The Mag-FET: Concept & Proof-of-Principle

Jonathan P. Bird, Department of Electrical Engineering, University at Buffalo

The use of magnetic microstructures to represent, and store, physical information has recently attracted enormous interest, and has been driven by the discovery of phenomena such as giant- and tunneling-magneto-resistance. Memory technologies based on these phenomena have the potential to revolutionize the principles of data storage, since they offer the advantages of reduced energy dissipation, increased switching speeds, and higher storage density, compared to conventional RAM approaches. Nanomagnets have even been proposed as the basis as the basic of a currentless computing scheme (so-called *magnetic quantum cellular automata*) and some initial experimental demonstrations of this approach have already been provided. While there has been impressive progress in the development of metal-based magnetoelectronics, the implementation of analogous *semiconductor* structures is lagging far behind. The development of semiconductor-based magnetoelectronics is desirable for at least two reasons. On the one hand, the metallic devices developed to date are *vertical* structures that are incompatible with *planar* semiconductor integrated circuits. To achieve compatibility with this technology, it is therefore desirable to explore the integration of nanomagnetic elements with planar semiconductor devices. In addition, we believe that there could be a fundamental advantage to implementing magnetoelectronic devices in semiconductors, in particular in semiconductor nanostructures. The discrete form of the density of states in these structures should allow very-strong modulations of their conductance to be induced when modulating the magnetic fields emanating from nanomagnets in close proximity to them. Little of this work has focused on how control of the fringing fields from a nanomagnet may be used to strongly modulate the current flowing through a nanostructure such as a narrow quantum wire. This is an important point, since the fringing field typically fall off on a length scale of order a few hundred nanometers, so that optimal coupling to these fields requires the use of semiconductor *nano*structures.

In this presentation, we provide a proof of concept demonstration of a novel hybrid semiconductor/nanomagnetic device, a ferromagnetic field-effect transistor, or ferro-FET. In this device, the current flowing through a high-mobility semiconductor channel is modulated by both the fringing electrostatic and magnetic fields that emanate from a single-domain nanomagnet. Use of an external magnetic field to modulate the latter yields measurable changes in the channel conductance, with a significantly enhanced tunneling magneto-resistance ($\Delta G/G$ ~ 600%) when the average conductance is less than $2e^2/h$. Temperature dependent studies reveal directly how this magneto-conductance arises from the modulation of the magnetic contribution to the total barrier electrons experience. Our results can be explained reasonably well by a simple modeling of tunneling through a saddle potential in the presence of a magnetic field. Further optimization of this device should allow for the observation of enhanced tunneling magneto-resistance, possibly even at room temperature.

For a recent review, *see*: A. Nogaret, "*Electron dynamics in inhomogeneous magnetic fields*", J. Phys.: Condens. Matt. **22**, 253201 (2010).

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