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Current and Upcoming Innovations in Spintronics

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ABSTRACT

In the present paper, authors briefly discussed the field of spintronics which has explored new spin related physics, including giant magnetoresistance, tunneling magnetoresistance, and spin transfer torque, which led to spin-based device applications.

Spintronics is a field of concentrate that exploits the intrinsic spin angular momentum of an electron. In conventional electronics, the charge degree of freedom of electron is considered and it focuses on improving the mobility or conductivity of the charge carriers. Whereas in spintronics, the spin degree of freedom of an electron in addition to its charge state is considered and it focuses on generation or manipulation of a spin polarized population of electrons, aiming at using the electron spins for efficient data storage and communication methods.

Keywords : Spintronics, Spin-based device, Spin angular momentum, Giant Magnetoresistance.

I. INTRODUCTION

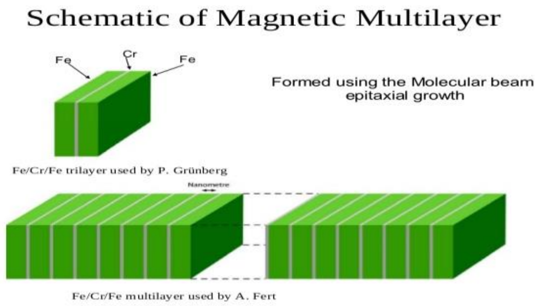
In order to overcome the current challenges of microelectronics devices such as the power dissipation and downscaling, researchers have been exploring an additional intrinsic property of electron, called spin. The field of spin electronics or spintronics has explored new spin related physics, including giant magnetoresistance, tunneling magnetoresistance, and spin transfer torque, which led to spin based device applications.

The origin of spintronics goes back to the first understanding of the electrical conduction in transition metals by Mott in 1936, who described the conduction of electrons in ferromagnetic(F) materials as a combination of two individual current channels, one channel consisting of electrons with spins parallel to the magnetization axis of F and the other with electron spins oriented in opposite direction[1]. Spintronics materials are the material retaining the spin polarization for a long duration.

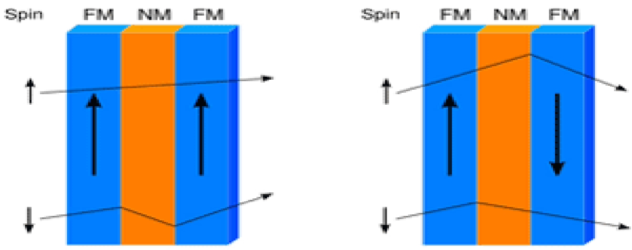
Magnetoresistance is that the tendency of a material (preferably ferromagnetic) to vary the value of its resistance in associate externally applied field of force. The first magnetoresistive effect was discovered by William Thomson, better called as Lord Kelvin, in 1856, but he was not able to lower the electrical resistance of anything by more than 5%. Nowadays, systems e.g.- semimetal or concentric ring EMR structures are better known whereever a magnetic field can change resistance by orders of magnitude[2]. There are a range of effects that can be called magneto resistance: some occur in bulk non-magnetic metals and semiconductors, such as geometrical magnetoresistance, Shubnikov de Haas oscillations, or the common positive magnetoresistance in metals [3]. Different effects occur in magnetic metals, like negative magnetoresistance in ferromagnets or anisotropic magnetoresistance (AMR)[4]. Finally, in multicomponent or multilayer systems (e.g.- magnetic tunnel junctions), giant magnetoresistance (GMR), tunnel magnetoresistance (TMR), colossal magnetoresistance (CMR), and extraordinary magnetoresistance (EMR) can be observed. Magnetoresistance converts magnetic signal into electrical signal.

II. GIANT MAGNETORESISTANCE (GMR)

The giant magnetoresistive (GMR) effect was discovered in 1988 in multilayered structures of ferromagnetic and non-ferromagnetic thin films by Grunberg,Binaschetal [5] as well as Fert, Baibich et al[6].



In principle, a typical GMR structure consists of a pair of ferromagnetic thin film layers separated by a non-magnetic conducting layer. The change in the resistance of this multilayer arises once the externally applied magnetic field aligns the magnetic moments of the successive magnetic layers. In absence of a magnetic field, the magnetic moments of the magnetic layers are antiparallel. Once a magnetic field is applied, the magnetic moments of the magnetic layers align with regard to each other; their magnetizations are parallel. This yields a drop in the resistance of the multilayer. Basically, the GMR is gotten from the connection of current conveying electrons and the polarization of the host attractive material. In the presence of a magnetic field the spin-dependent electron scattering among the structure reduces and the electrical resistance decreases [7, 8]. GMR structures have an advantage in size, power consumption, cost and thermal stability with respect to search coil, fluxgate, SQUID, Hall and spin resonance sensors. Furthermore, GMR sensors are ideal for low cost applications since they are simply energized by applying a constant current and the output voltage is a measure of the magnetic field[9]. The resistance of Magnetoresistance is higher if the field is parallel to the current and lower if the field is perpendicular to the current [10]. The phenomenon that the resistance of a ferromagnetic material depends on the relative angle between the current and magnetization direction of the material is known as the anisotropic Magnetoresistance effect, or AMR , that was discovered by Thomson in 1857[11].



The reason for the changing electrical resistance is that the spin dependence of an electron transport, that affects the scattering rates at film interfaces for spin-up (spin parallel to layer magnetization) and spin-down (spin antiparallel to layer magnetization) electrons[12].

III. LITERATURE SURVEY

Mohamed et al [13] carried out the research on alternative method for realizing a carbon nanotube spin field-effect transistor device by the direct synthesis of single-walled carbon nanotubes (SWNTs) on substrates by alcohol catalytic chemical vapor deposition. They observed hysteretic magnetoresistance (MR) at low temperatures due to spin-dependent transport. In their devices, the maximum ratio in resistance variation of MR was found to be 1.8%.

Shinji Yuasa et al [14] reported a giant MR ratio up to 180% at room temperature in single-crystal Fe/MgO/Fe MTJs. The origin of this enormous TMR effect is coherent spin-polarized tunneling, where the symmetry of electron wave functions plays an important role. Moreover, they observed that their tunnel magnetoresistance oscillates as a function of tunnel barrier thickness, indicating that coherency of wave functions is conserved across the tunnel barrier.

Xiong et al[15] report the injection, transport and detection of spin-polarized carriers using an organic semiconductor as the spacer layer in a spin-valve structure, yielding low-temperature giant magnetoresistance effects as large as 40 per cent.

Husmann et al [16] describe a hitherto unexplored class of magnetoresistive compounds, the silver chalcogenides. At high temperatures, the compounds Ag_2S, Ag_2Se and Ag_2Te are superionic conductors; below ~400 K, ion migration is effectively frozen and the compounds are non-magnetic semiconductors, that exhibit no appreciable magnetoresistance. They show that slightly altering the stoichiometry can lead to a marked increase in the magnetic response. At room temperature and in a magnetic field of ~55 kOe, $Ag_{2+\delta}Se$ and $Ag_{2+\delta}Te$ show resistance increases of up to 200%, which are comparable with the colossal-magnetoresistance materials.

Mazhar N. Ali et al [17] report the observation of an extremely large positive magnetoresistance at low temperatures in the non-magnetic layered transition-metal dichalcogenide WTe_2: 452,700 per cent at 4.5 kelvins in a magnetic field of 14.7 teslas, and 13 million per cent at 0.53 kelvins in a magnetic field of 60 teslas.

Stefan Schmaus et al [18] demonstrate giant Magnetoresistance across a single, non-magnetic hydrogen phthalocyanine molecule contacted by the ferromagnetic tip of a scanning tunnelling microscope. They measure the magnetoresistance to be 60% and the conductance to be $0.26G_0$, where G_0 is the quantum of conductance. Theoretical analysis identifies spin-dependent hybridization of molecular and electrode orbitals as the cause of the large magnetoresistance.

K. S. Novoselov et al [19] describe monocrystalline graphitic films, which are a few atoms thick but are nonetheless stable under ambient conditions, metallic, and of remarkably high quality. The films are found to be a two-dimensional semimetal with a tiny overlap between valence and conductance bands, and they exhibit a strong ambipolar electric field effect such that electrons and holes in concentrations up to 10^{13} per square centimeter and with room- temperature mobilities of ~10,000 square centimeters per volt-second can be induced by applying gate voltage.

IV. Applications

1) The largest technological application of GMR is in the data storage industry. IBM was first to place on the market hard disks based on GMR technology and theseadays all disk drives make use of this technology[20].
2) Other applications of GMR are as diverse as automotive sensors, solid-state compasses and non-volatile magnetic memories.
3) Magnetoresistive materials and structures are used as sensors for magnetic recording, MRAM, motion sensors or just simply to measure the strength of a magnetic field.
4) Spin valve sensors – used in ABS and ESP systems of car.
5) Quantum computers, Spin transistor etc.
6) Biomedical diagnostic devices.
7) Integrated spintronics biochips (neuroelectronic studies and biomedical imaging).

V. CONCLUSION

Giant Magnetoresistance is the large change in electrical resistance of metallic layered systems which occurs when the magnetizations of the ferromagnetic layers are reoriented relative to one another under the application of an external magnetic field. Both the electronic structure and the scattering of the conduction electrons in these systems are altered by reorientation of the magnetic moments, which causes the change in the resistance. Various types of magnetic layered structures have been found which show sizable values of GMR. In spintronics, the spin degree of freedom of an electron in addition to its charge state is considered and it focuses on generation or manipulation of a spin polarized population of electrons, aiming at using the electron spins for efficient data storage and communication methods.

VI. REFERENCES

[1]. Tian, Y., & Yan, S. (2012). Giant magnetoresistance: history, development and beyond. Science China Physics, Mechanics and Astronomy, 56(1), 2–14.

[2]. “Unstoppable Magnetoresistance.”

[3]. Pippard, A. B.: Magnetoresistance in Metals, Cambridge University Press (1989).

[4]. Coleman, R. V., Isin, A. “Magnetoresistance in Iron Single Crystals”, Journal of Applied Physics, 37 :1028, 1966.

[5]. Binasch, G., Grunberg, P., Saurenbach, F., Zinn, W. Enhanced magnetoresistance in layered magnetic structures with antiferromagnetic interlayer exchange. Phys. Rev. B 1989,39,4828-4830.

[6]. Baibich, M. N., Broto, J. M., Fert, A., Van Dau, F. N., Petroff, F. Giant Magnetoresistance of (001) Fe/(001) Cr Magnetic Superlattices. Phys. Rev. Lett. 1988,61,2472-2475.

[7]. Varadan, V.K., Chen, L., Xie, J. Nanomedicine: Design and Applications of Magnetic Nanomaterials, Nanosensors and Nanosystems; John Wiley & Sons, Ltd.: West Sussex,UK,2008.

[8]. Xu, L., Yu, H., Akhras, M.S., Han, S.-J., Osterfeld, S., White, R.L., Pourmand, N., Wang, S.X. Giant magnetoresistive biochip for DNA detection and HPV genotyping. Biosens. Bioelectron. 2008,24,99-103.

[9]. Gooneratne, C., Liang, C., Giouroudi, I., Kosel, J. An integrated micro-chip for rapid detection of magnetic particles. J. Appl.Phys>2012,111,07B327.

[10]. Principles of Nanomagnetism A.P. Guimaraes Springer-Verlag, Berlin,2009.

[11]. Thomson, W., Proc. R. Soc. 8,546(1857).

[12]. Lisa Jogschies, Daniel Klaas, RahelKruppe, Johannes Rittinger, PiriyaTaptimthong, Anja Wienecke, Lutz Rissing and Marc Christopher Wurz,; Recent Developments of Magnetoresistive sensors for Industrial Applications. Sensors 2015,15,28665-28689.

[13]. Mohamed, M. A., Inami, N., Shikoh, E., Yamamoto, Y., Hori, H., & Fujiwara, A. Fabrication of spintronics device by direct synthesis of single-walled carbon nanotubes from ferromagnetic electrodes. Science and Technology of Advanced Materials. 9(2), 2008, 025019.

[14]. Shinji Yuasa, Taro Nagahama, Akio Fukushima, YoshishigeSuZuki& Koji Ando; Giant room-temperature magnetoresistance in single-crystal Fe/MgO/Fe magnetic tunnel junctions; Nature materials 3, 2004, 868-871.

[15]. Xiong, Z. H., Wu, Di, ValyVardeny Z. & Jing Shi ; Giant magnetoresistance in organic spin valves; Nature 427, 26 February 2004, 821-824 .

[16]. Xu, R., Husmann, A., Rosenbaum, T. F., Saboungi, M. L., Enderby, J. E. & Littlewood, P. B. Large magnetoresistance in non-magnetic silver chalcogenides; Nature 390,06 November 1997, 57-60 .

[17]. Mazhar N. Ali, Jun Xiong, Steven Flynn, Jing Tao, Quinn D. Gibson, Leslie M. Schoop, Tian Liang, Neel Haldolaarachchige, Max Hirschberger, OngN. P. & CavaR. J.; Large non-saturating magnetoresistance in WTe2 .
[18]. Stefan Schmaus, Alexei Bagrets, Yasmine Nahas, Toyo K. Yamada, Annika Bork, Martin Bowen, Eric Beaurepaire, Ferdinand Evers & Wulf Wulfhekel ; Giant magnetoresistance through a single molecule; Nature Nanotechnology 6,2011, 185-189 .
[19]. Novoselov, K. S., Geim, A. K., Morozov, S. V., Jiang, D., Zhang, Y., Dubonos, S. V., Grigorieva, I. V. Electric field effect in Atomically thin Carbon films.
[20]. http://simple.wikipedia.Org/wiki/Giant magnetoresistance.