Form 3

Abstract of Thesis

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Title	Quantum Dots in Strained Two-Dimensional Systems: Twisted Bilayer Graphene and Ge Two-Dimensional Hole Gases (歪み2次元系における量子ドット：ツイスト二層グラフェンとゲルマニウム2次元正孔ガス)

Quantum dots are tiny structures that can confine individual charge carriers and exhibit quantum phenomena, making them promising building blocks for future quantum technologies. This thesis investigates two different approaches to creating quantum-dot systems: twisted bilayer graphene (TBG) and germanium-based semiconductor devices. In TBG, we examine whether the intrinsic moiré structure can produce naturally confined QD-like states, while in Ge/SiGe we develop conventional gate-defined QD devices.

For the TBG system, exploring natural individual AA-stacked regions requires very small twist angles, where the moiré pattern becomes large enough for nanofabrication to access these regions. This makes precise identification and selection of the local twist angle essential. A fabrication method was therefore developed in which TBG heterostructures were first prepared in an open geometry, allowing the moiré pattern and local twist-angle distribution to be measured by conductive atomic force microscopy. Regions with the desired twist angles were then selected, patterned into devices, and encapsulated with top hexagonal boron nitride. Devices fabricated near the first magic angle exhibited characteristic correlated insulating and superconducting behavior, confirming that this approach can produce high-quality TBG devices with locally selected twist angles.

Based on this technique, we fabricated tiny-angle TBG devices with twist angles below 0.1°, where the enlarged moiré period enables individual or small numbers of AA-stacking dots to be isolated by nanofabrication. The observed transport behavior depended strongly on the connection between the moiré structure and the reservoirs. When AA regions were directly connected through AB/BA domain walls, the application of a perpendicular displacement field suppressed transport through the Bernal-stacked bulk regions and guided current along the domain-wall channels. Robust finite conductance, preferred zigzag propagation, and quantum-interference effects, including Fabry–Pérot and Aharonov–Bohm resonances, were observed. However, clear Coulomb-blockade behavior was absent, indicating that AA regions connected by conducting domain walls may not serve as isolated QDs.

When the domain walls were not directly connected to the reservoirs, pronounced QD-like behavior emerged. Coulomb resonances and Coulomb diamonds were observed, together with strongly anisotropic magnetic-field responses. Effective g-factors of approximately 2 and 41 were extracted for in-plane and out-of-plane magnetic fields, respectively. The in-plane response is consistent with the spin magnetic moment, whereas the large out-of-plane response is attributed to valley-orbital magnetic moments. The strong dependence on device configuration suggests that these localized states originate mainly from disorder, edge roughness, or non-uniform electrostatic potentials in the gapped Bernal-stacked regions, rather than from isolated AA regions alone.

To establish a more controllable QD platform, gate-defined devices were also fabricated in Ge/SiGe heterostructures. These devices exhibited Coulomb oscillations, Coulomb diamonds, and coupled double-QD charge-stability diagrams under a precise control. Charge-noise measurements further demonstrated the quality of the fabricated structures. This work establishes a foundation for future Ge-based experiments, including coherent charge shuttling and spin–photon conversion.

Overall, this thesis clarifies the possibilities and limitations of quantum confinement in moiré graphene and semiconductor heterostructures. Ge provides a well-controlled platform for forming quantum dots. In twisted bilayer graphene, no strong evidence was found that the moiré structure itself forms quantum dots, while coherent transport through the reconstructed moiré network was clearly observed. Together, these studies provide experimental insight and device platforms for future quantum-electronic research.