Quantum Interference of Identical Photons from Remote GaAs Quantum Dots

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Abstract—We present near-unity two-photon interference visibilities for single-photon states generated from two separate GaAs quantum dots. This level of interference visibility is the first of its kind among solid-state quantum emitters and matches the performance of pure platforms such as atoms and ions.

Keywords—Quantum dot, Hong-Ou-Mandel interference, Indistinguishability, Droplet-etched quantum dot, Scalable quantum photonics

I. INTRODUCTION

Advances in photonic quantum technologies call for the creation, manipulation, and detection of a large number of identical single photons. The most popular platform for generating these states is based on parametric down-conversion processes, which work probabilistically, and deterministic single-photon sources meeting these needs are still lacking. Self-assembled quantum dots (QDs) represent a semiconductor platform that can create single photons in a near-deterministic manner. QDs can be integrated into various microstructures and nanostructures using well-established fabrication methods [1]–[3]. For applications, however, a significant roadblock is the poor quantum coherence upon interfering photons created by two or more independent QDs. In other words, the photons created by different QDs are not identical due to the presence of noise in the environment of the QDs. So far, the highest visibility on interfering photons created by two separate QDs is only marginally [4] above 50%. On sacrificing efficiency and removing the noise via temporal and spectral filtering, 77% visibility has been achieved [5]. This limits the employment of more than one QD source for practical quantum technologies. For applications, interference visibility between separate-QD photons must be improved to near-unity.

II. METHODS

Here, we show that it is possible to achieve nearly identical photons from different QDs [6]. We employ droplet-etched gallium arsenide (GaAs) QDs in an aluminum gallium arsenide (AlGaAs) matrix, see. Fig. 1a for a sketch. These QDs enjoy several advantages over self-assembled QDs. Firstly, these dots are free from strain as the lattice mismatch between GaAs and AlGaAs is negligible. Secondly, these dots have a larger oscillator strength which makes them more robust against noise sources. Thirdly, these dots are grown by droplet-etching, which is a more smooth and defect-free process as opposed to Stranski-Krastanov self-assembly and hence results in a significantly less number of charge traps in the environment of the quantum dots. Finally, Fourier transform limited transitions have been observed with these dots recently [7], which hints that high coherence between separate QDs might be achievable.

In order to minimize the charge noise in the environment, we embed the QD layer in the intrinsic region of a P-i-N diode. Details of the geometry of the diode can be found in reference [7]. The added advantage of using a diode is that the transition energies of QDs can be tuned via the Stark effect. In our sample, we can tune individual QDs by 250 GHz without compromising their coherence. This is crucial for tuning different QDs exactly to resonance with each other.

III. RESULTS

We present two-photon interference with a 93% interference visibility from two QDs placed in different cryostats [6]. The separation guarantees that different quantum dots are subject to uncorrelated noise. Figure 1b shows a sketch of the experiment.
Photons from either QD are sent to the input ports of a beam splitter, and we measure the correlation between the detection events on the two outputs of the beam splitter. Fig. 2a shows the cross-correlation between the two for two cases, blue: when the photons from the two QDs have identical polarization (HOM ||), and red: when the photons have perpendicular polarization (HOM ⊥). Lack of coincidence counts around zero time delays for HOM || is direct evidence of Hong-Ou-Mandel interference between photons from the two QDs. By comparing these two curves, we extract an interference visibility of 94%. This high visibility is achieved under rigorous conditions: no Purcell enhancement, no temporal post-selection, no narrow spectral filtering, and no frequency stabilization. The key is the employment of gated GaAs QDs in a p-i-n diode. We repeat these measurements while introducing a small detuning between the two QDs (Fig. 2b), or imparting a small between photons (Fig. 2c). As evident from these graphs, the interference visibility disappears as the detuning between QDs increases, as would be expected for two-photon interference. We further repeat these measurements for a third QD, which yields similar results confirming that these measurements are not a rare case and can be reproduced between different QDs.

This level of interference visibility from independent GaAs QDs is a first of its kind and matches the performance achieved in trapped ions [8], [9] and cold atoms, the seemingly most identical emitters. While the experimental setups here are significantly less complicated than that of atomic experiments. These interference visibilities are also comparable to the visibilities achieved with state-of-the-art parametric photon sources [10], while parametric sources operate in an intrinsically probabilistic manner and the photon generation rate is compromised to achieve high interference visibility.

IV. CONCLUSIONS AND OUTLOOK

The near-unity mutual coherence between photons from different QDs unlocks the potential of employing multiple QD sources in quantum applications. The HOM visibility can also benefit from the reduced lifetime (Purcell effect) provided the low noise can be preserved. With the present noise level, a Purcell factor of ten should result in HOM visibilities of 99.0%.

From a quantum-information point of view, increasing the number of identical photons to ~50 will lead to a quantum advantage in a boson sampling experiment [11]. As another direction, few-photon cluster states can be generated using individual QDs [12], [13], and interference-based entangling gates will allow the small clusters to be “fused” into large-scale computational resources.

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