Magnetic Semiconductors

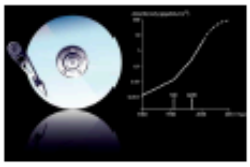
Ben Ruck, Franck Natali, Joe Trodahl, Eva Anton, Harry Warring, James McNulty, Tanmay Maity, and Luis Figueras

The MacDiarmid Institute for Advanced Materials and Nanotechnology, School of Chemical and Physical Sciences, Victoria University of Wellington, Wellington, New Zealand

Contacts: ben.ruck@vuw.ac.nz, franck.natali@vuw.ac.nz, joe.trodahl@vuw.ac.nz

Spintronics

- Most of modern electronics is based on semiconductors controlling the flow of electric charge (electrons)
- Data storage is largely based on magnetic memory (hard disks)
- *Future challenge*: develop novel electronic devices that utilise both magnetism (i.e., the *spin* of the electrons) and semiconducting technology - ***Spintronics***

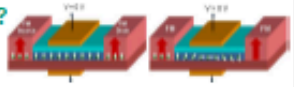


A modern hard disk drive. Spintronics technology has led to dramatic increases in data storage density

In addition to carrying electric charge every electron is also a tiny magnet.

What kind of materials are required?

- Need strong coupling between magnetic properties and electrical conductivity
- Look for **magnetic semiconductors**



Schematic diagram of the Datta-Das field-effect transistor. The spin orientation in a spin polarised electric current rotates under the influence of an applied gate voltage, thereby modulating the source-drain current.

Devices and Applications

Magnetic Random Access Memory (MRAM)

High resistance («1») *Low resistance («0»)*

A magnetic tunnel junction can be used as a memory element, where the two magnetic states represent the binary elements « 0 » or « 1 ». They are distinguished by having different electrical resistance.

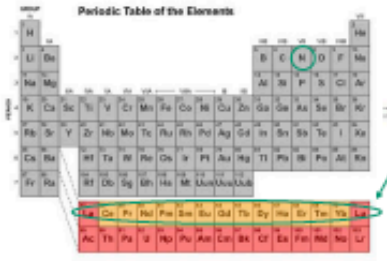
- A single magnetic *bit* can be made from a magnetic tunnel junction, a sandwich of two magnetic layers separated by a thin insulating barrier
- The resistance of the device depends on the relative orientation of the magnetism in the two magnetic layers
- MRAM is now commercially available

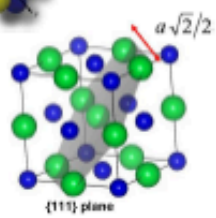
MRAM Target Applications

Everspin Technologies is presently marketing a 64 Mb MRAM.

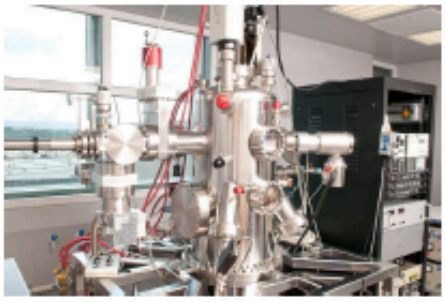
- MRAM is very fast and non-volatile – the memory is not lost if power goes off
- Applications in consumer electronics, cloud storage, or assembly lines

Rare-earth nitrides





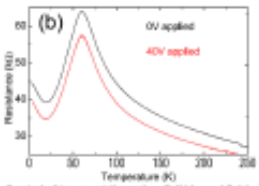
- Simple crystal structure (rock salt)
- Most show ferromagnetism at low temperature
- Most are also semiconductors: unusual combination



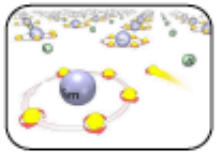
Ultra-high vacuum system at VUW used for rare-earth nitride thin film growth.

Spintronics Potential of Rare-Earth Nitrides

- We have shown that we can control electric current using the magnetic properties of rare-earth nitrides
- We are now investigating further novel device concepts based on these materials



Control of transport through a GdN-based field-effect transistor: (a) device structure; (b) temperature-dependent electrical resistance is lower with an applied gate voltage, demonstrating transistor action. (H. Warring et al., Appl. Phys. Lett. 102, 132409 (2013))



Acknowledgements

•Collaborators

S. Granville (Robinson Research Institute, Victoria University), K. Smith (Auckland University), W. Lambrecht (Case-Western Reserve U., Cleveland), F. Semond (CRHEA/CNRS, Valbonne), L. Hirsch (IMS, Bordeaux), S. Sorieul (CENBG/IN2P3, Gradignan), L. Ranno, C. Meyer (Institut Neel/CNRS, Grenoble), J.C. Cezar, F. Wilhelm, A. Rogalev (European Synchrotron, Grenoble), V.N. Antonov (Institute of Metal Physics, Ukraine)

•Funding

The MacDiarmid Institute for Advanced Materials and Nanotechnology, FRST/MBIE (New Economy Research Fund), the Marsden Fund, the Von Humboldt Fellowship Scheme