THE ART OF SPIN ELECTRONICS

John F. Gregg

Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom

Conventional electronics has ignored the spin of the electron. Indeed, with the exception of solenoids, relays, Hall sensors and the occasional specialised microwave device, magnetism has traditionally been the "poor relation" in the world of electronic circuitry. In the everyday silicon transistor, the different families of electrical carrier are distinguished by their different effective charges: however no practical use is made of the fact that some are spin-up and others are spin-down.

The recognition of this distinction is the key which promises to unlock a whole new generation of Spin Electronic devices whose operation relies upon differential manipulation of independent families of current carriers with opposite spin polarisation.

The technical basis for Spin Electronics rests on the fact that electrical currents in ferromagnets are carried by two distinct and independent "spin channels", one consisting of electrons with spin parallel to the magnetisation and the other with spins antiparallel. The relative independence of these two families of carriers arises since, although spin flip processes are possible which move electrons from one channel to the other, they occur on a timescale which is long compared with those of other processes. Moreover, the carrier mobilities of the two channels are very different, and this implies that small ferromagnetic elements incorporated into spin electronic devices may be used to encode magnetic information onto the conduction electrons. The nature of the coded information may be externally varied by application of magnetic fields which change the magnetisation states of the encoder ferromagnets.

Spin Electronic devices work by transferring this spin information from one part of the device to another where it is subsequently "read". The information is mediated by the electrical carriers and it decays on a characteristic lengthscale (the spin diffusion length) which is the average distance diffused by a carrier spin before flipping. This can vary from nanometers to microns depending on material. An essential criterion for the creation of Spin Electronics is thus the ability to engineer structures whose physical dimensions are of this order or smaller. With the advent of modern thin film and nanofabrication technology this dream is now a reality.

Potential applications of Spin Electronics lie in the data-storage industry as might be expected, but also in programmable gate arrays, robotics, and precision engineering where fast accurate position and motion sensing of mechanical components is a requirement. In particular, there is a growing awareness of the need for such technology in the development of improved fuel handling systems and electronic engine control in the automotive industry. The requirement for robust, temperature stable, high signal to noise sensors extend to many other aspects of automobiles including antiskid systems, speed controls and crash avoidance.

The Oxford Spin Electronics Group is currently supported by the European Commission and EPSRC. In collaboration with eight European physics laboratories and two major electronics companies, work is in progress on novel 3- and 4-terminal spin electronic devices. Hybrid designs using semiconductor/ferromagnetic metals are being developed with a view to achieving enhanced gain, signal-to noise and field sensitivity. The research is wide-ranging and includes fabrication of materials and structures, study of the fundamental transport physics of semiconductor/ferromagnetic interfaces, characterisation of novel spin electronic materials, theoretical modelling of interfacial processes and comparison with non-linear optical studies of real interfaces, study of spin tunnelling processes, design of actual device structures and even implementation of such devices in real automotive machinery.