QD spin-mediated tailoring of the photon-number coherence of vacuum—one-photon qubits

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Coherent control of semiconductor quantum dot (QD)-based single photon sources has enabled high-rate deterministic generation of coherent superpositions of the vacuum and single-photon states, called vacuum—one-photon qubits, with strong coherence in the photon-number basis [1]. Although this photon-number coherence $\mathcal{C}$ constitutes a critical resource for numerous quantum information processing protocols (QIP) [2, 3], it represents a security hazard for most quantum communication protocols, sparking interest in photon-number coherence tuneability which do not affect photonic emission rate [4]. In this study, we demonstrate manipulation of the spin degree of freedom of a single charge confined in the QD can be leveraged to taylor vacuum—one-photon qubits photon-number coherence. We then experimentally verify this mechanism using self-homodyne field interference visibility $\mathcal{V}$ detection and demonstrate full tuneability of the photon-number coherence, from $\mathcal{C} = 0.5$ % to $\mathcal{C} = 99.1$ % (**Fig. 1**). Our results establish cavity-embedded QD-based sources as a versatile platform for spin-controlled vacuum—one-photon qubits engineering and highlight their potential as a key resource for advanced QIP protocols.

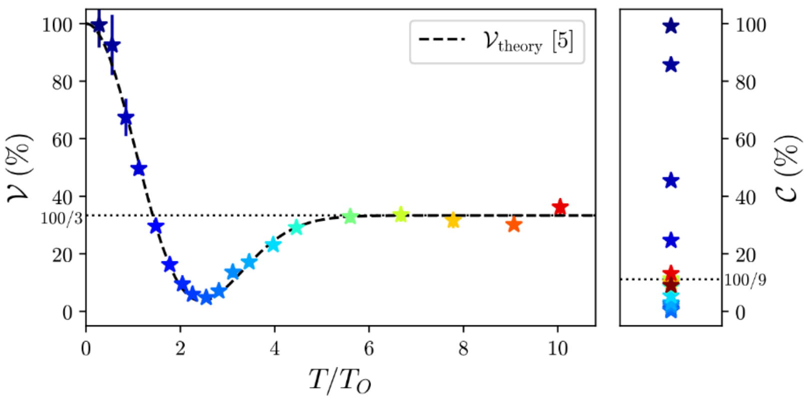

Fig. 1*: Interference visibility $\mathcal{V}$ measurement shows photon-number coherence $\mathcal{C}$ tuneability, in agreement with spin-driven dynamics described by the Merkulov model [5].*

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References

[1] J. C. Loredo, C. Antón, B. Reznychenko et al., Nat. Photon. 13, 803-808 (2019).

[2] M. Lucamarini, Z. L. Yuan, J. F. Dynes et al., Nature 557, 400–403 (2018).

[3] J. J. Renema Phys. Rev. A 101, 063840 (2020).

[4] Y. Karli et al., npj Quantum Inf 10, 1–9 (2024).

[5] I. A. Merkulov, A. L. Efros, M. Rosen, Phys. Rev. B 65, 205309 (2002).