High-precision quantum resistance metrology based on epitaxial graphene and all-graphene-based multi-parameter quantum metrology devices

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In recent years, the quality of epitaxial graphene on silicon carbide has been continuously improved. Coupled with its compatibility with semiconductor processes, it exhibits great potential for the development of functional devices and monolithic integration applications. On the other hand, its distinctive interface pinning effect provides significant advantages for quantum resistance metrology under relaxed experimental conditions.

Traditional quantum resistance metrology generally employs n-type doped epitaxial graphene, yet the understanding of how doping type affects quantum metrology performance remains insufficient. We systematically compared the quantum Hall effect behaviors of epitaxial graphene with different doping types and concentrations, and analyzed the influence of scattering mechanisms on the robustness of the quantum Hall effect via quantum interference effects. This work provides an important reference for the design of quantum resistance metrology devices [1]. Based on relevant experience, we fabricated high-quality quantum resistance metrology devices using epitaxial graphene. Through comparison with the national primary standard, it is confirmed that a relative standard uncertainty of resistance value at the 10^{-9} level can be achieved under relatively relaxed experimental conditions (4.4 K, 5.8 T).

In addition, graphene shows the potential for the simultaneous quantum realization of the three basic electrical units: volt, ohm, and ampere. Drawing on our experience in constructing complex graphene functional devices [2], we designed multi-electrical-parameter quantum metrology devices [3]: we achieved quantum voltage output at liquid helium temperatures in graphene-based Josephson junctions through in situ modulation of the superconducting dissipation mechanism; we fabricated high-quality graphene double quantum dot devices, enabling quantum current output at pumping frequencies exceeding 1 GHz; and we developed quantum resistance devices based on graphene heterostructures that operate at extremely low magnetic fields. These advances lay the foundation for realizing an electrical quantum metrology multimeter based on a unified material system in the future.

References:
[1] Xinyi Wan, **Xiaodong Fan*** et al. Chin. Phys. Lett. 40 (2023) 107201.
[2] Shuai Wang, Zhen Zhan, **Xiaodong Fan*** et al., Phys. Rev. Lett. 133 (2024) 066302.
[3] In preparation.

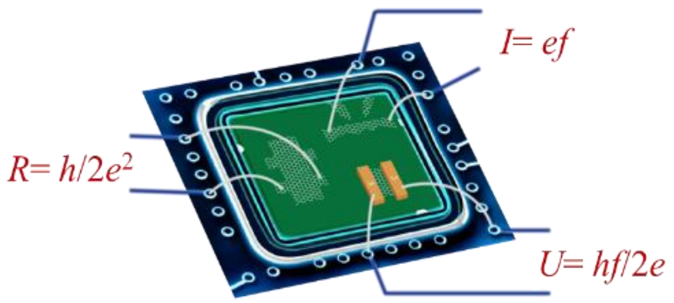

Fig. 1: Schematic of all-graphene-based multi-electrical-parameter quantum metrology devices.