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Fast optical control of atom-light interactions using quantum dots coupled to photonic crystal cavities

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Quantum dots (QDs) are stable, bright, semiconductor based light emitters that exhibit a quantized energy spectrum. For these reasons they are excellent candidates for development of lasers, optoelectronic components, and could serve as basic building blocks for future quantum information technology. By coupling these nanostructures to optical cavities the interaction strength between QDs and light can be significantly increased. Photonic crystals (materials with a periodic index of refraction) are particularly promising for enhancing these interactions due to their ability to guide and confine light on the size scale of an optical wavelength. Photonic crystal based optical cavities have already been shown to enable the strong coupling regime of cavity quantum electrodynamics (cQED). In this regime a significant modification of both the QD emission spectrum and cavity reflectivity can be observed due to quantum mechanical mixing of atom-photon states. Control of QD-photon interactions on fast timescales is an important capability that enables strong nonlinear optical effects, opening up the door for a new class of opto-electronic devices at ultra-low light levels. It could also provide a promising route towards quantum information processing using photons and QDs to store and transmit quantum coherence. Here we describe a method to achieve fast all-optical control of atom-light interactions using indium arsenide (InAs) QDs coupled to photonic crystal cavities. We show that a QD strongly coupled to a photonic crystal cavity can exhibit very large optical Stark shifts due to resonant cavity enhancement of the electromagnetic field. Stark shifts as large as 20 GHz are demonstrated with as few as 10 photons in the cavity. These shifts can be used to control the QD resonant frequency on fast time scales, and therefore modify its interactions with the optical cavity through resonant detuning. Using this approach we demonstrate the ability to perform all optical switching with control pulse energies as small as 400 photons and switching times as fast as 140 ps. The approach can be improved through better cavity coupling methods to approach nonlinear optics near the single photon level.