Time-Resolved Studies of Pulsed Electrical Spin Injection into Single InGaAs Quantum Dots

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Spin light emitting diodes (spin-LEDs) are prominent for electrically injecting electronic spin states into semiconductor quantum dots (QDs) and are highly suitable for spin storage [1]. For an efficient quantum information processing with these QDs, the initialization of the electronic spin states has to be accomplished repeatably and reliably with short electrical pulses. Here, we report on an anomaly of the circular polarization degree (CPD) emitted by InGaAs QDs within a spin-LED with a ZnMnSe spin aligner, if the device is excited with pulses of some nanoseconds width.

For the detection of the emitted light, we employed a time-correlated single photon counting technique. Gold apertures located on top of the spin-LEDs were used for the detection of light from single quantum dots. On the left graph of Fig. 1, the CPD at different times of the pulse is shown for several wavelengths, corresponding to the emission from the QDs, the wetting layer (WL) and the GaAs, respectively. Surprisingly, for the confined states (WL, QDs) the CPD is considerably higher at the beginning of the pulse than at the end. This feature is not an ensemble effect, since a single quantum dot, like the ensemble, exhibits the same initially higher CPD (see the right graph of Fig. 1). Note that the CPD of this special single quantum dot amounts to 0.5 in the quasistatic equilibrium, but that other QDs can be initialized with a fidelity close to unity [2].

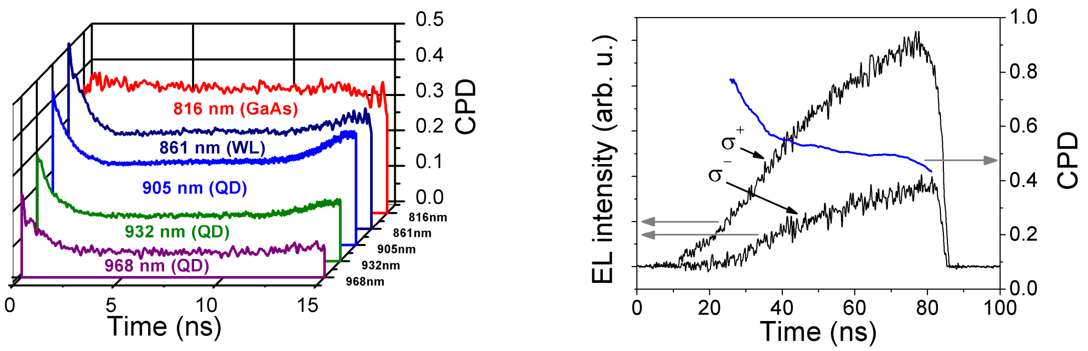

Fig. 1 *Left:* Time-resolved *CPD*, measured at $B = 6$ T and for different emission wavelengths of the same device, corresponding to the spectral range of GaAs, the wetting layer (WL), and the QDs, respectively. The CPD of the QDs refers to ensemble measurements. *Right:* Temporal evolution of the emission intensity for left and right circularly polarized light at $B = 6$ T from a single quantum dot, and the time-dependent CPD.

As shown in previous work, the CPD drops with increasing current through the spin-LED [3]. However, the current dependence of the polarization degree cannot fully account for the increased CPD. Hence, the reason for the change of the CPD must be related to spin scattering events. One factor we attribute these scattering events to is a potential barrier forming within the spin-LED, which the spin-polarized carriers have to pass by a (phonon-assisted) tunneling process [2,3]. When the carrier density at the beginning of the pulse is still low, spin-polarized electrons can easily tunnel into the empty QD states and retain their polarization. However, as dynamic equilibrium is reached, a certain fraction of the dots will always be filled by electrons. Therefore, tunnelling will only be possible when an empty target state becomes available, i.e., after injection of a hole into an occupied dot and subsequent optical recombination. The resulting retardation should give more opportunity for spin relaxation in the device.

References

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