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Quantum and nonlinear optics at the single photon level with quantum dots in optical nanocavities

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By embedding a single InAs/GaAs quantum dot (QD) inside a nanocavity that strongly localizes optical field, it is possible to achieve a very strong light-matter interaction. The strength of this interaction is characterized by the coherent emitter-field coupling strength (g) which also sets the limit on the operational speed of such a system. While in systems consisting of a single neutral atom coupled to a cavity maximum $g/(2\pi) \sim 20$ MHz has been demonstrated, InAs/GaAs QDs inside photonic crystal cavities have reached $g/(2\pi) \sim 40$ GHz. Such a QD-cavity platform has also been employed in a series of quantum and nonlinear optics experiments at the single or few photon level which will be discussed in this talk, including: 1) photon blockade and photon induced tunneling (which can be employed to build high throughput sources of single or n-photons); 2) all optical switching at the single photon level and at the speed of 25GHz (which can be employed in all optical gates); 3) single quantum dot based optical modulators that operate at the sub-fJ control energies and potentially at >10GHz speeds; 4) single QD spin-photon interfaces that could be employed as nodes of a quantum repeater. However, considering that the speed of each of these elements is ultimately limited by g, which in turn scales as $\sim 1/\sqrt{V}$, where V is the optical mode volume, it is worthwhile building structures with V even smaller than those of photonic crystal cavities (which typically have V on the order of a cubic optical wavelength). With our recently demonstrated metal- GaAs nanocavity, V is squeezed by more than 10 times relative to photonic crystal cavities, and we demonstrate $g/(2\pi) > 100$GHz with a single, embedded InAs/GaAs quantum dot. We are also working on extensions of this platform from two-level to multi-level quantum emitters strongly coupled to a cavity, as well as the extensions to emitters coupled to photonic molecules and cavity arrays, with applications in nonclassical light generation and quantum simulation.