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Photonic Crystal Devices for Quantum and Nanoscale Photonics

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Photonic crystal structures can be built to operate in two opposite regimes: one is a suppression of photon states inside the photonic band gap, and the other is a large enhancement of the density of photon states. Both regimes are of consequence to a number of applications in nanoscale and nonlinear optics, as well as to photonic quantum information technologies. Our work on the employment of photonic crystals to build hardware of solid-state photonic quantum information systems, as well as to construct miniaturized optical devices will be reviewed in this talk. We have demonstrated sources of single photons on demand based on quantum dots in micropost microcavities that exhibit a large spontaneous emission rate enhancement (Purcell factor of five) together with a small multi-photon probability (2% compared to a Poisson-distributed source of the same intensity). We have also tested the indistinguishability of emitted single photons from such a source through a Hong-Ou-Mandel-type two-photon interference experiment, and found that consecutive photons exhibit a mean wave-packet overlap as large as 0.81, making this source useful in a variety of experiments in quantum optics and quantum information. The applications of such a device include secure quantum cryptography and linear optical quantum computation. We have also developed two-dimensional photonic crystal microcavities of finite depth with embedded quantum dots that exhibit large quality factors ($\sim$3000) together with small mode volumes ($\sim 0.5(\lambda/n)^3$) and with a maximum field intensity in the high-index region, which is of importance for enhanced interaction with quantum dot excitons. We have performed spectroscopy on a single quantum dot coupled to such a cavity, and demonstrated a very strong modification of its radiative properties, as well as a single-photon generation on demand. A strong interaction between a quantum dot exciton and the field enabled by such a microcavity is of importance for construction of single photon sources with improved efficiency, visibility, and speed, as well as for construction of entangled photon sources. Finally, we will also discuss some of our ongoing work on the integration of many photonic crystal components into functional circuits and devices, such as two-dimensional coupled arrays of photonic crystal microcavities for miniaturized lasers or sensors, or integration of photonic crystal cavities and waveguides for quantum networking.