Single photon nonlinearities induced by giant polariton-polariton interactions in semiconductor photonic structures

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Quantum platforms that use photons as qubits hold great promise for quantum optical applications, including computing, communication and optical neural networks, paving the way towards sustainable quantum photonic artificial intelligence. A key challenge in these applications is the realization of scalable systems with strong effective photon-photon interactions, enabling high probability, or even a deterministic generation and control of complex multi-photon entangled states. Hybrid light-matter states, based on 2D exciton-polaritons in quantum wells or 2D materials, offer a potential solution by providing the necessary giant photon-photon interactions and scalability [1]. This advancement paves the way for the development of controlled phase-shift gates [2], photon number detectors and sorters [3], and the generation of complex entangled photonic states[4], both in discrete and continuous variables, combining the advantages of both for resource-efficient quantum signal processing[5].

In my work, I will review our experimental findings on strong cross-phase modulation between signal and control beams at low photon intensities in solid micropillar [6] and tunable openaccess microcavity systems [7]. In these systems, strong nonlinearity is achieved through polariton lateral confinement (~1 μm) and a high Q-factor (up to 30,000). We observe phase shifts of up to 150 mrad per polariton, approaching the values found in photonic structures containing single-photon emitters, such as quantum dots or atoms. The phase shift per polariton is strongly dependent on exciton-cavity mode energy detuning, decreasing rapidly from positive to negative detuning. This behavior is attributed to biexciton resonance effects, which induce a strong energy dependence in interactions between cross-circularly polarized polaritons, as well as nonlinear dissipation. Additionally, we measure the phase shift as a time delay between ~2 ns control and signal pulses, with a rise time of approximately 200 ps. The shift completely disappears when the pulses no longer overlap in time, confirming the ultrafast nature of polariton nonlinearity. Finally, I will discuss potential strategies for further enhancing polariton optical nonlinearity, such as utilizing dipolaritons or Rydberg excitons [8].

References

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