Measuring single spin noise with single detected photons

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Charged quantum dots are among the best candidate platforms for quantum information processing. Entanglement between the spin degree of freedom of a charge confined in the QD (acting as stationary qubit) and the polarization of single photons (flying qubits) would allow the realization of a quantum communication network. A promising strategy, in this respect, is to take advantage of the giant rotation induced by a single spin on the polarization state of single photons, as in micropillar cavity-based spin-photon interfaces [1, 2]. In parallel, spin-induced polarization rotation has been extensively used, though with very small rotation angles in the absence of cavity enhancement, to study the dynamics of spin ensembles and even single spins using optical spin noise spectroscopy (SNS) [3]. Here we show that by taking advantage of the cavity-enhanced interaction, we can push the measurement of single spin noise to the single photon level. Our system is an InAs positively charged quantum dot embedded in an electrically contacted and deterministically coupled microcavity [4]. A linearly polarized continuous wave laser is sent to the cavity around resonance with the trion transition. The output polarization of the reflected photons is rotated, providing spin-state dependant polarization Stokes vectors. Using the tools of quantum optics, we perform optical SNS using single detected photons via cross-correlation measurements between two photon detection events in orthogonal polarizations. Giant SNS signals are observed at various powers (Fig. 1), and allow us probing the spin dynamics, revealing valuable information on the charge and nuclear spin fluctuations in the QD environment. We will show that measuring the optical polarization and its cross-correlations, in various states of the Poincaré sphere [5] with single photon detectors, provides a very powerful tool to characterize both the coherent and incoherent optical processes in our system. Finally, we will discuss how these results pave the way for the implementation of quantum non-demolition measurements of a single spin with a single photon, and towards deterministic spin-photon and photon-photon quantum gates, exploiting the giant spin-induced Kerr rotation.

References

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[2] Hu et al, PRB, 78 (2008) 085307
[3] Dahbashi et al, PRL, 112 (2014) 156601
[4] Hilaire et al, PRB, 102 (2020) 195402
[5] Antón et al, Optica, 4 (2007) 1326

Figures

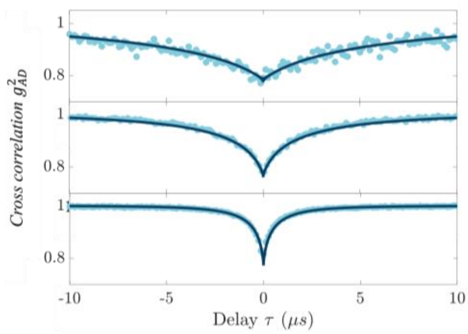

Figure 1: Cross correlation measurement as a function of the excitation power.