Towards quantum optics at the nanoscale: bringing electrons and photons together in the electron microscope

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Electron microscopy techniques have been used to probe the optical properties of materials in the subwavelength scale [1]. In particular, it has been shown that using cathodoluminesncence [2] and by a propitious choice of electron beam energy and target material, resolution below 10 nm is attainable [3]. However, typical cathodoluminescence experiments only probe the spectral information of the emitted light, being an analogue of photoluminesncence at the nanoscale [4].

In this seminar we will describe recent advances in our laboratory, mainly concerning cathodoluminescence spectroscopy in a STEM. Three types of experiments attempting to implement quantum optics techniques in the electron microscope will be presented. In these experiments a 1-nm-wide 60 keV electron beam was used to excite the sample. Fundamentally, we have measured the spectroscopic signal and the second order correlation function ($g^2(t)$) of the emitted light of different materials using an optical spectrometer and a Hambury-Brown and Twiss interferometer.

Firstly, we will show how we can use a focused electron beam to probe material properties down to the nanometer scale. As an example, we will show how the stacking order in hBN can influence the emission energy of excitons and how electron microscopy help solve this problem [5].

In the second group of experiments, we have detected single photon emission from NV^0 centers in diamond (observing light antibunching) [6]. More interestingly, we have detected changes in the $g^2(t)$ within single 150 nm wide diamond crystals. With the same setup, we have detected a new single photon source in hBN emitting in the 350 nm range.

In the final set of experiments, we have used the same interferometer to measure the $g^{(2)}(t)$ of nanodiamonds containing hundreds NV^0 emitters. Surprisingly, we have observed a large *bunching* effect in the nanosecond time scale. This bunching arises due to the simultaneous excitation of multiple centers by a single incoming electron and it gives information about the excitation mechanism behind light emission in cathodoluminescence [7]. This effect allows the measurement of objects' lifetimes in close proximity.

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