Coherent control of electron spin dynamics in nano-engineered semiconductor structures

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Summary

The research presented in this thesis aimed at improving the understanding of, and abilities to control the evolution of spin ensembles in semiconductor device structures. Various fundamental aspects of spin ensemble evolution like dephasing, decoherence, relaxation, diffusion and drift are addressed. All experiments used GaAs or GaAs/AlGaAs-based semiconductor materials and devices that were engineered at the nanoscale for obtaining properties that are advantageous for controlling coherent spin dynamics. These GaAs-based systems provide interesting test systems since they combine the highest available material quality, a very advanced level of possibilities for device processing and engineering, and strong optical transitions across the semiconductor bandgap that obey clear selection rules with respect to optical polarization and spin. Progress with this research is relevant for realizing new spintronic- and quantum-information functionalities.

The work aimed at answering questions and realizing new proof-of-principle demonstrations in this field. The focus was on using the advantages of ultrafast optical pump-probe studies, which was a well-established technique at the start of this thesis work. Thus, the goal was to apply this for the first time to studies of the spin dynamics that is specific for devices structures, rather than studies on bulk materials, and several interesting results in this direction were obtained. However, in the course of this work, several experiments led to observations that pointed out that the fundamental understanding of the underlying physical mechanisms was –despite the large body of earlier work on bulk materials– in fact incomplete, or even to observations that were in conflict with the established descriptions. On these occasions the reported work aimed at characterizing and understanding these new observations.

The research gave results in three areas:

1) Suppressed spin dephasing for mobile electrons in wire structures

The research obtained results that showed that spin dephasing due to spin-orbit interactions for electrons in wires can be suppressed by engineering of the var-

ious spin-orbit interaction terms. This effect was predicted for wires made of two-dimensional electron systems, and we demonstrated this effect. An unexpected observation was that it also occurs for wires from materials with a three-dimensional electron system. The work included numerical simulations that show good agreement with the experimental observations, both for the wires with a two- and three-dimensional electron system.

2) Spin preparation and detection for localized electron spins

The second topic addressed in this thesis is related to obtaining fully quantum coherent behavior for the interaction between electron spins and optical preparation and detection pulses. This work used the spin state of a donor-bound electron, localized at a Si donor site in low-doped GaAs material. These were addressed as a homogeneous ensemble. The experiments demonstrated a new ultrafast method for spin preparation and spin detection with picosecond laser pulses. Notable, both for preparation and detection the method supports a complete mapping between the quantum states of optical polarization and the quantum state of the electron spins.

3) Fully time-resolved study of the Landé g factor in n-doped GaAs materials

The final part of this thesis presents a detailed study of the electron g factor in bulk GaAs. This study was initiated by observations of g factor values as negative as $g = -0.48$, while most of the established literature assumes $g \geqq -0.44$. Further studies revealed why the observed g factor values strongly depend on the experimental parameters that are used, and identified that the unconventional g factor values around $g = -0.48$ originate from low-energy electrons in GaAs samples where the donor states form a band.