Towards Quantum Spintronics with Graphene-based Magnetic Heterostructures

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Graphene-based van der Waals heterostructures offer a new platform for spintronic devices with exceptional functionalities. Through proximity effects, graphene's superior spin and charge transport properties are enriched by induced spin-orbit coupling (SOC) [1,2] and magnetic exchange interactions [3-5]. We experimentally demonstrate that these proximity effects give rise to various spin-related phenomena, enabling graphene to play an active role in the electrical and thermal generation of spin currents [3,4]. Furthermore, we show that the induced SOC and staggered potentials in graphene open a topological gap in its band structure, leading to the quantum spin Hall effect. We observe topologically protected spin-polarized edge states at zero magnetic field in magnetic graphene heterostructures [5], evidenced by a quantized conductance of $2e^2/h$, as shown in Figure 1. These observations pave the way for developing two-dimensional quantum spintronic circuitry based on graphene.

[1] Ghiasi, TS, et al. *Nano Letters* 17, 7528 (2017)
[2] Ghiasi, TS, et al. *Nano Letters* 19, 5959 (2019)
[3] Ghiasi, TS, et al. *Nature Nanotechnology* 16, 788 (2021)
[4] Kaverzin, AA, et al. *2D Materials* 9, 045003 (2022)
[5] Ghiasi, TS, et al. arXiv:2312.07515 (2024)

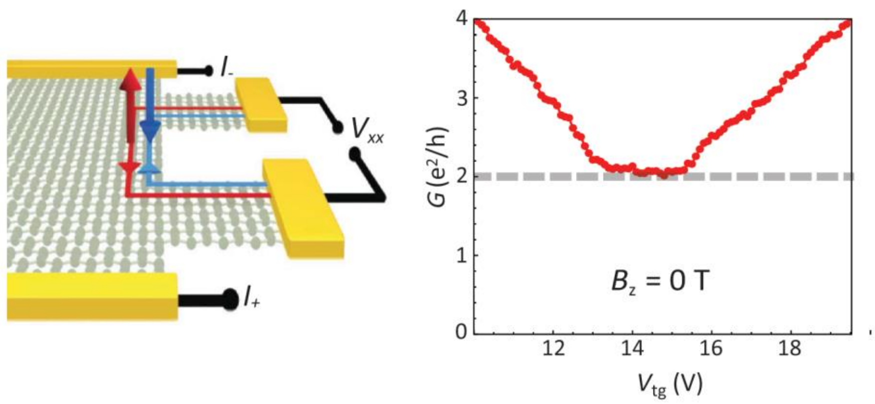

Figure 1: Observation of quantized conduction of $G = I/V_{xx} = 2e^2/h$ at B = 0 T, providing evidence for the emergence of the QSH effect in graphene-$CrPS_4$.