Wigner function Reconstruction of Non-Gaussian Superposition States emitted from a Quantum Dot

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Semiconductor quantum dot (QD) devices are forefront and versatile quantum light sources that exhibit high in-fiber single-photon brightness [1], strong single-photon nonlinearities [2], and controllable photon-number superpositions [3]. These assets position QD as promising light sources for continuous-variable quantum information processing. In this framework, homodyne detection is a crucial technique to measure the Wigner function (WF), a complete quantum state description. We demonstrate the reconstruction of the non-Gaussian WFs for coherent photon-number superposition states $\sqrt{p_0}|0\rangle + e^{i\varphi}\sqrt{1-p_0}|1\rangle$ emitted from our QD system using a variation of the direct probing method [4]. Instead of photon counting, we rely on a maximum likelihood algorithm to approximate the desired photon-number distribution from zero-photon probabilities $Z_{0,k}$ measured at k detection efficiencies η_k [5]. The probabilities $Z_{0,k}$ are extracted from superconducting nanowire single-photon detector rates, with detection efficiency η_k adjusted via an optical attenuator. Phase-space points are explored by displacing the WF via interference with a weak coherent state on a beam splitter. The amount of displacement $|\gamma|$ is controlled by tuning the amplitude of the coherent state. A fiber stretcher modulates the relative phase with a 50 Hz sine wave, leveraging the oscillatory detector rates to extract nine phases $\Delta\varphi_p$ by binning. The method's accuracy depends on optical transmission (~6.5 %) - corrected in post-processing via binomial loss modeling - and optimal mean wavepacket overlaps M between classical and quantum light [4]. We developed two photon-correlation methods leveraging bunching to monitor and optimize M = 0.68 ± 0.03 [6]. Additionally, the maximum likelihood algorithm requires precise knowledge about desired distributions described by η_k, $|\gamma|$, $\Delta\varphi_p$, M, and p_0, which are measured independently. We demonstrate the Wigner negativity in our loss-corrected WF of $\sqrt{p_0}|0\rangle + e^{i\varphi}\sqrt{1-p_0}|1\rangle$ with p_0 = 0.53 ± 0.01 (Fig. 1). In total, we acquire six non-Gaussian Wigner functions, demonstrating the method's robustness and the first WF measurements from QD sources.

References

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Figure

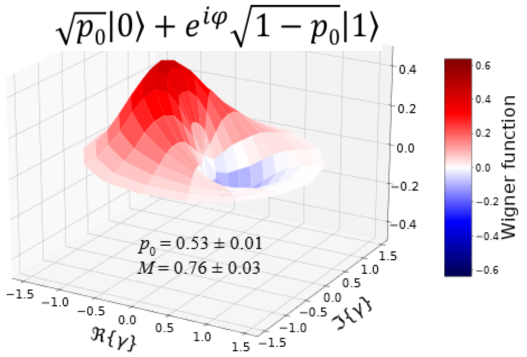

Figure 1: Reconstructed WF with an averaged approximation error of ε = (0.36±0.25) % and acquisition time ≈ 30 min.