The Role of Phonons for the Optical Control of Excitons and Biexcitons in Semiconductor Quantum Dots

Tilmann Kuhn

Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Semiconductor quantum dots (QDs) are attractive candidates for a variety of new applications in fields such as quantum cryptography or quantum information processing, where the presence of discrete energy levels is mandatory. Examples of such applications are single-photon sources, sources of entangled photon pairs and qubit devices or quantum gates. The functionality of these applications relies on the preparation of a well-defined quantum state. Therefore, a precise optical control of excitonic and biexcitonic states in semiconductor QDs is a crucial step towards their usage in quantum information technology. Since QDs are embedded in a semiconductor matrix, their interaction with phonons often plays a major role in the preparation process.

In most QDs the fundamental excitons are of heavy hole type consisting of a hole with angular momentum ±3/2 and an electron with spin ±1/2. The excitons can then be divided in two classes, those with total angular momentum ±1, which correspond to dipole-allowed transitions and are therefore called *bright excitons*, and those with total angular momentum ±2, which are dipole-forbidden and therefore called *dark excitons*. The biexciton consisting of two electron-hole pairs has vanishing angular momentum and is dipole-coupled to the bright excitons.

For the four-level system consisting of ground state, bright excitons and biexciton different techniques have been employed to selectively prepare exciton or biexciton states [1]. The most direct way is to use a resonant laser pulse which, in the absence of phonons, for a suitable choice of the pulse area provides a complete inversion, i.e., a complete excitation of the exciton or biexciton. An alternative is the excitation by a chirped laser pulse which, due to the phenomenon of *adiabatic passage,* results in an excitation which is much less sensitive to pulse and material parameters. For both processes the exciton-phonon interaction limits the fidelity, which gives rise to restrictions in the range of pulse parameters and temperature. Using detuned pulses, a phonon-assisted exciton or biexciton generation can be employed, which relies on the exciton-phonon coupling and thus even works better for stronger coupling.

Dark excitons have the advantage of rather long lifetimes. However, they cannot directly be excited optically. It has recently been shown that the combination of a chirped laser pulse and a tilted magnetic field nevertheless allows for an efficient optical generation of dark excitons [2]. A suitably chosen in-plane component of the magnetic field weakly couples bright and dark exciton which, in combination with the adiabatic passage effect, gives rise to a population inversion between ground state and dark exciton. For low temperatures this mechanism turns out to be almost unaffected by phonons. On the other hand, also in the case of dark excitons a parameter regime can be found for which an efficient phonon-assisted dark exciton generation takes place.

[1] D. E. Reiter, T. Kuhn, M. Glässl, and V. M. Axt, J. Phys.: Cond. Mat. **26**, 423203 (2014).
[2] S. Lüker, T. Kuhn, and D. E. Reiter, Phys. Rev. B **92**, 201305(R) (2015).