Coherent Dynamics of the Swing-up Excitation and Signatures of Dynamically Dressed States in Quantum Two-Level System

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Finding a suitable excitation method for quantum systems and understanding of the dynamics during light-matter interaction of quantum systems are of major research interests in quantum technologies. Semiconductor quantum dots, often referred to artificial atoms, are one of the promising systems for quantum technologies and for the fundamental study of quantum optics. In this seminar, we will discuss our two recent works where (1) a recently proposed excitation technique for a single-photon emitter is experimentally demonstrated and (2) we present the first experimental observation of the theoretically predicted resonance fluorescence emission spectrum.

Recently, Bracht et al. proposed a promising excitation technique for single-photon emitters based on two red-detuned excitation pulses which enable a high-fidelity swing-up effect of the population from the ground- to the excited state in a coherent manner [1], with successful experimental demonstration of its functionality by Karli et al. [2]. In this contribution, we extend the analysis of this method and explore the coherent dynamics of the swing-up technique with an InGaAs quantum dot [3 and investigate the multidimensional parameter-space of the excitation to study their impact on the scheme. Furthermore, we analyze the single-photon performance of our two-level system under swing-up excitation. We find nearly perfect single-photon purity with a raw value of $g^2_{\mathrm{swing,\,raw}}(0) = 0.033$, as shown in Fig. 1. In contrast, the measured indistinguishability is limited to $v_{\mathrm{HOM,\,swing}} = 0.439$, which can be attributed mostly to the impact of the high laser intensities on the semiconductor environment of the quantum dot. Therefore, we conclude that the method is very promising, although further engineering is required to make it suitable for applications.

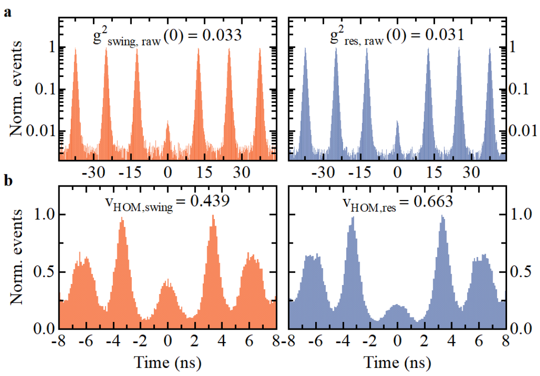

Fig. 1. **a** Single-photon purity and **b** indistinguishability of emitted photons under swing-up (left) and resonant excitation (right).

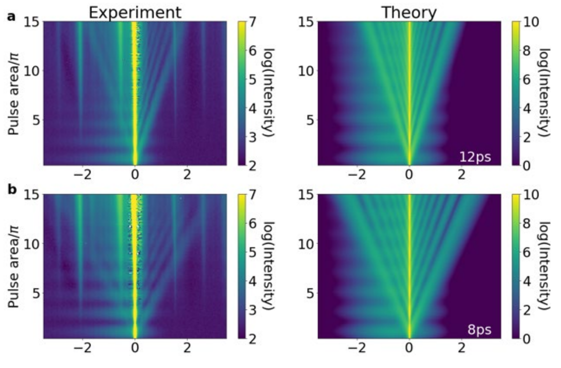

Fig. 2. Power-dependent measured and simulated emission spectra from pulsed resonant excitation for different Gaussian pulses.

The interaction of a resonant light field with a quantum two-level system is of key interest for both fundamental quantum optics and quantum technological applications employing resonant excitation. While emission under resonant continuous-wave excitation has been well studied, the more complex emission spectrum of dynamically dressed states – a quantum two-level system driven by resonant pulsed excitation – has so far been investigated in detail only theoretically [4, 5] We experimentally observed for the first time the complete resonance fluorescence emission spectrum of a single quantum two-level system in form of an excitonic transition in an InGaAs quantum dot, driven by finite pulses [6]. As an example, Fig. 2 shows the emission spectra of the quantum dot under resonant excitation for excitation with 12ps and 8ps long pulses. With increasing power, together with Rabi rotations of the main emission peak at zero detuning multiple sidepeaks emerge from the center showing excellent agreement between experiments (left) and theory (right). Our results confirm the nearly 40 years long standing prediction of the characteristic emission spectrum of a two-level system under pulsed resonant excitation.

[1] Bracht, Thomas K., et al. "Swing-up of quantum emitter population using detuned pulses." PRX Quantum 2.4 (2021): 040354.
[2] Karli, Yusuf, et al. "SUPER Scheme in Action: Experimental Demonstration of Red-detuned Excitation of a Quantum Dot." Nano letters, 22.16 (2022): 6567-6572
[3] Boos, Katarina, et al. "Coherent Swing-Up Excitation for Semiconductor Quantum Dots." Advanced Quantum Technologies (2024): 2300359
[4] Rząewski, Kazimierz, and Jakub Zakrzewski. "Resonance scattering of a short laser pulse on a two-level system: Time-dependent approach." Physical Review A 31.3 (1985): 1558
[5] Moelbjerg, Anders, et al. "Resonance fluorescence from semiconductor quantum dots: beyond the Mollow triplet." Physical review letters 108.1 (2012): 017401
[6] Boos, Katarina, et al. "Signatures of dynamically dressed states." Physical Review Letters 132.5 (2024): 053602.