NANOSPIN: Semiconductor NanoSpintronics

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Objectives:
Spintronic devices based on metallic ferromagnets have recently revolutionized the hard-drive storage industries and have led to orders of magnitude increases in data storage capacities. Micro-structured versions of these devices are currently being introduced into the memory chip market. These magnetic random access memories (MRAM) are among the leading candidates for the "holy grail" of universal memory chips combining non-volatility, short write and read times, large scale integrability, and lowpower consumption. MRAMs offer the prospect of instant on and off desktop and portable electronics. Indeed, MRAM is a successful example of the integration of a spintronics device into microelectronics. However, with metal-based spintronics devices, such integration is limited by the challenges of associating ferromagnetic metals and semiconductors in the same heterostructure. As such, the development of a semiconductor based technology is highly desirable and of great technological and economic relevance.
NANOSPIN looks beyond the current state of the art metal-based spintronics to the exciting possibilities offered by ferromagnetic semiconductor (FS) nanospintronics devices. Such devices can realize the full potential of spintronics as they offer integration of magnetic and semiconducting properties allowing for a combination of information processing and storage functionalities. Moreover, discoveries in this field are also providing new effects and functionalities that have been overlooked by conventional spintronics but whose exploitation will have major impact in the information technology industry.

- The primary objectives of NANOSPIN are to develop novel FS based spintronics devices for information storage and manipulation. This overall ambition can be compartmentalized into 4 aspects:. -The writing of information into the magnetic state of the device by electrical means such as current induced domain wall motion or current induced magnetization reversal.
- Retrieval of the information by a non-perturbative electrical technique, in many cases based on the recently discovered tunnelling anisotropic magnetoresistance effect.
- High speed operation of the device at commercially relevant frequencies.
- Theoretical modelling of the devices to provide basic understanding of their operation and allow for optimization of performance.

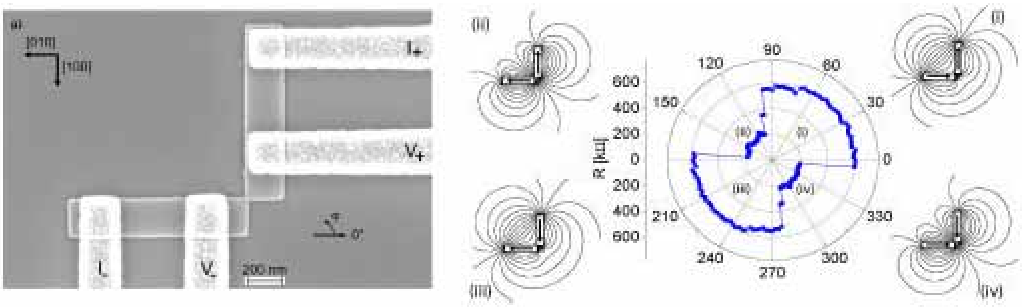
Key results to date:

In the first half of the program, Nanospin has achieved significant results on all 4 of these aspects.
Highlights include:

Writing: The progress made writing information into the magnetic state of (Ga,Mn)As can be classified in two categories: Local lithographic control of magnetic anisotropies and current induced magnetization switching. For the first part, we have developed a method using lithographical patterning of layers to controllably engender local anisotropic strain relaxation in samples leading to designable local anisotropies. The second important element of progress in our ability to write information is the optimization of a current induced magnetization reversal process to store the information using an electrical technique instead of a magnetic field. Here we have achieved positive results in both lateral and vertical geometries.

Reading: To achieve read-out, we first needed to develop a reliable method for determining the magnetic state of (Ga,Mn)As by electric means. The result of this effort was the establishment of the "anisotropy fingerprint" technique to fully characterize the magnetic behaviour by purely transport methods. Our studies also revealed additional terms which play a role in linking transport characteristics to the magnetic state and which are typically overlooked in metals.

Combining reading and writing, we proceeded to demonstrate a memory device prototype. The device consists of two uniaxial bars as in the photo. Because of anisotropic magnetoresistance, the resistance in the constriction formed where the two nanobars meet depends on the orientation of the local magnetic field lines.



The field lines are very different depending on whether the magnetization of the two bars point towards each other (head-head) or one runs into the other (head-tail). The device can thus be written into one of the states illustrated in the schematics by applying a magnetic field in the proper direction, and then, after reducing the field to zero, be read out non perturbatively by measuring the constriction resistance. The device thus constitutes a non-volatile memory element.

High speed operation: In terms of progress in moving from single shot lab demonstrators to devices operating at commercially relevant rates, we have achieved operation of simple devices using sub nanosecond writing pulses.

Theory: Much progress has also been made on the theoretical side. In addition to successful models having been developed to explain many aspects of the important phenomena of TMR, TAMR and CBAMR observed experimentally in semiconductor spintronic systems, specific models have been established to describe all the devices used in the reading and writing studies. Moreover, fundamental progress on understanding the materials has also been made, including investigations on the role of various extrinsic strain terms and the elucidation of the role of hole magnetization.