

SPINTRONICS: EXHAUSTING OF THE SEMICONDUCTOR MATERIALS

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Abstract

Spintronics is a rapidly emerging field of science and technology that will most likely have a significant impact on the future of all aspects of electronics as we continue to move into the 21st century. Conventional electronics are based on the charge of the electron. Attempts to use the other fundamental property of an electron, its spin, have given rise to a new, rapidly evolving field, known as spintronics, an acronym for spin transport electronics. Initially, the spintronics program involved overseeing the development of advanced magnetic memory and sensors based on spin transport electronics. It was then expanded to include Spins IN Semiconductors (SPINS), in the hope of developing a new paradigm in semiconductor electronics based on the spin degree of freedom of the electron. Studies of spin-polarized transport in bulk and low dimensional semiconductor structures show promise for the creation of a hybrid device that would combine magnetic storage with gain-in effect, a spin memory transistor. This paper reviews some of the major developments in this field and provides a perspective of what we think will be the future of this exciting field. And on basic principles of spin polarized transport.

I. INTRODUCTION

Nanotechnology is the latest technology giving hope to man, to achieve the smallest possible devices. As rapid progress in the miniaturization of semiconductor electronic devices leads toward chip features smaller than 100 nanometers in size, device engineers and physicists are inevitably faced with the looming presence of quantum mechanics--the branch of physics where wavelike properties of the electron dominate the particle (charge) behavior. One such is the quantum property of the electron known as spin, which is closely related to magnetism. Devices that are based on an electron's spin to perform their functions form the basis of spintronics (spin-based electronics), also known as magneto electronics. Magnetism has always been important for information storage. Spintronics is a new branch of electronics in which electron spin, in addition to charge, is manipulated to yield a desired outcome.

To date, electronics uses electron charge as a state variable which is often represented as voltage or current. In this representation of state variable in today's electronics, carriers in electronics devices work independently even to a few and single electron cases. As the scaling continues to reduce the feature size, power dissipation and variability become two major challenges among others as identified in ITRS. This

paper presents the exposition that spintronics as a collective effect may be favorably used as state variables in the near future information processing beyond conventional electronics for room temperature. An example is presented to compare electronics and spintronics in terms of variability, quantum and thermal fluctuations. This example shows the benefit of scaling to smaller sizes in the case of spintronics (nanomagnetism), which will have a much reduced Variability problem as compared with today's electronics. Finally, spin wave bus is used to illustrate the potential use as a state variable for logic application.

II. CONCEPT

All spintronic devices act according to the simple scheme: (1) information is stored (written) into spins as a particular spin orientation (up or down), (2) the spins, being attached to mobile electrons, carry the information along a wire, and (3) the information is read at a terminal. Spin orientation of conduction electrons survives for a relatively long time (nanoseconds, compared to tens of femtoseconds during which electron momentum decays), which makes spin-tronic devices particularly attractive for memory storage and magnetic sensors applications, and, potentially for quantum computing where electron spin would represent a bit of information. The hard drives of the latest computers rely on a spintronic effect, giant magneto resistance (GMR), to read dense data.

III. TYPES OF SPINTRONICS DEVICES

Spintronic devices can be divided into three categories.

- 1) The first is flow of spin-polarised current metal-based Devices.
- 2) In the second category, the spin polarized currents flow in semiconductors instead of metals. Achieving practical spintronics in semiconductors would allow a number of existing microelectronics techniques to be co-opted and would also invent many more types of devices made possible by semiconductors' high-quality optical properties and their ability to amplify both optical and electrical signals. This avenue of research may lead to a new class of multifunctional electronics that combine logic, storage and communications on a single chip.
- 3) The most complex is the third category of devices: ones that manipulate the quantum spin states of individual electrons. This category includes spintronic quantum logic gates that would enable construction of large-scale quantum computers, which would extravagantly surpass standard computers for

certain tasks. A research of the technologies is aimed toward the goal: ions in magnetic traps, "frozen" light, ultra cold quantum gases called Bose-Einstein condensates and nuclear magnetic resonance of molecules in liquids etc.

IV. SPIN POLARISED CURRENT

In an ordinary electric current, the spins point at random and play no role in determining the resistance of a wire or the amplification of a transistor circuit. Only the charge and flow of electrons as particles matters. Spintronic devices, in contrast, rely on differences in the transport of "spin up" and "spin down" electrons. In a ferromagnetic material, such as iron or cobalt, the spins of certain electrons on neighboring atoms tend to line up. In a strongly magnetized piece of ferromagnetic material, this alignment extends throughout much of the metal. When a current passes through the ferromagnet, electrons of one spin direction tend to be obstructed. This result in a current called as SPIN POLARISED CURRENT in which all the electron spins point in the other direction. A ferromagnet can even affect the flow of a current in a nearby nonmagnetic metal. This principle is used in present-day read heads in computer where hard drives use a device dubbed a spin valve, in which a layer of a nonmagnetic metal is sandwiched between two ferromagnetic metallic layers. The magnetization of the first layer is fixed, or pinned, but the second ferromagnetic layer is not. As the read head travels along a track of data on a computer disk, the small magnetic fields of the recorded 1's and 0's change the second layer's magnetization back and forth, parallel or antiparallel to the magnetization of the pinned layer. In the parallel case, only electrons that are oriented in the favored direction flow through the conductor easily. In the antiparallel case, all electrons are impeded. The resulting changes in the current allow GMR read heads to detect weaker fields than their predecessors, so that data can be stored using more tightly packed magnetized spots on a disk,

Increasing storage densities by a factor of three. The basic GMR device consists of a three-layer sandwich of a magnetic metal such as cobalt with a nonmagnetic metal filling such as silver. A current passes through the layers consisting of spin-up and spin-down electrons. Those oriented in the same direction as the electron spins in a magnetic layer pass through quite easily while those oriented in the opposite direction are scattered. If the orientation of one of the magnetic layers can easily be changed by the presence of a magnetic field then the device will act as a filter, or 'spin valve', letting through more electrons when the spin orientations in the two layers are the same and fewer when orientations are oppositely aligned. The electrical resistance of the device can therefore be changed dramatically.

V. SPINTRONICS QUBITS

In any electronic orbit or energy level there can be a maximum of two electrons with two distinct spins, "up" or "down". Each electron spin can represent a bit; for instance, a 1 for spin up

and a 0 for spin down. With conventional computers, engineers go to great lengths to ensure that bits remain in stable, well-defined states. A quantum computer, in contrast, relies on encoding information within quantum bits, or qubits, each of which can exist in a superposition of 0 and 1. By having a large number of qubits in superposition's of alternative states, a quantum computer intrinsically contains a massive parallelism so that quantum algorithms can operate on many different numbers simultaneously. Spin polarization decays becomes all the more acute if one is to build a quantum computer based on electron spins. That application requires control over a property known as quantum coherence, in essence the pure quantum nature of all the computer's data-carrying components. Quantum data in semiconductors based on the charges of electrons tend to lose coherence, or dissipate, in mere picoseconds, even at cryogenic temperatures.. For electrons the horizontal quantum spin states are actually coherent superposition's of the spin-up and spin down states. In effect, such electrons are in both the up and the down state at the same time. This is precisely the kind of coherent superposition of states employed by quantum computers. Electron-spin qubits interact only weakly with the environment surrounding them, principally through magnetic fields that are no uniform in space or changing in time. Such fields can be effectively shielded. Experiments were conducted to create some of these coherent spin states in a semiconductor to see how long they could survive. The results are also useful for understanding how to design devices such as spin transistors that do not depend on maintaining and detecting the quantum coherence of an individual electron's spin.

VI. SPIN FET

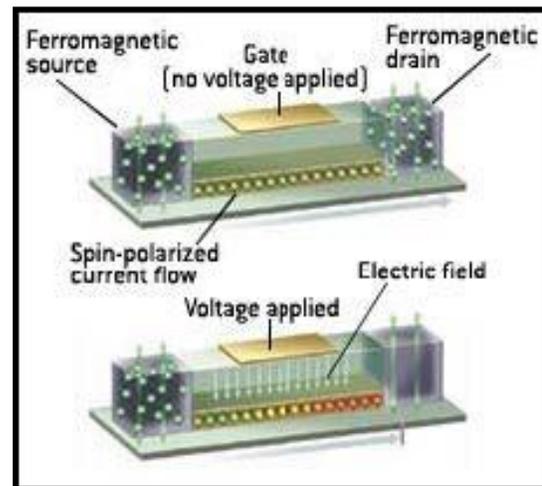


Figure 1 spin FET

Figure 1: shows a model of spin fet. In 1990 Supriyo Datta and Biswajit A. Das, then at Purdue University, proposed a design for a spin-polarized field-effect transistor, or spin FET. 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. A spin FET would have several advantages over a conventional FET. Flipping an electron's spin takes much less energy and can be done much faster than pushing an electron out of the channel. There is also a possibility of changing the orientation of the source or drain with a magnetic field, introducing an additional type of control that is not possible with a conventional FET: logic gates whose functions can be changed on the fly.

VII. MAGNETIC SEMICONDUCTORS

As yet, however, no one has succeeded in making a working prototype of the Datta-Das spin FET because of difficulties in efficiently injecting spin currents from a ferromagnetic metal into a semiconductor. Although this remains a controversial subject, recent optical experiments carried out at various laboratories around the world indicate that efficient spin injection into semiconductors can indeed be achieved by using unconventional materials, called **MAGNETIC SEMICONDUCTORS**, which incorporate magnetism by doping the semiconductor crystals with atoms such as manganese. Some magnetic semiconductors have been engineered to spintronic component called a gate able ferromagnet. In this device, a small voltage would switch the semiconductor between nonmagnetic and ferromagnetic states. A gate able ferromagnet could in turn be used as a spin filter--a device that, when switched on, passes one spin state but impedes the other. The filtering effect could be amplified by placing the ferromagnet in a resonant tunnel diode. Conventional resonant tunnel diodes allow currents to flow at a specific voltage, one at which the electrons have an energy that is resonant with the tunneling barrier. The version incorporating a ferromagnet would have a barrier with different resonant voltages for up and down spins. A key research question for this second category of spintronics is how well electrons can maintain a specific spin state when traveling through a semiconductor or crossing from one material to another. For instance, a spin FET will not work unless the electrons remain polarized on entering the channel and after traveling to its far end. Subsequent studies of electrons in Znse, gallium arsenide (GaAs) have shown that, under optimal conditions, spin coherence in a semiconductor could last hundreds of nanoseconds at low temperatures.

VIII. HAZARDS OF HOLES

These experiments also revealed characteristics that are crucial for attaining long spin coherence times. Of primary importance

is the nature of the carriers of spin and charge. A semiconductor has two key bands of states that can be occupied by electrons: a valence band, which is usually full, and (at a slightly higher energy) a conduction band, which is usually empty. Charge carriers in semiconductors come in two flavors: conduction electrons, which are electrons in the conduction band, and valence holes, which are electrons missing from the valence band. The holes carry a spin because in a filled valence band all the spins cancel out: the removal of one electron leaves a net spin imbalance in the same way that it leaves behind a net positive charge. Holes have dramatically shorter spin coherence times than electrons, and spin exchange between electrons and holes is very efficient, accelerating the decoherence of both. For these reasons, it is advantageous to have no hole carriers, a condition that is achieved by using n-doped semiconductor crystals, which are doped to have some excess electrons in the conduction band without any corresponding valence holes. When holes have been eliminated, the dominant remaining source of decoherence comes from a relativistic effect: a body moving at high speed through an electric field sees the field partially transformed into a magnetic field.

For an electron moving in a semiconductor, the crystal structure of the material provides the electric field. The spin of a fast-moving electron precesses around the resulting local magnetic field that it sees. Two electron spins that start off parallel can soon evolve to point in opposite directions. As this misalignment among the electrons grows, the average spin polarization of the population diminishes, which the experiment conducted measures as loss of coherence. This population-based origin of decoherence holds forth the hope that the spin coherence times of individual electrons may turn out to greatly exceed even the remarkably long times seen in ensembles. In conjunction with the carrier's lifetime, two other properties are crucial for semiconductor applications: how far excitations can be transported and how fast the state of a device can be manipulated. Macroscopic spin transport was first demonstrated in n-doped gallium arsenide. A laser pulse excited a "puddle" of coherently processing electrons, much as in the lifetime experiments, but then a lateral electric field dragged the electrons through the crystal. Spin packets traveled more than 100 microns with only moderate loss of spin polarization. Recent experiments have successfully driven coherent spins across complex interfaces between semiconductor crystals of different composition (for instance, from GaAs into ZnSe). A number of semiconductor applications, from lasers to transistors, are based on hetero structures, which combine disparate materials. The same design techniques can be implemented on spintronics devices.

IX. SPIN DRAGGING IN SEMICONDUCTOR

poles of electrons in spin-polarized states are dragged more than 100 microns by an electric field--a fundamental step toward technology relying on large-scale quantum coherence. The peaks diminish as quantum coherence of the states is lost. Apart from GMR, another three-layered device, the magnetic

tunnel junction, has a thin insulating layer between two metallic ferromagnets. Current flows through the device by the process of quantum tunneling: a small number of electrons manage to jump through the barrier even though they are forbidden to be in the insulator. The tunneling current is obstructed when the two ferromagnetic layers have opposite orientations and is allowed when their orientations are the same. Whereas the metallic spintronic devices just described provide new ways to store information, semiconductor spintronics may offer even more interesting possibilities. Because conventional semiconductors are not ferromagnetic, it is a question how semiconductor spintronic devices can work at all. One solution employs a ferromagnetic metal to inject a spin-polarized current into a semiconductor.

X. LATEST DEVELOPMENTS

Ohio State University researchers have made nearly all the moving electrons inside a sample of plastic spin in the same direction — an effect that could yield plastic memories. Spintronics with traditional inorganic semiconductors is difficult because most such materials are only magnetic at very low temperatures. Creating the cold environment needed would be expensive and space-consuming. The researchers used a plastic called vanadium tetracyanoethanide. The material is magnetic at high temperatures, and would be suitable for use inside a computer operating above room temperature. Plastic Spintronic devices would weigh less than traditional electronic ICs and cost less to manufacture. They suggests that inexpensive inkjet technology could one day be used to quickly print entire sheets of plastic semiconductors for spintronics.

XII. CONCLUSION

This spintronic device technology will easily overcome the problem of exhausting of the semiconductor materials. It is very useful for the field of advanced magnetic memory and sensors based on spin transport electronics. So this spintronics, rapidly emerging field that will most likely have a significant impact on the future of all aspects of electronics as we continue to move into the 21st century.

XIII REFERENCES

[1] J J Attema, G A de Wijs and R A de Groot Spintronics, “*Spintronic materials based on main-group elements*” of Physics, IOP PUBLISHING, JOURNAL OF PHYSICS: CONDENSED MATTER, J. Phys.: Condens. Matter **19** (2007) 165203 (11pp), doi:10.1088/0953-8984/19/16/165203.

[2] Hélène Béa, Manuel Bibes, Gervasi Herranz, Xiao-Hong Zhu, Stéphane Fusil, Karim Bouzouane, Eric Jacquet, Cyrille Deranlot, and Agnès Barthélémy, “*Integration of Multiferroic BiFeO3 Thin Films into Heterostructures for Spintronics*”, IEEE TRANSACTIONS ON MAGNETICS, VOL. 44, NO. 7, JULY 2008, Unité Mixte de Physique CNRS-Thales, Route départementale 128, 91767 Palaiseau, France.

[3] Hao Meng, Jianguo Wang, and Jian-Ping Wang, “*A Spintronics Full Adder For Magnetic CPU*”, IEEE ELECTRON DEVICE LETTERS, VOL. 26, NO. 6, JUNE 2005.

[4] Manuel Bibes and Agnès Barthélémy, “*Oxide Spintronics*”, IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 54, NO. 5, MAY 2007.

[5] Michael E. Flatté, Member, IEEE, “*Spintronics*”, IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 54, NO. 5, MAY 2007.

[6] Kang L. Wang, Igor V. Ovchinnikov, Alex Khitun and Ming Bao, “*Comparison of Spintronics and Nanoelectronics for Information Processing*”, Device Research Laboratory (DRL) University of California, Los Angeles Los Angeles, CA, 90095-1594, USA, wang@ee.ucla.edu.

[7] S.J. Pearton, D.P. Norton, R. Frazier, S.Y. Han, C.R. Abernathy and J.M. Zavada, “*Spintronics device concepts*”. IEE Proc.-Circuits Devices Syst. Vol. 152, No. 4, August 2005.

[8] S. Das Sarma, Jaroslav Fabian, Xuedong Hu, and Igor ZuM, “*Issues, Concepts, and Challenges in Spintronics*”, Department of Physics, University of Maryland at College Park College Park, Maryland 20742- 4111, USA.

[9] Marc Cahay and Supriyo Bandyopadhyay, “*AN ELECTRON'S SPIN—PART I*”, 0278-6648/09/\$25.00 © 2009 IEEE.

[10] Hiro Akinaga and Hideo Ohno, Member, IEEE, “*Semiconductor Spintronics*”, IEEE TRANSACTIONS ON NANOTECHNOLOGY, VOL. 1, NO. 1, MARCH 2002.

[11] David D. Awschalom, “*Engineering single spins and coherence for Spintronics*”, Center for Spintronics and Quantum Computation University of California, Santa Barbara, CA 93106 USA.

[12] Simon Kos, Marina Hrušková, Scott A. Crooker, Avadh Saxena, and Darryl L. Smith, “*Modeling Spin-Polarized Electron Transport in Semiconductors for Spintronics Applications*”, Los Alamos National Laboratory. 1521-9615/07/\$25.00 © 2007 IEEE Copublished by the IEEE CS and the AIP.

[13] Igor Zutic, Jaroslav Fabian, S. Das Sarma, “*Spintronics: Fundamentals and applications*”, REVIEWS OF MODERN PHYSICS, VOLUME APRIL 2004.

[14] Scientific American 2006.

[15] Advanced Technology Oct, 2005.

[16] Hideo Ohno, “*A Hybrid CMOS/Magnetic Tunnel Junction Approach for Nonvolatile Integrated Circuits*”, Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication ohoku University, Sendai 980-8577, Japan e-mail:.

[17] D. B. Tuckerman and R. F. W. Pease, “*Implications for highperformance heat sinking for electronic devices*,” IEEE Trans. Elec. Dev., vol. 28, p. 1230, Oct. 1981.

[18] J. Daughton, J. Brown, E. Chen, R. Beech, A. Pohm, and W. Kude, “*Magnetic field sensors using GMR multilayer*,” IEEE Trans. Magn., vol. 30, no. 6, pp. 4608–4610, Nov. 1994.