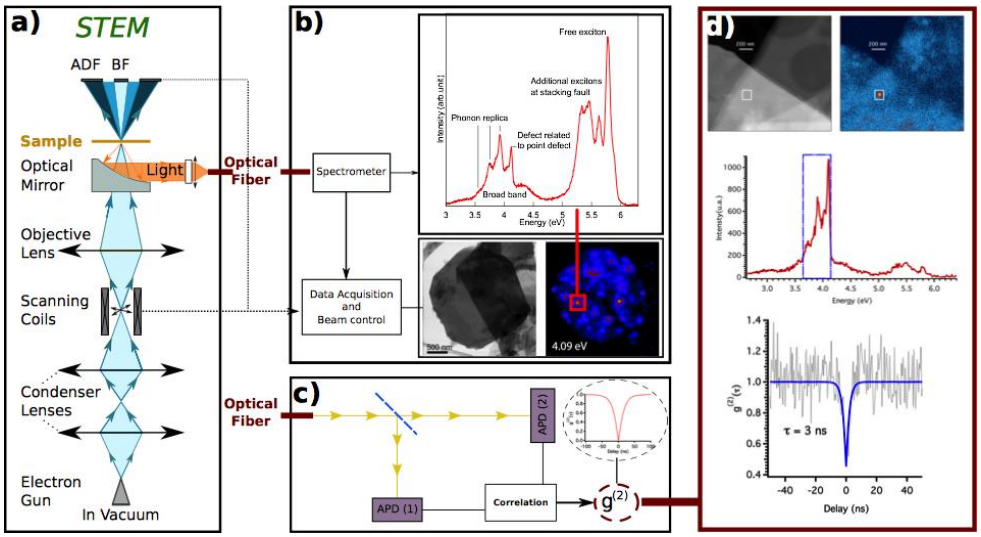

Figure 1. ***Study of a localized defect in BN :*** The CL signal is sent **b)** to an spectrometer which records the emission spectrum at each pixel or **c)** to an Hanbury Brown and Twiss interferometer for CL−$g^{(2)}(\tau)$ measurement [2]. A filtered energy map at 4.09 eV of a BN flake is shown in **b)**. Very localized emission of a common defect [4] (spectrum displayed in **b)** and **d**)). **d)** Evidence of single photon emitter behavior. Up Filtred (blue square on the spectra) imaging of the localized BN-defect. Middle Spectrum taken on after the CL−$g^{(2)}(\tau)$ acquisition. Bottom autocorrelation CL−$g^{(2)}(\tau)$ of the localized BN-defect studied (Bottom)

2.3 Light Bunching

In order to further understand this new technics, we will see that even if the interaction mechanisms of photoluminescence (PL) and CL-STEM are close enough to give the same emission spectra [3], they may lead to huge differences in their $g^{(2)}(\tau)$ function, called respectively PL−$g^{(2)}(\tau)$ and CL−$g^{(2)}(\tau)$. Indeed the interaction of electrons with mater produces a plasmon which will decay into multiple electron-hole pairs at the gap energy (Eg e-h), while the PL-photon mater interaction produces only one Eg e-h. Thus, if there is more than one SPE in the sample, one electron can excite simultaneously multiple centers leading to the synchronization of emission and thus to the emission of packets of photons. Therefore if the number of excited center is above high the CL- $g^{(2)}(\tau)$ function will exhibit a huge bunching effect ($g^{(2)}(0) > 1$) in stark contrast to the expected flat PL-$g^{(2)}(\tau)$ function ($g^{(2)}(0) = 1$) see figure 3.

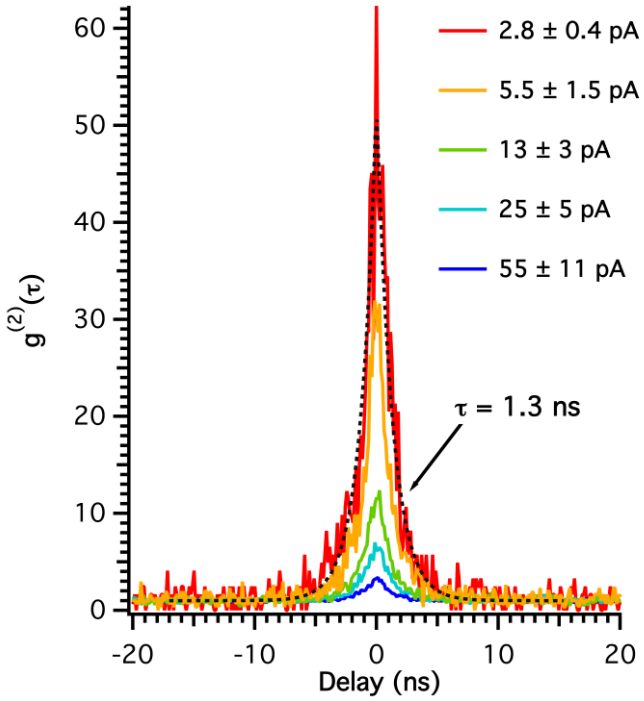

Figure 2. **.** The CL−$g^{(2)}(\tau)$ for different excitation currents when there is more than one defect excited at the same time. A huge bunching effect ($g^{(2)}(0) >> 1$) is clearly visible.

2.4 Lifetime Measurement

In addition to presenting a new physical phenomenon we will see that the CL bunching effect is also a way to measure the lifetime of emitter without pulsed electron gun and to reach nanometer resolution due to electronic excitation. It allows the correlation in no time of HADF images, emission spectrum and lifetime measurement.

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