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# Graphene Magnetic Tunnel Junctions

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In contrast to the well studied in-plane charge and spin transport properties of graphene, its out-of-plane transport behavior is less well understood. Unlike in-plane transport, out-of-plane transport cannot rely on a network of conjugated pi bonds to carry charge and spin. Interlayer interaction in graphite is known to be very weak, as evidenced by its van der Walls bonds. Further, graphite exhibits a large conductance anisotropy with much lower out-of-plane conductance, indicating that fewer mechanisms exist for c-axis transport. Recently, multiple theoretical studies have predicted a high degree of spin filtering in out-of-plane ferromagnet-graphene-ferromagnet junctions[1,2] due to graphene's peculiar density of states at the Fermi level and the spin-resolved band structure of close-packed ferromagnetic metal surfaces. Such a spin filter would have obvious applications in generating spin-polarized currents in spintronics.

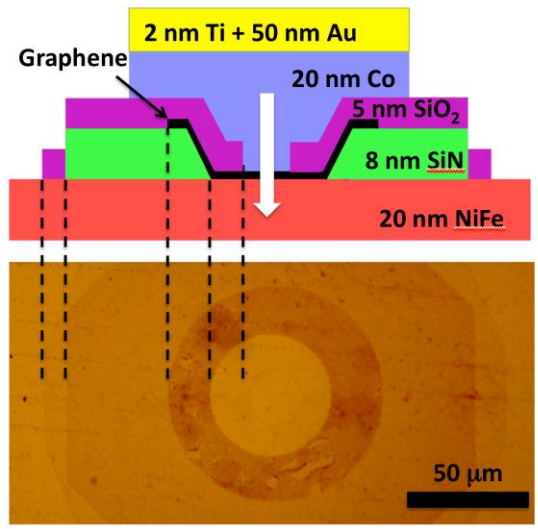


**Figure 1. Cross-section diagram and optical micrograph of a graphene magnetic tunnel junction prior to top contact deposition.**

We have fabricated and studied arrays of four-terminal NiFe-graphene-Cobalt junctions where the top and bottom magnetic layers can be switched independently. Large-grain CVD-grown single layer graphene was transferred onto prefabricated polycrystalline Permalloy bottom electrodes and the junction was capped with a Cobalt top layer (Figure 1). Care was taken to avoid the highly conductive edge states of the graphene mesa and to rule out conventional magnetoresistance effects like anisotropic magnetoresistance.

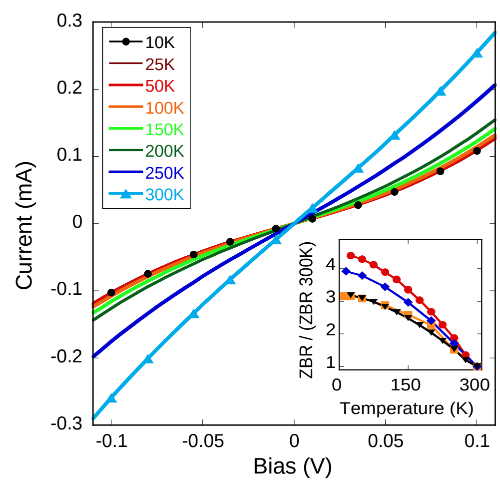


**Figure 2. Charge transport characteristics of a graphene MTJ at temperatures from 50K to 300K. Inset: Zero-bias junction resistance as a function of temperature for four different graphene MTJs showing a weak temperature dependence.**

Non-linear, largely temperature-independent charge transport is observed only in the graphene-containing junctions, indicating tunneling is the dominant mechanism for charge transport (Figure 2) while control junctions without graphene exhibited Ohmic behavior.

The top and bottom ferromagnetic layers are switched by an applied external magnetic field, resulting in two distinct junction resistance states characteristic of a magnetic tunnel junction (MTJ).

We study this junction magnetoresistance as a function of applied bias and temperature. Asymmetric behavior consistent with tunneling magnetoresistance (TMR) is observed in the bias dependence. The temperature dependence is well described by TMR models incorporating temperature-dependent spin-wave excitation in the metal electrodes. The TMR reaches two percent at a temperature of 4K and remains clearly observable even above room temperature.[3,4]

Further progress in producing wafer-scale arrays of in-situ graphene spin filters with multiple graphene layers will be discussed. The results shown have clear implications for the field of spintronics, including magnetic random access memory (MRAM) and reconfigurable spin logic as well as magnetic field sensors.

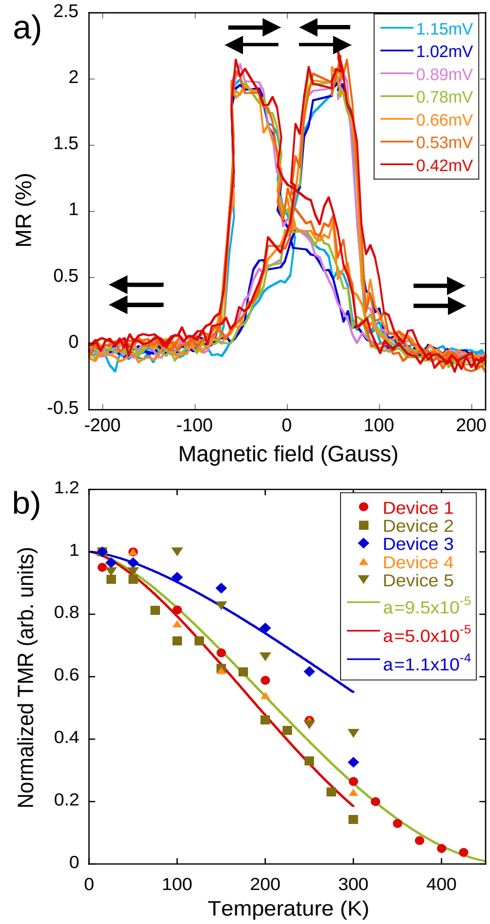


**Figure 3. Magnetoresistance switching behavior of a graphene tunnel junction at 4K (a) and plot of the normalized peak TMR for various junctions as a function of temperature, compared with an adapted model of temperature-dependent TMR (b).**

## References


[1] V. M. Karpan, P. A. Khomyakov, A. A. Starikov, G. Giovannetti, M. Zwierzycki, M. Talanana et al., *Phys. Rev. B*, **78,** 195419, 2008.

[2] Oleg V. Yazyev and Alfredo Pasquarello, *Phys. Rev. B*, **80**, 035408, 2009.

[3] Enrique Cobas, Adam L. Friedman, Olaf M. J. van 't Erve, Jeremy T. Robinson and Berend T. Jonker, *Nano Letters* **12,** 3000-3004, 2012.

[4] Enrique Cobas, Adam L. Friedman, Olaf M. J. van't Erve, Jeremy T. Robinson and Berend T. Jonker, *IEEE Trans. on Magnetics* **49**(7), 4343-4346, 2013.