Spin dynamics, dephasing, and relaxation in clean and disordered graphene

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Abstract

Early on, graphene was expected to be an ideal material for spintronics applications, owing to its small spin-orbit coupling [1,2] and the subsequent prediction of long spin lifetimes [3,4]. Spin lifetime is an essential quantity that fixes the upper time and length scales on which spin devices can operate, so that knowing its value and variability is a prerequisite to realizing graphene spintronic technologies [5]. However, experimental measurements reveal spin lifetimes that are orders of magnitude lower than the original predictions [6,7]. A variety of extrinsic mechanisms have been proposed to explain this discrepancy, including enhanced SOC due to chemical adsorbates [8,9], or the presence of magnetic impurities [10]. Nevertheless, the exact nature of spin relaxation in graphene is still not entirely clear, and a deeper understanding of the spin relaxation mechanisms is needed.

In this work we use numerical simulations to examine the role of the substrate in determining the spin lifetime in graphene in the presence of Rashba SOC [11]. We consider both SiO_2 and hBN substrates, and find that the spin relaxation mechanism is dictated by the substrate-induced electron-hole puddles. For the case of SiO_2 we find that the spin lifetime follows a traditional Dyakonov-Perel behavior, while for hBN substrates the behavior is reminiscent of the Elliot-Yafet mechanism. This transition in behavior is determined by the ratio of the charge scattering time and the spin precession time induced by the Rashba SOC, and appears to echo recent experimental measurements [12].

Finally, we also consider the spin dynamics of graphene in the ultraclean limit [13]. Here the decay of the spin signal is driven by pure dephasing that arises from a combination of nonuniform spin precession and energy broadening. We show that reasonable values of Rashba SOC and energy broadening can lead to fast dephasing times, on the order of nanoseconds. This sets a fundamental upper limit on the spin lifetimes in ballistic graphene, indicating the need for careful control of the SOC and the energy broadening in this regime.

References

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