Novel concepts for deterministic quantum light sources and on-chip quantum optics

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The emerging field of quantum optics in semiconductor nanostructures has benefited enormously from the excellent optical properties of self-assembled quantum dots (QDs). Acting as high quality photon emitters, they have paved the way for single photon sources, and sources of entangled photon pairs [1]. Recently, they allowed for the observation of spin-photon entanglement and quantum teleportation which are key results for future quantum communication networks.

Despite these successes, there exist still a number of severe issues which, up till now, have hindered the integration of single QDs into practical devices. First of all, one needs to tailor the photonic environment of single QDs to enhance the photon extraction efficiency using, e.g., cavity quantum electrodynamics (cQED) effects in QD-microcavity systems. Such approaches put stringent requirements on the sample technology, and deterministic device technologies are required to align photonic nanostructures spatially and spectrally to target QDs. Moreover, regarding the coupling of single objects to larger nanophotonics networks, it will be crucial to establish efficient concepts for the on-chip integration and inter-chip coupling of QD based quantum devices.

In this work, we report on recent developments in the deterministic fabrication of single QD quantum devices and the on-chip and external coupling of cQED systems. The structures are based on self-assembled InGaAs QDs which are embedded into optically and electrically pumped devices. We will present an in-situ electron beam lithography approach which allows us to precisely pattern photononic nanostructures which are aligned to pre-selected QDs in order to boost their extraction efficiency in deterministic quantum light sources [2, 3]. Beyond the realization of single nanophotonics structures we will present a novel scheme for fully integrated on-chip quantum optics. Here, we use for the first time an integrated electrically driven QD-microlaser to resonantly excite a coupled QD-microcavity system operating in the weak coupling regime [4]. This concept pave the way for compact integrated sources of single photons and entangled photon pairs. Finally, we will give an outlook towards the external quantum control of nanophotonic systems which provides exciting opportunists to study non-linear dynamics in the quantum regime [5] and to stabilize cQED systems [6].

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