Comparison of back focal plane imaging of nitrogen vacancy centers in nanodiamond and core-shell CdSe/CdS quantum dots

Justus Christinck[1,2], Beatrice Rodiek[1,2], Marco Lopéz[1], Hristina Georgieva[1], Helmuth Hofer[1,2], Xiao-Liu Chu[3,4], Stephan Götzinger[3,4] and Stefan Kück[1,2]

[1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany
[3]Max Planck Institute for the Science of Light, Erlangen, Germany
[4]Friedrich Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany
Corresponding e-mail address: justus.christinck@ptb.de

We report on the characterization of the angular-dependent emission of two different single-photon emitters based on nitrogen-vacancy centers in nanodiamond and core-shell CdSe/CdS quantum dot nanoparticles.

The emitters were characterized in a confocal microscope setup by spectroscopy and Hanbury-Brown and Twiss interferometry. The angular-dependent emission is measured using back focal plane imaging technique. A theoretical model of the angular emission patterns of the 2D dipoles of the emitters is developed to determine their orientation. Experiment and model agree well with each other.

EXPERIMENTAL SETUP

Both emitters were characterized in a similar confocal microscope setup using a laser operating at a wavelength of 532nm for excitation and an oil-immersion objective with a numerical aperture (NA) of 1.4 for the quantum dots (QD) and 1.45 for the nitrogen-vacancy (NV-) centers. Spectral filters were used to cut off wavelengths below 550 nm and above 750 nm and a fiber with core diameter of 9 µm was used as a pinhole. Two single avalanche photodiodes were used in the Hanbury-Brown and Twiss interferometer and for the sample scanning. Back focal plane imaging was carried out using a sCMOS camera.

The nitrogen-vacancy center nanodiamonds have a size of about 75 nm and the core-shell CdSe/CdS quantum dot nanoparticles are of about 15 nm in diameter.

MODEL OF THE ANGULAR EMISSION

Lukosz [1] developed a model for the angular-dependent emission patterns of a dipole at a dielectric interface. Nitrogen-vacancy centers consist of two perpendicular dipoles in plane perpendicular to the symmetry axis of the NV-center [2]. The quantum dot emission is also originated from 2D dipoles [3]. The orientation of the emitters refers to the orientation angles θ and φ of the normal vector of the dipole emission plane, because the orientation of the two dipoles is unambiguously described. The angular-dependent emission patterns were calculated as the sum of the patterns of the two dipoles.

EXPERIMENTAL RESULTS

After sample scanning, one emitter on each sample has been chosen for further characterization. While the nitrogen-vacancy center emits a broad spectrum between about 600 nm and 750 nm, the QD emission is relatively narrow at about 640 nm (FWHM=18 nm) as shown in Figure 1. The Hanbury-Brown and Twiss measurement prove non-classical emission for both emitters with $g^{(2)}(0)$ values of 0.09 for the NV-center and 0.31 for the QD, respectively, as can be seen in Figure 2.

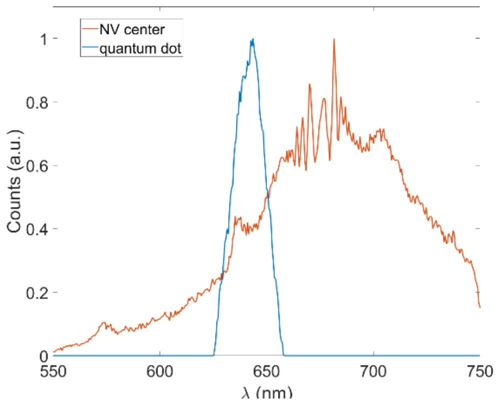

Figure 1. Spectra of the quantum dot and nitrogen-vacancy center emission.

Background corrected back focal plane images were taken by first collecting the emission for about 60 seconds and then imaging the background light near the emitter for the same time. In the insets of Figure 3 and 4 back focal plane images of the emitters are shown.

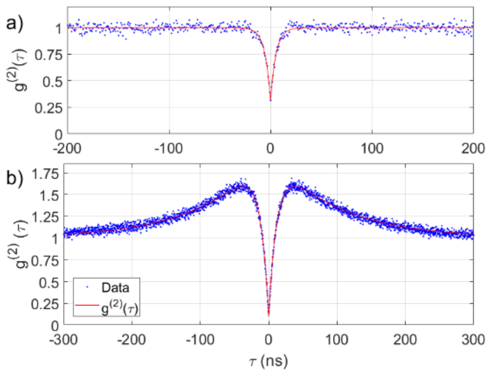

Figure 2. Intensity correlation function $g^{(2)}(\tau)$ for a) quantum dot and b) nitrogen-vacancy center.

For better comparison angular-dependent emission patterns were calculated from the back focal plane images along a line that is shown in their respective back focal plane image. In Figure 3 and 4 the angular-dependent emission patterns are shown together with calculated data from the model. The angle α is the angle against the optical axis. The NV-

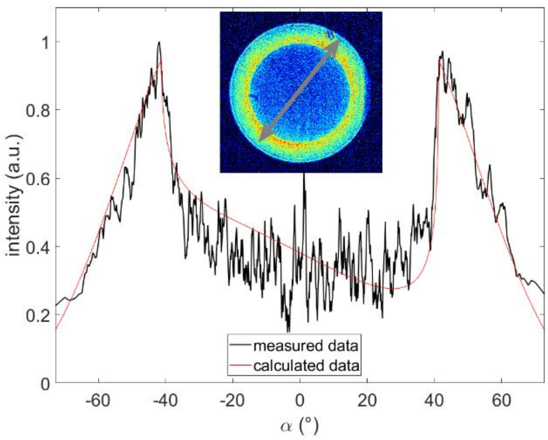

Figure 3. Comparison of model and experimental data of the angular-dependent emission of the quantum dot. In

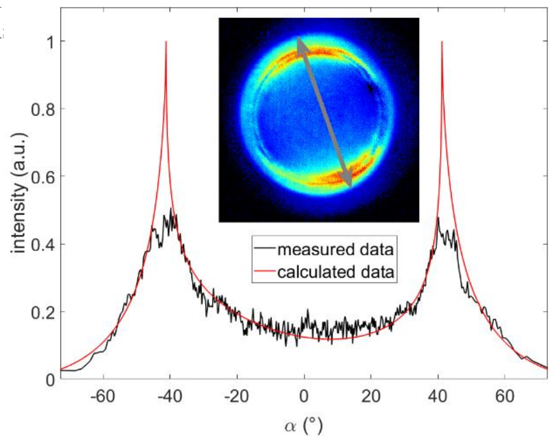

Figure 4. Comparison of model and experimental data of the angular-dependent emission of the nitrogen-vacancy center. Inset: back focal plane image of the nitrogen-vacancy center.

center emission is in good agreement with the model. The difference at the peaks may be caused by blurriness in the picture. The QD emission is accurately reproduced by the model of the 2D dipoles. The orientation angles of the nitrogen-vacancy center are θ = 60° and φ = 334°, while for the quantum dot they are θ = 30° and φ = 35°.

CONCLUSION

Back focal plane imaging has been successfully shown on nitrogen-vacancy centers in nanodiamond and core-shell CdSe/CdS quantum dots. Model and experiment agree well for both emitters. The orientation of the 2D emission dipoles of the quantum dot and the orientation of the symmetry axis of the nitrogen-vacancy center were calculated. Further details will be presented at the conference.

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