Ordered Quantum-Wire and Quantum-Dot Systems for Nonophotonics

Eli Kapon

Laboratory of Physics of Nanostructures

Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Integration of semiconductor quantum wires (QWRs) and quantum dots (QDs) with nanophotonic structures is useful for studying basic light-matter interaction in the solid state, production of new states of light, transmission of quantum coherence across macroscopic distances, and implementation of novel mesoscopic photonic systems (e.g., few-QD lasers). However, the implementation of such systems presents significant challenges in terms of position and spectral alignment of the nm-sized constituents involved. Here, we review the investigation of site- and spectrum-controlled InGaA/GaAs QWRs and QDs grown by metallorganic vapor phase epitaxy, integrated within nanophotonic waveguides and cavities for studying QD-cavity interactions and nanolasers.

Site-controlled V-groove QWRs are useful for defining the active regions of nanolasers and matching them with the designed cavity modes. Such InGaAs/GaAs QWRs were employed in optically pumped photonic crystal (PhC) nanolasers [1], studies of PhC cavity coupling [2], elucidating the role of disorder in PhC waveguides [3], and demonstration of optical coupling in arrays comprising several PhC cavities [4]. The site-control and specific optical polarization features of these QWR light sources is particularly useful for unambiguous observation of delocalized optical fields in coupled systems in the presence of optical disorder.

Site-controlled InGaAs/GaAs pyramidal QDs grown on patterned (111)B GaAs substrates constitutes a unique QD system offering ~20nm positioning accuracy, reproducible excitonic spectra [5], small inhomogeneous broadening (few meV) [6], reasonably narrow exciton spectral linewidths (<100μeV), high symmetry yielding small fine-structure splitting [7], and compatibility with integration with PhC waveguides and cavities [8]. The absence of a "wetting layer" in these dots yields a system with atomic-like energy levels with weaker coupling to barrier states, reducing the effects of multi-excitonic recombination in the optical spectra. When confined in PhC cavities, the pyramidal QDs provide an attractive system for exploring cavity quantum electrodynamics in the solid state. Thus, coupling of cavity modes to QD excitons mediated by phonons over small (3-5meV) cavity-exciton detuning and free from far-off-resonance coupling has been observed [9]. More complex QD systems involving several pyramidal QDs with PhC cavities [10], as well as simultaneous Purcell effect in a two-QD system coupled to the same cavity mode, impact of dephasing on QD-cavity coupling, and coupling of QDs to delocalized modes of coupled PhC cavities will also be presented and discussed.

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