

Ultrafast electric control of coherent quantum states

Alex Widhalm^{1,2}, Amlan Mukherjee^{1,2}, Sebastian Krehs¹, Timo Langer¹,
Peter Kölling², Andreas Thiede², Jens Förstner², Dirk Reuter¹, and Artur Zrenner¹

¹ Physics Department and Center for Optoelectronics and Photonics Paderborn (CeOPP),
Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

² Electrical Engineering Department, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Abstract

We report the manipulation of quantum states by ultrafast optoelectric control. Our work is based on a new protocol, which allows for the phase and amplitude control of single quantum bits by solely electric control [1,2]. We demonstrate experimental data for electrically controlled Ramsey interference and electrically chirped rapid adiabatic passage.

The control of single quantum systems is usually performed by pulsed laser fields. In addition, ultrafast electric fields allow for new protocols and new routes towards scalable quantum technologies. The application of such coherent optoelectronics requires the synchronous action of ps optics and electronics. Furthermore, electrically tunable Quantum systems have to be designed, which are compatible with ps-electronics.

In our work we have developed low capacitance photodiodes with a total capacitance in the range of 100 fF. The quantum system, which is represented by an InGaAs quantum dot, is embedded in an intrinsic GaAs region between an n+ and a semitransparent metal contact. Thus, the excitonic ground state energy can be controlled by the quantum-confined Stark-effect, the occupancy of the qubit can be checked in an extremely sensitive way by photocurrent measurement, even in the regime of single photon emission. Such optoelectronic devices allow also for new routes for the frequency stabilization of single photon emitters.

For the coherent electric control of InGaAs quantum dots we have developed ultrafast SiGe-BiCMOS chips, which are designed for low temperature operation. With this technology electric pulses with rise times below 20 ps become available for the transient laser-synchronous Stark tuning of quantum dots.

Performing Ramsey experiments [3] we have been able to demonstrate the electric phase control of a quantum dot exciton on sub-100 ps timescales [2]. Based on this we propose a protocol, which allows full control of the exciton Bloch vector by solely electric control.

In the past, the robust inversion of quantum dots has been demonstrated by applying chirped ps laser pulses, which drive a rapid adiabatic passage [4, 5]. An ultrafast electric transient results in a transient Stark shift and hence in a chirp of the ground state transition. Realizing such conditions, we have been able to drive a rapid adiabatic passage using electric chirp but un-chirped laser pulses. A comparison to Rabi oscillations observed for increasing pulse areas shows that the electrically chirped rapid adiabatic passage leads to full inversion.

- [1] S. Michaelis de Vasconcellos, S. Gordon, M. Bichler, T. Meier and A. Zrenner, *Coherent control of a single exciton qubit by optoelectronic manipulation*, Nature Photonics **4**, 545 (2010).
- [2] A. Widhalm, A. Mukherjee, S. Krehs, N. Sharma, P. Kölling, A. Thiede, D. Reuter, J. Förstner, and A. Zrenner, *Ultrafast electric phase control of a single exciton qubit*, APL **112**, 111105 (2018).
- [3] S. Stuffer, P. Ester, A. Zrenner, M. Bichler, *Ramsey Fringes in an Electric-Field-Tunable Quantum Dot System*, Phys. Rev. Lett. **96**, 037402 (2006).
- [4] Y. Wu, I. M. Piper, M. Ediger, P. Brereton, E. R. Schmidgall, P. R. Eastham, M. Hugues, M. Hopkinson, and R. T. Phillips, *Population Inversion in a Single InGaAs Quantum Dot Using the Method of Adiabatic Rapid Passage*, Phys. Rev. Lett. **106**, 067401 (2011).
- [5] C. M. Simon, T. Belhadj, B. Chatel, T. Amand, P. Renucci, A. Lemaitre, O. Krebs, P. A. Dalgarno, R. J. Warburton, X. Marie, and B. Urbaszek, *Robust Quantum Dot Exciton Generation via Adiabatic Passage with Frequency-Swept Optical Pulses*, Phys. Rev. Lett. **106**, 166801 (2011).