Spin-Orbit Torque without Heavy Metals: A Graphene-2D Magnet Platform

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Abstract

Spin-orbit torques (SOTs) have emerged as a central mechanism for controlling magnetization in non-volatile spintronic devices. While conventional SOT-MRAM relies on heavy metals to generate spin currents, achieving efficient and tunable torques at reduced energy cost requires exploring alternative platforms. Two-dimensional (2D) materials and their van der Waals heterostructures provide such opportunities, not only because of their high mobility and long spin coherence, but also due to their ability to host proximity-induced spin-orbit and magnetic effects. Using fully relativistic density functional theory combined with non-equilibrium Green's function transport approach, we propose proximity-engineered graphene as an all-2D platform for spin-orbit torque generation. We show that when graphene is coupled to suitable 2D magnetic or spin-orbit-active materials, such as monolayer CrSBr or magnetic charge-density-wave 1T-TaS_2, proximity-induced exchange and spin-orbit interactions render graphene an active torque-generating layer. We demonstrate that a charge current flowing through graphene produces a nonequilibrium spin density within the Dirac states themselves, giving rise to a self-induced spin-orbit torque without any heavy-metal spin source. These results establish graphene-2D magnet heterostructures as a minimal and versatile platform for electrically driven spin-orbit torque, opening a pathway toward compact and energy-efficient spintronic devices without heavy metals.

References

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Figures

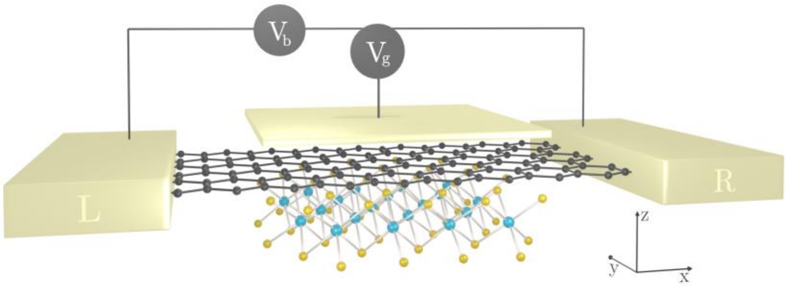

Figure 1: A Schematic view of the device composed of a central region made of a graphene/2D Magnet heterostructure attached to the left (L) and right (R) leads.