Aachen Graphene & 2D Materials Center

2D Materials and Quantum Device Group

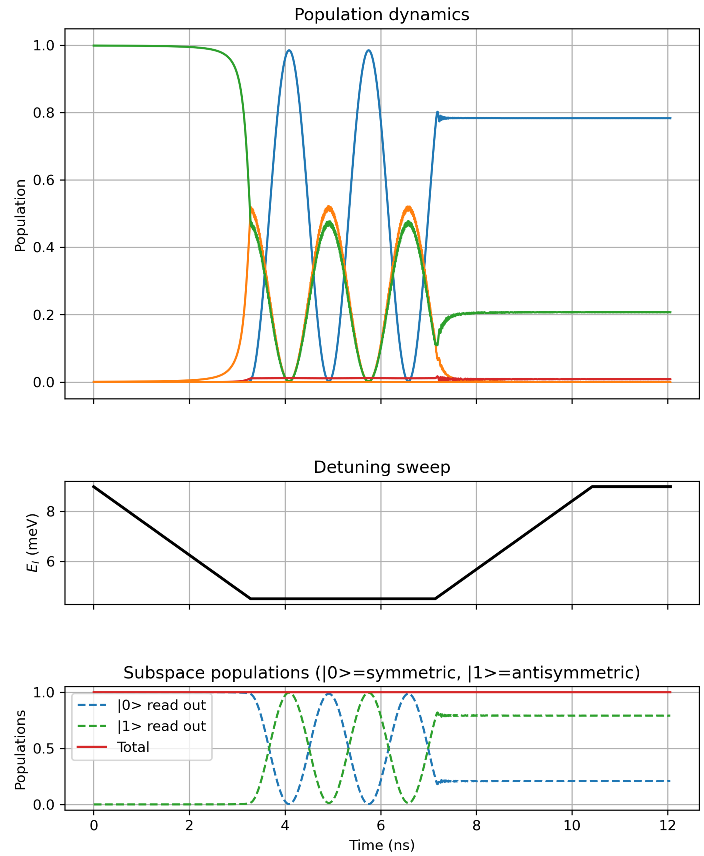
RWTH AACHEN UNIVERSITY

Bachelor Thesis: Modelling graphene-based quantum dot systems

Motivation: A detailed understanding of the energy spectrum and device behaviour in gate-defined graphene quantum dots is essential for both interpreting measurements and identifying regimes suited for qubit operations. In bilayer graphene-based devices, this task becomes challenging because several internal degrees of freedom, valley, spin, and orbital states can be relevant at comparable energy scales. In addition, common simplifying concepts from conventional semiconductor quantum dots do not always carry over directly. For instance, the effective-mass description becomes insufficient as the band structure is strongly non-parabolic, anisotropic, and field-tunable. This complicates both intuitive reasoning and quantitative extraction of parameters from measured spectra.

To make progress, simplified models are needed: models that reduce complexity while retaining the key ingredients required to explain observed features, predict trends, and guide experimental device tuning. Such models can be used to simulate relevant quantum-dot regimes, interpret measured state spectra, and systematically explore parameter space to identify operating points. Ultimately, this approach enables informed choices for the next experimental directions and accelerates the search for optimal regimes for controlled quantum-state operation.

Aim of the thesis: The aim of this thesis is to develop and apply simplified modelling and simulation approaches for bilayer graphene quantum dot systems in order to interpret measured spectra and identify operating regimes relevant for quantum control. The overarching objective is to extract design principles and working points that support progress toward planning qubit experiments.



Simulation results for the relevant low-energy states during a detuning sweep in a BLG double quantum dot, showing oscillations in the state populations. The bottom panel shows the same behavior after projection onto the computational basis, highlighting oscillations that could be resolved experimentally.

Your tasks: You will contribute to the development and implementation of numerical models that capture the essential physics of graphene-based gate-defined quantum dots, for example, the interplay of spin, valley, and orbital degrees of freedom or the limitations of simple effective-mass descriptions. Building on these tools, you will simulate experimentally relevant regimes, connect model predictions to characteristic measurement signatures, and use the results to guide further experimental planning.

You will gain experience in the following topics:

- Quantum physics, van der Waals materials, electronic transport
- Construction and selection of physical models
- Numerical simulations

Furthermore, you participate in group seminars and journal clubs where you follow current developments in this field of research and discuss recent experiments.

Contact: For further information, please contact Lars Mester (lars.mester1@rwth-aachen.de) or Hubert Dulisch (hubert.dulisch@rwth-aachen.de). More information about our work can be found at stampferlab.org and www.graphene.ac.