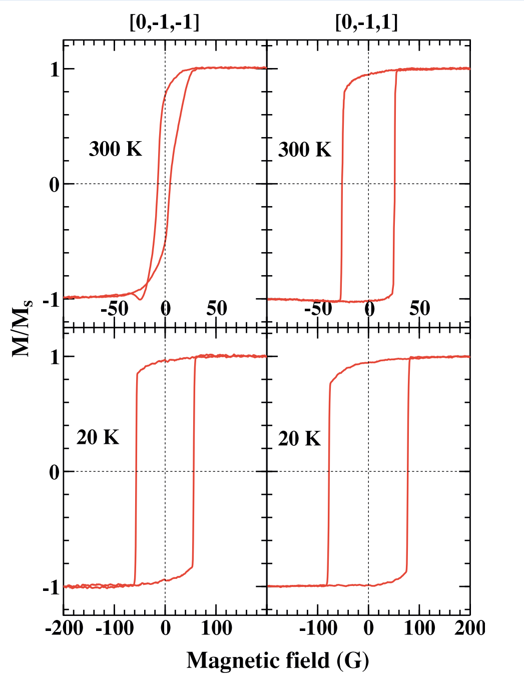
Heusler alloys for spin-injection devices

S. Holmes and M. Pepper from the Cambridge Research Laboratory at Toshiba Research Europe have used a Microstat Rectangular Tail to help them elucidate the electrical and magnetic properties of Cobalt-based Heusler alloys. This group of magnetic materials are ideal half-metallic materials for spin-injection in nanostructured semiconductor devices.



Semiconductor spintronics may offer interesting new ways of storing information. As conventional semiconductors are not ferromagnetic, however, a ferromagnetic metal is needed to inject a spin-polarized current into the semiconductor.

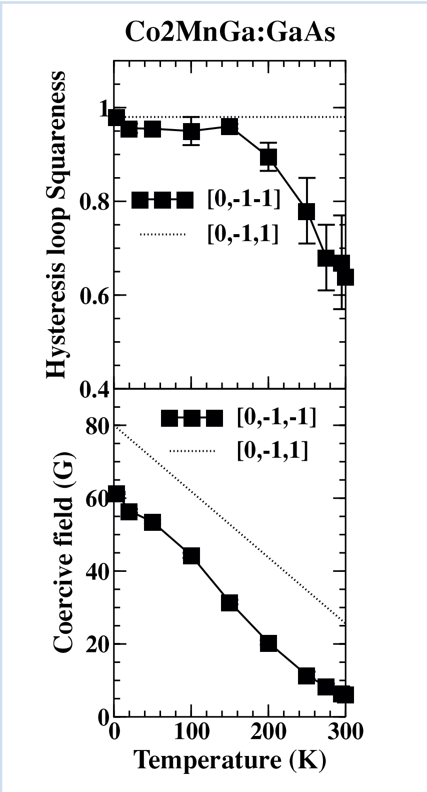
Datta and Das put forward a design for a spin-polarized field-effect transistor, or spin FET, in 1990[1]. In a conventional FET, a narrow semiconductor channel runs between two electrodes named the source and the drain. When voltage is applied to the gate electrode, which is above the channel, the resulting electric field drives electrons out of the channel (for instance), turning the channel into an insulator. The Datta-Das spin FET has a ferromagnetic source and drain so that the current flowing into the channel is spin-polarized. When a voltage is applied to the gate, the spins rotate as they pass through the channel and the drain rejects these anti-aligned electrons.

Although a spin FET would have several advantages over a conventional FET, making a working prototype of the Datta-Das spin FET remains a complex task. This is due to the difficulties in efficiently injecting spin currents from a ferromagnetic metal into a semiconductor. Magnetic semiconductors, such as the Heusler alloys characterised here, are one means of achieving this spin injection. These incorporate magnetism by doping the semiconductor crystals with atoms such as manganese.

Heusler alloys were constructed by growing wafers of Co_2MnGa, at a pressure of 10^{-7} mbar with a nominal temperature of 30 °C, on GaAS(001) substrates. X-ray diffraction measurements indicated that the films were polycrystalline. Wafer thicknesses of 12.9, 17.0, 53.9 and 73.0 nm were determined using an in situ crystal monitor and verified with an atomic force microscopy Nanoscope.

A decrease in resistance on cooling was observed for all wafers, a property that is characteristic of metallic rather than intrinsic semiconducting behaviour. The residual resistivity ratio was shown to extrapolate to 1 at the same thickness that the anisotropic magnetoresistance (AMR) extrapolates to 0. This may indicate that metallic behaviour is concomitant with ferromagnetic behaviour in Co_2MnGa. The largest AMR was 6% at 300 K in a 73 nm thick wafer, increasing to 8% at 1.6 K. This is remarkably large considering the polycrystalline nature of the wafers. In the thin wafers (*t* <20 nm), the AMR is weakly temperature-dependent, due to dominant scattering from the surface and the GaAs interface.

In summary, Co_2MnGa:GaAs(001) is metallic rather than showing intrinsic semiconducting properties. Ferromagnetic behaviour was observed at 300 K in wafers down to approximately 10 nm thickness. A very robust AMR signal, 1% in a 12.9 nm thick wafer, demonstrates the usefulness of this material for nanostructured metals, particularly for spin injection into semiconductor structures operating at room temperature. The efficiency of spin injection, however, will be determined by the first 10 nm of Co_2MnGa growth. Compositional control and coherent growth in this region will therefore be essential. In addition, an anisotropic magnetoresistance of 6% at 300K demonstrates the importance of spin-orbit scattering of these disordered alloys, indicating their potential for use for more conventional computing-based devices.



Reference:

1. S. Datta and B. Das, "Electronic Analog of the Electro-Optic Modulator", Appl. Phys. Lett., 56, 665 (1990).

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