Graphene Spintronics

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Graphene is an attractive material for spintronics due to the low intrinsic spin-orbit coupling, low hyperfine coupling, and high electronic mobility. These should lead to long spin lifetimes and long spin diffusion lengths. Experimentally, the gate-tunable spin transport at room temperature has been achieved with spin diffusion lengths of ~2 microns. This makes it a very unique and promising material for spin transport. However, the spin injection efficiency has been low and the spin lifetime is still much shorter than expected theoretically. Overcoming these challenges will make graphene a very strong material for spintronics.

In this talk, I will present three of our recent results in graphene spintronics.

(1) **Tunneling spin injection into graphene [1].** We utilized TiO_2-assisted deposition of MgO tunnel barriers in order to reduce pinholes, which easily form for thin films on graphene. The use of tunnel barriers enhances the spin injection efficiency by alleviating the conductivity mismatch between the ferromagnetic metal (Co) and the single layer graphene (SLG). The non-local spin signal is found to be as high as 130 ohms at room temperature, with a spin injection efficiency of 30%. This is the highest spin injection efficiency observed in graphene spin valves.

(2) **Long spin lifetimes in graphene [2].** In addition to enhancing the spin injection efficiency, we find that the measured spin lifetime is also enhanced by the tunnel barriers. This indicates that the reported values of spin lifetime are shorter than the actual spin lifetime in graphene due to the invasive nature of the ferromagnetic contacts. Using the tunneling contact to suppress the contact-induced spin relaxation, we investigate the gate and temperature dependence of SLG and bilayer graphene (BLG) spin valves. We find spin lifetimes as high at 771 ps at 300 K in SLG, 1.0 ns at 4 K in SLG, and 6.2 ns at 20 K in BLG (see figure). These are the longest spin lifetimes observed in SLG, and the 6.2 ns is longest spin lifetime observed in a graphene spin valve so far.

(3) **Modification of spin transport properties by surface doping [3].** Because graphene is extremely surface sensitive, there are opportunities to manipulate the spin transport properties by modifying the surface with various dopants. In the initial study, we investigated the effect of gold doping on spin transport and spin lifetime. We find that the spin transport properties such as nonlocal signal and spin lifetime can be enhanced, despite the presence of additional charged-impurity scattering. Mainly, the presence of the gold impurities does not produce a degradation of spin transport, despite greatly reducing the electronic mobility.

These advances are important for the development of spin-based computing with integrated logic and memory.

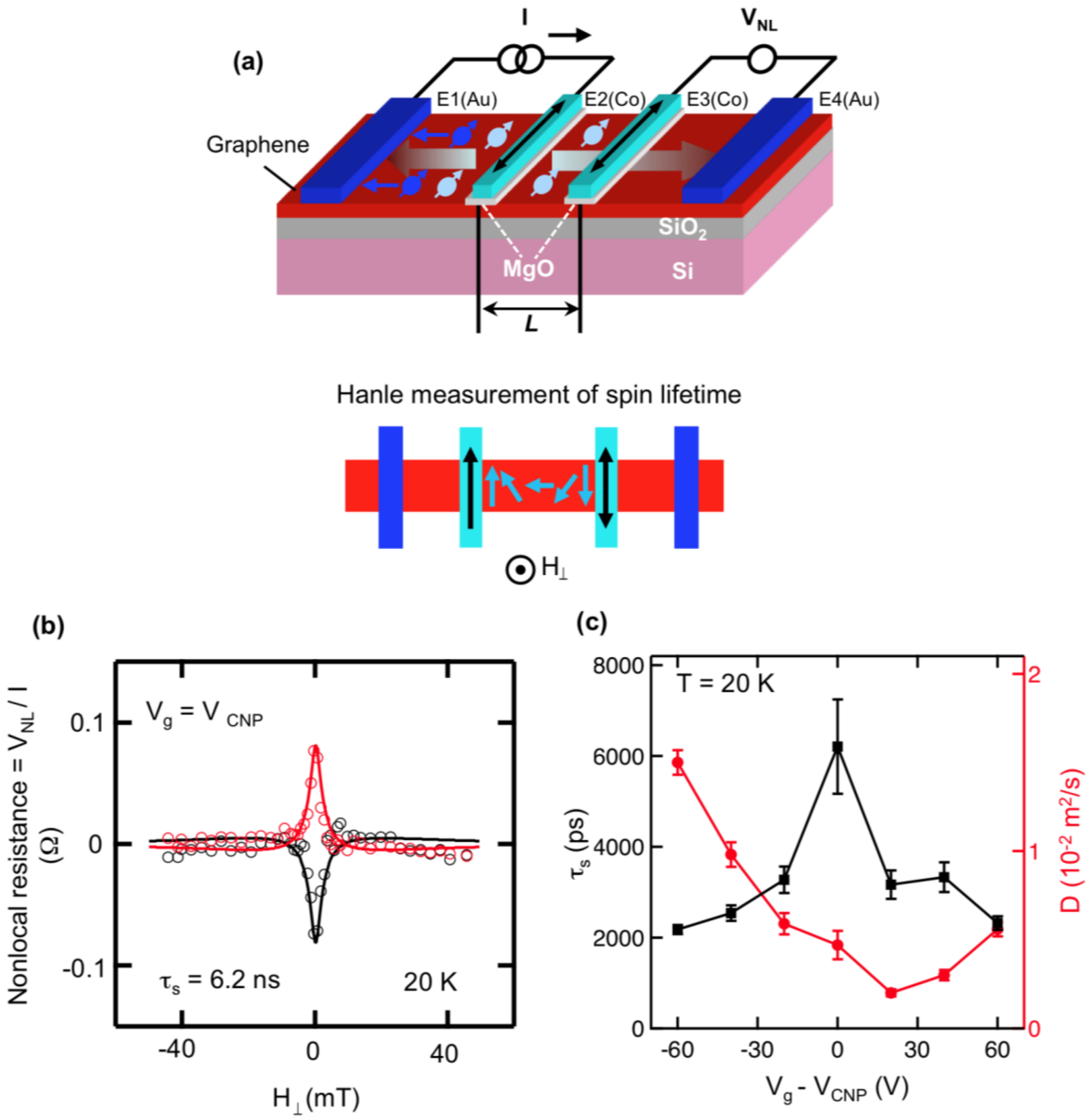
References

[1] Wei Han, K. Pi, K. M. McCreary, Yan Li, Jared J. I. Wong, A. G. Swartz, and R. K. Kawakami, Physical Review Letters, **105** (2010) 167202.

[2] Wei Han and R. K. Kawakami, arXiv:1012.3435 (2010).

[3] K. Pi, Wei Han, K. M. McCreary, A. G. Swartz, Yan Li, and R. K. Kawakami, Physical Review Letters, **104** (2010) 187201.

Figures



Long spin lifetimes in graphene. *(a) Schematic drawing of a graphene spin valve in the nonlocal measurement geometry. A current source (I) is utilized to inject spin-polarized carriers into the graphene at electrode E2. The spins subsequently diffuse to electrode E3 where they are detected as a voltage* V_{NL} *measured across electrodes E3 and E4. The spin injection and transport is measured as the nonlocal resistance (*$R_{NL} = V_{N}L/I$*). Hanle spin precession measurements are performed to determine the spin lifetime. An out-of-plane magnetic field is applied to induce spin precession. (b) Hanle measurement of a bilayer graphene spin valve with L = 3.05 microns, gate voltage (*V_g*) tuned to the charge neutrality point (CNP), and T = 20 K. The red (black) data is for parallel (antiparallel) alignment of the the Co magnetizations. The narrow Hanle peak corresponds to a spin lifetime of 6.2 ns. (c) Gate dependence of spin lifetime (black) and diffusion coefficient (red) in bilayer graphene at 20 K. Their opposite behaviors indicate the relevance of Dyakonov-Perel spin scattering.*