TT 14: Focus Session: Graphene Quantum Dots (joint session HL/TT)

Quantum dots have emerged as one of the contenders for a future quantum information processor. Bilayer graphene is now established as a material that allows high quality bi-polar Coulomb blockade measurement, time-dependent transport measurements and first relaxation time measurements. In contrast to the more conventional GaAs and Si-based systems, several exiting and unexpected observations in graphene have been explained by the peculiar graphene bandstructure, which is gate- tunable, the additional valley degree of freedom, and spin-valley coupling.

Organized by Klaus Ensslin

Time: Monday 15:00–17:45 Location: POT 361

Invited Talk TT 14.1 Mon 15:00 POT 361
Spin and valley lifetime in graphene quantum dots — •Guido Burkard — University of Konstanz, Germany

Graphene with its low nuclear spin density and weak spin-orbit coupling allows for long electron spin relaxation and coherence times. The spin and valley degrees of freedom of localized electrons can therefore be seen as potential embodiments of classical or quantum bits for computation. However, the formation of localized states in quantum dots requires some form of badgap engineering, and the mechanisms for spin and valley relaxation have not been completely understood so far. Bilayer graphene has an electrically controllable bandgap that allows for the formation of quantum dots. We present general theoretical considerations regarding the formation of quantum dots in graphene and report on recent progress in understanding the relevant physical mechanisms of spin and valley relaxation in electrostatically gated bilayer graphene quantum dots.

Invited Talk TT 14.2 Mon 15:30 POT 361
Microscopic modelling of electrostatically induced bilayer graphene quantum dots — •Angelika Knothe — Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany

Quantum nanostructures, e.g., quantum wires and quantum dots, are needed for applications in quantum information processing devices, such as transistors or qubits. In gapped bilayer graphene, one can confine charge carriers purely electrostatically, inducing smooth confinement potentials and thereby limiting edge-induced perturbances while allowing gate-defined control of the confined structure. In this talk, I will give an overview of our recent contributions toward the theoretical modelling of gate-defined bilayer graphene quantum dots, taking into account microscopic details of the material properties and the confinement. As an outlook, I will point towards current and future challenges in describing coupled bilayer graphene nanostructures, e.g., setups with multiple bilayer graphene quantum dots.

TT 14.3 Mon 16:00 POT 361
Valley relaxation in a single-electron bilayer graphene quantum dot — •Lin Wang and Guido Burkard — Department of Physics, University of Konstanz, D-78457, Germany

Bernal-stacked bilayer graphene (BLG) has a tunable gap controlled by an out-of-plane electric field. This makes BLG a possible candidate to form quantum dots (QDs) via quantum confinement. Spin-based qubits in BLG QDs have received great attention due to outstanding spin-coherence properties. Very recently, long spin relaxation times of a single-electron state in BLG QDs was reported [1,2]. In addition to spin, valley pseudospin is another degree of freedom in BLG. The two valleys experience opposite Berry curvatures and associated magnetic moments via an out-of-plane electric field. This provides a promising way to control valleys and further establish valley qubits. To assess the potential of valley qubits, the valley relaxation time is a crucial parameter since it directly limits the lifetime of encoded information. Here, we investigate the valley relaxation in a single-electron BLG QD due to intervalley coupling assisted by (i) 1/f charge noise and (ii) electron-phonon couplings arising from the deformation potential and bond-length change. Our calculation shows that valley relaxation time decreases with a power law dependence as a function of magnetic field, which is in a good agreement with very recent experiment.

References: [1]L. Banszerus, K. Hecker, S. Möller, E. Icking, K. Watanabe, T. Taniguchi, C. Volk and C. Stampfer, Nat. Commun. 13, 3637 (2022). [2] Lisa Maria Gächter et al., PRX Quantum 3, 020343 (2022).

30 min. break

Invited Talk TT 14.4 Mon 16:45 POT 361
Single-shot spin and valley Pauli blockade read-out in bilayer graphene quantum dots — •Chuyao Tong[1], Rebekka Garreis[1], Wister Wei Huang[1], Annika Kurzmann[1,2], Jocelyn Terle[1], Samuel Jele[1], Kenji Watanabe[3], Takashi Taniguchi[3], Thomas Ihn[1], and Klaus Ensslin[1] — [1]ETH Zurich, CH-8093 Zurich, Switzerland — [2]RWTH Aachen University, Aachen, 52074, Germany — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

In bilayer graphene quantum dots, apart from spins up and down, the additional valley degree of freedom K- and K+ gives rise to an unconventional single-dot two-carrier ground state: spin-triplet valley-singlet, altering the canonical even-odd double dot Pauli spin blockade picture. This ground state can be switched to a spin-singlet valley-triplet by a perpendicular magnetic field, allowing us to switch between valley-blockade at low, and spin-blockade at higher magnetic field for the two-carrier Pauli blockade (1,1) to (0,2). We employ charge sensing technology and perform single-shot Pauli blockade read-out at the two field regimes, probing characteristic relaxation times T1 between spin or valley -triplet and -singlet. The spin-T1 is measured to be up to 60ms, drastically decreasing with increasing inter-dot tunnel coupling and corroborating with recent experiments performed with single-dot Elzerman read-out. Moreover, we observe exceedingly long valley T1 longer than 500ms, robust with inter-dot tunnel coupling. These promisingly long spin- and valley T1 herald for long-living spin and valley bilayer graphene quantum dot qubits.

Invited Talk TT 14.5 Mon 17:15 POT 361
Particle-hole symmetry protects spin-valley blockade in graphene quantum dots — •Christian Volk[1,2], Luca Banszerus[1,2], Samuel Möller[1,2], Katrin Hecker[1,2], Eike Icking[1,2], Kenji Watanabe[3], Takashi Taniguchi[4], Fabian Hassler[5], and Christoph Stampfer[1,2] — [1]JARA-FIT and 2nd Institute of Physics, RWTH Aachen University — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich — [3]Research Center for Functional Materials, NIMS, Tsukuba, Japan — [4]International Center for Materials Nanoarchitectonics, NIMS, Tsukuba, Japan — [5]JARA-Institute for Quantum Information, RWTH Aachen University

Particle-hole symmetry plays an important role for the characterization of topological phases in solid-state systems. Graphene is a prime example of a gapless particle-hole symmetric system. The intrinsic Kane-Mele spin-orbit coupling in graphene leads to a lifting of the spin-valley degeneracy and renders graphene a topological insulator in a quantum spin-Hall phase while preserving particle-hole symmetry.

Here, we show that the Kane-Mele spin-orbit gap leads to a lifting of the spin-valley degeneracy in bilayer graphene quantum dots, resulting in Kramer's doublets with different ordering for electron and hole states preserving particle-hole symmetry. We observe the creation of single electron-hole pairs with opposite quantum numbers and use the electron-hole symmetry to achieve a protected spin-valley blockade in electron-hole double quantum dots. The latter will allow spin-to-charge and valley-to-charge conversion, which is essential for the operation of spin and valley qubits.