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SPINTRONICS DEVICE CONCEPTS

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Abstract:

Spin-dependent phenomena in semiconductors may lead to devices with new or enhanced functionality, such as polarized solid-state light sources (spin light-emitting diodes), novel microprocessors and sensitive biological and chemical sensors. The realization of robust semiconductor spin-device technology requires the ability to control the injection, transport and detection of polarized carriers, and to manipulate their density by a field gating. The absence of Si-based or room-temperature dilute magnetic semiconductors has subdued the initial excitement over semiconductor spintronics, but recent reports demonstrate that progress is far from dormant. The authors give examples of a number of different spin-device concepts for polarized light emission, spin field-effect transistors) and nanowire sensors. It is important to re-examine some of the earlier concepts for spintronics devices, such as the spin field-effects. In some of these cases, the spin device appears to have no advantage relative to the conventional charge-control electronic analogue. There have been demonstrations of device-type operation in structures based on GaMnAs and InMnAs at low temperatures. The most promising materials for room-temperature polarized light emission are thought to be GaN and ZnO, but results to date on realising such devices have been disappointing. The short spin-relaxation time observed in GaN/InGaN heterostructures probably results from the Rashba effect. Possible solutions involve either cubic phase nitrides or the use of additional stressor layers to create a larger spin-splitting, to get polarised light emission from these structures, or to look at alternative semiconductors and fresh device approaches.

1. Introduction

The use of electron spin, in addition to electron charge, has been suggested to hold promise for a new class of devices with new or enhanced functionality. Magnetism (and therefore electron spin) in metals has been the basis of information storage since the discovery of the giant magneto-resistance (GMR) effect, in which the resistance of a thin-film ferromagnetic/nonmagnetic layer sandwich is strongly magnetic-field-dependent. The GMR effect is now used in most computer hard drives. The discovery of GMR in metallic multilayer structures has led to much more sensitive position sensors (used in automobile braking systems), perimeter defense systems. The ability to produce ferromagnetism in semiconductors above room temperature has been suggested to lead to devices such as light-emitting and laser diodes with polarised output (which would enable much more information to be encoded in lightwave communication systems), transistors with novel designs, magnetic devices with gain, integrated logic and memory chips (leading to computers that would turn on immediately like a television set, without having to boot-up the operating system that is currently stored in magnetic memory in the hard drive), and powerful remote sensor systems that incorporate magnetic detection functions with on-chip signal processing and off-chip optical communication. Efforts are underway to achieve these goals through hybrid approaches that integrate the metallic magnetic elements on top of conventional Si circuits, or by injecting spin-polarised electrons from metals into semiconductors (Figs. 1a and b). However, the initial enthusiasm on many of these device concepts has been tempered by the lack of progress on realising operational devices and a reexamination of some of the proposed structures suggests they may have little or no advantage relative to conventional approaches. The most direct method of realising spintronic devices would be to induce ferromagnetism in a semiconductor at practical operating temperatures, by introducing appropriate magnetic dopants such as Mn at levels of a few per cent, producing a dilute magnetic semiconductor (DMS) (See Fig. 1c). DMSs are alloys where a stoichiometric fraction of the constituent atoms has been replaced by transition metal atoms. Such alloys are semi conducting, but can possess well-defined magnetic properties (e.g. paramagnetic, ant ferromagnetic, ferromagnetic) that conventional semiconductors do not have. Thus, they can potentially serve as a means to inject spin to and control spin properties in adjacent nonmagnetic semi conducting layers.

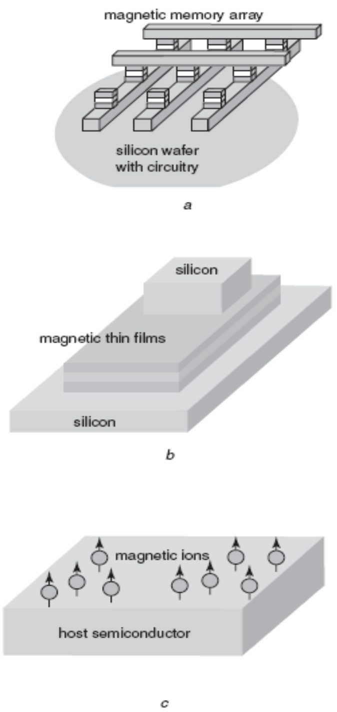

Fig.1: Schematic of possible integration approaches for obtaining spintronic – functional materials

a. Hybrid systems
b. Hybrid devices
c. Magnetic semiconductors

2. Candidate device concepts

A number of initital device configurations for GaMnAs have already been demonstrated at low temperatures. This list includes exchange-biased samples, spindependent resonant tunneling diodes, magnetic tunnel junctions and spin-polarised light-emitting diodes (spin LEDs). The presence of tunable wave-function overalap between magnetic ions and carriers confined to quantum structures has also been reported. More controversial are reports of very large magneto-transport effect, the so-called giant planar Hall effect’. There are also numberous theoretical analyses of new bipolar device configurations combining n-doped semiconductors with GaMnAs.

Most existing device configurations that exploit the spin degree of freedom are extensions of ordinary electronic devices, with enhanced but not qualitatively new functionality. Attempts have been made to explore the potential of ferromagnetic semiconductors for new functions such as reconfigurable logic, using a unipolar spin transistors, electrically tunable ferromagnetism has been explicitly demonstrated in In_1-xMnxAs-based field-effect devices.

2.1 Spin FET

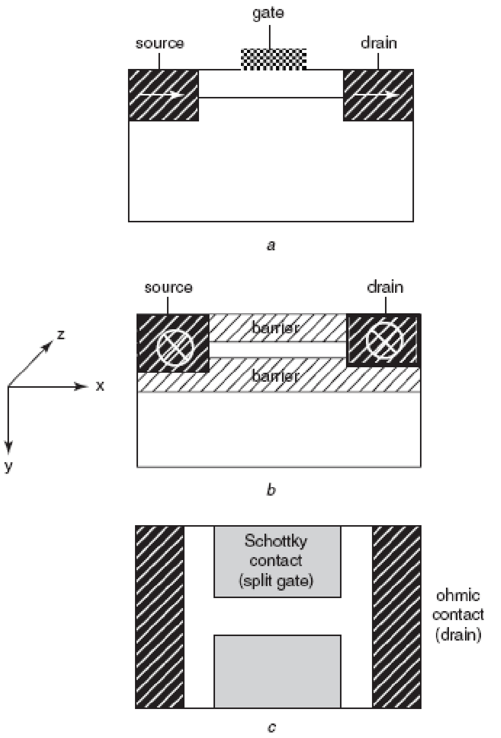

Fig. 2 *Schematic views of classical spin FET (a), new approach suggested by Bandyopadhyay and Cahay (b) and top view of split gates (c)*

The most common example of a spintronic device structure is the spin field-effect transistor (spin FET). A schematic diagram of the device is shown in Fig. 2a. In the spin FET, the drain and source of a conventional transistor are made ferromagnetic, either by having an ohmic contact metal scheme that is magnetic or using injection from a magnetic semiconductor into the channel. If the two ferromagnets are aligned, a spin-polarised current will behave like a normal FET current. If the ferromagnets are anti-aligned the transistor will be shut off. The selection of the spin current is achieved via electric – field modulation. Electrons are injected with a definite spin orientation from the source, which is then controllably processed in the channel with a gate – controlled. Rashba spin – orbit interaction, and finally sensed at the drain. At the drain end, the electron’s transmission probability depends on the relative alignment of its psin with the drain’s (fixed) magnetization. By controlling the angle of spin precession in the channel with a gate voltage, the relative spin alignment at the drain end can be controlled, and, hence, the source-to-drain current. This realizes the basic ‘transistor’ action. Through the application of a gate voltage, we can move the two spin – split sub-bands relative to the Fermi energy, which can effectively pinch off both channels (no current), pinch off one channel (polarised current), or let both channels through (unpolarised current). Compared to other spin filters, this device offers selectivity and easy integration into an integrated circuit. The interaction of an applied gate voltage with polarised carriers can alter their spin alignment and the spin FET is expected to be able to turn off at lower voltages than a conventional charge – controlled transistor, leading to potential applications in very low-power micro-processors. Control of the spin alignment could also be attained dynamically, allowing for microprocessors that reconfigure their hardware in real time.

2.2 Transparent ferromagnetic

A proposed photomagnet structure is shown in Fig.4. The concept is based on the theory that ZnO: MnCr is a half-metalic ferromagnet upon hole doping, while.

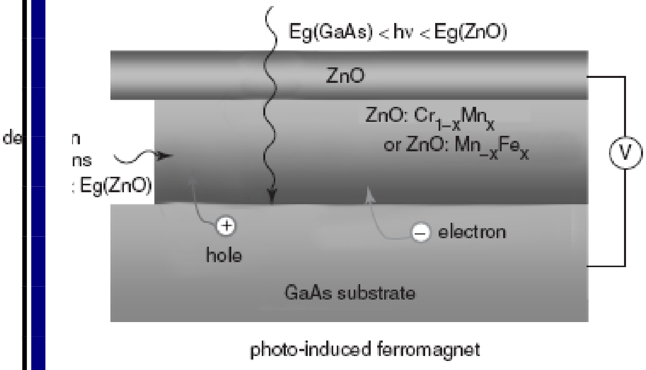

Fig.4: Schematic of Zno-based transparent photomagnet (after and also H. Katayama-Yoshida, private communication, and presented at Spring MRS, San Francisco, April 2002)

ZnO:FeMn is a half-metallic ferromagnet upon electron doping. For photons of appropriate energy, electrons and holes created in the GaAs substrate near the interface with the ZnO:MnCr or ZnO:FeMn can be drawn into those materials by biasing, causing them to become half-metallic ferromagnets. The presence of these ordered states can be detected using the magneto-optical effect from another probe beam of photons with energy lower than the ZnO bandgap. The device is readily grown on conducting GaAs to provide good ohmic contact to the substrate. The potential use of this light- or field-controlled ferromagnet has been described in detail previously and ZnO has some attributes such as ease of growth at low temperatures on low-cost substrates such as glass.

Determination of spin polarization

A major hindrance for the practical implementation of these concepts is that they require efficient spin-polarised carrier injection and transport. Conventional ferromagnetic metals are often incompatible with existing semiconductor technology. Moreover, the spin injection efficiency is often very low due to receptivity differences and to the formation of

Schottky barrient. A key materials aspect to overcoming this problem is the use of DMSs.

3.1 Exchange constant

The degree of spin polarization in DMSs is the most relevant parameter to any spintronics device applications. Of primary concern in many spin-based materials is the magnetic coupling strength between the mobile or localized change carriers and the localized (Mn) ion moments. Complete spin polarization is possible only if the conduction or valence-band Zeeman splitting in the ferromagnetic state is larger than the Fermi energy, and the size of the splitting is directly proportional to the exchange parameter ?x Measurement of ?xis therefore vital for device considerations of the grown materials.

3.2 Superconducting tunneling

A method that has been widely used to directly measure the spin polarization of ferromagnetic metals is electron tunneling with a superconducting counter electrode. This technique, pioneered by Tedrow and Massive, is particularly useful for the determination of spin polarization at the interface. The experiment requires that a tunnel junction be fabricated, which can be accomplished via epitaxial growth of an insulating barrier or surface treatment of the DMS. The superconductor has to be a light metal with minimal spin-orbit interaction so that the spin-up and spin-down density of states can be split with the application of a magnetic field. Al is a common choice and Be can also be used.

3.3 Spin – dependent ‘Hall effect’

The technique of superconducting tunneling requires the often difficult task of creating a thin uniform tunnel barrier and is limited to temperatures below ~ 1K. Another scheme to directly measure the spin polarization is a conceptual analogue of the Stern-Gerlach experiment: a patterned Hall bar of the DMS is placed in a uniform magnetic field gradient such that a force $F = \nabla (m . B)$ is exerted on the conduction electrons with spon magnetic moment of 1ìB. If the electron spins are polarized parallel to the field gradient, which may be accomplished through crystalline anisotropy or the application of a background magnetic field, then majority and minority spin populations will separate and build up charge on the sample edges. This will induce an electric field which will pose further charge build up, exactly as is encountered in the ordinary Hall effect. A rough estimate with field gradient of 1T/cm gives 1ìV as an order-of-magnitude signal for a fully polarized material, a voltage that is easily measurable. A field gradient of this magnitude can be obtained at the centre of the top surface of a SmCo ring-shaped magnet. This technique requires minimal processing and should be applicable to any ferromagnetic material over a wide temperature range. It development should facilitate easy determination of the spin polarization of the DMS.

3.4 Spin injection

Numerous experiments and theoretical discussions have led to a general belief that efficient spin injection from a DMS into a conventional semiconductor is promising because of the comparable conductivity, good Fermi wave vector matching and clean interface. It has been more than a decade since the first semiconductor spintronics device, spin FET, was proposed. There are three critical elements for this and any other all-electronic spin logic device: injection of polarized spins from a ferromagnetic into the semiconducting channel, coherent manipulation of spins in the semiconducting channel, and spin detection at the drain. So far, the experimental efforts to implement the proposed device schemes have largely followed the traditional microelectronics approach, except that the source and drain electrodes are replaced by ferromagnetic metals or semi conductors. However, the much more stringent requirement.

DMS-based sensors

There is a growing market for magnetoresitive DNA chops. These involve the use of MR sensors to detect bimolecular recognition processes between an immobilized probe and a magnetically labeled target. The integration of DNA and other bimolecular array and detection methods based on a portable, inexpensive and fully electronic approach is being actively pursued. Magnetic labels are often used to provide a means for cell separation, drug delivery or contrast enhancement in magnetic resonance (MR) imaging. Integrated MR sensors detect the fringe field of the label that binds to the hybridized target. For MR biochip applications, a small magnetizing field is applied to magnetise the nonremanent particles. The magnetic field can be created by either on-chip current lines or an external electromagnet. If an AC field is used, lock-in amplifiers are used for optimal signal-to-noise during particle detection. One concept based on DMS thin films is illustrated in Fig.9. The transition metal-doped DMS would serve as the source S to inject spin-polarised electrons into a nanoscale wire in which the spin polarization would be maintained, Fig.9a. The electrons would then be collected at the drain D. This device is not a conventional field – effect transistor as there is no gate. A specific receptor R, either for chemical or biological sensing, would be attached to the nanowire, Fig.9b. Many chemical or biological agents possesses magnetic ions. Binding of such an agent A with the receptors, Fig.9c, would lead to changes in the local magnetic field of the nanowire and would alter the polarized current. A single device could be replicated thousands of times with an assortment of receptors to form a microarray.

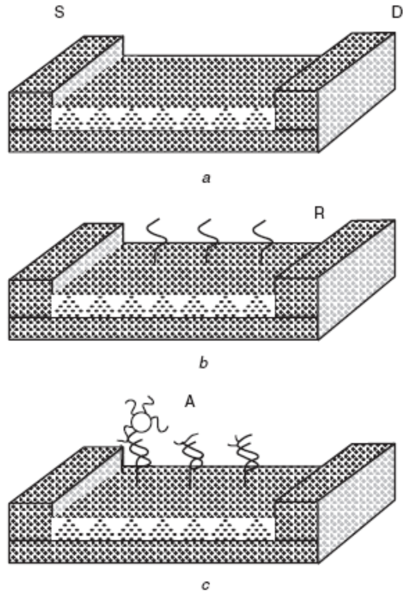

Fig. 9 *Schematic representation of detection of biological molecules using a nanowire spin filter (S. von Molnar and J.M. Zavada, private communication)*
a Spin-polarised electrons passing in nanoscale wire from source region S to detector region D
b Bioreceptors R attached to nanoscale wire
c Bonding of a single receptor R_i with a bioagent A

Summary and conclusions

There is a strong need for a practical device demonstration showing spin functionality at room temperature in a nitride-or oxide-based structure, such as spin LED or tunneling magnetoresistance devices. The control of spin injection and manipulation of spin transport by external means such as voltage from a gate contact or magnetic fields from adjacent current lines or ferromagnetic contacts is at the heart of whether spintronics can be exploited in device structures and these areas are still in their infancy. There has been tremendous progress in developing GaMnAs, TiO_2, SnO_2 and other materials, in addition to the materials we have focused on here, and steadily improving curie temperatures suggest that the control of synthesis is much better than even a year ago. The challenge is now to translate this to device embodiments. In particular, there is also a need to examine the device operation from a theory viewpoint first, to ensure that spintronics does in fact have an advantage for that device function.

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References

1. Wolf, S.A., Awschalom, D.D., Buhrman, R.A., Daughton, J.M., von Molnar, S., Roukes, M.L., Chtchelkanova, A.Y., and Treger, D.M.: ‘Spintronics: a spin-based electronics vision for the future’, *Science*, 2001, 294, p. 1488
2. von Molnar, S.: ‘Spin electronics: from concentrated to diluted magnetic semiconductors and beyond’, *J. Supercond.*, 2003, 16, pp. 1-5
3. von Molnar, S., and Read, D.: ‘New materials for semiconductor spintronics’, Proc. *IEEE*, 2003, 91, p. 715