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Opinion

Outlook: Magnetic Memory and their Future

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Introduction

The 21st century is the information age represented by computers, mobile phones. Magneto-resistance random-access memory (MRAM) is a type of non-volatile memory, and the related product have a market value of tens of billions of dollars, which has grown exponentially in recent decades. In addition, MRAM could play a key role in high-tech products, and can use MRAM for face recognition, aerospace, 5G communication, etc.

As a commercialization model for magnetic chips, giant magneto-resistance (GMR) was first applied in magnetic hard disk reading technology and promoted the fast development of magnetic recording technology. Subsequently, magnetic tunnel junction devices based on tunneling magneto-resistance (TMR) have caught up, and their TMR values can be as high as 1000%. The emerging magnetic chip MRAM is composed of MTJ and complementary metal-oxide semiconductor (CMOS). The traditional MTJ in industrial production is composed of the ferromagnetic material CoFeB and the insulator material MgO. Compared with ferromagnetic materials, antiferromagnetic (AFM) materials have the characteristics of ultrafast dynamic, robustness against perturbation and no stray fields. Recent theoretical calculations show that the antiferromagnetic tunnel junction (CMOS) has a larger TMR. For example, by controlling the Nell vector of the non-collinear antiferromagnetic oxide Mn3Sn, a 300% TMR effect can be generated, and four nonvolatile resistance states can be generated. Another example is that the TMR in $RuO_2/TiO_2/RuO_2$ AMTJ is as high as 500%, which provides a new idea for reading AFM. In addition, not only the AFM oxide RuO_2 can be used as the magnetization layer in the AMTJ, but also can generate spin-neutral current, out-of-plane spin polarization, large spin splitting torque, and ultra-high spin Hall conductance. et al, which provides a new direction for our fully electronically controlled AFM materials.

In addition, non-collinear AFM (Mn3Sn, Mn3Pt, Mn3Ir, etc.) can lead to large anomalous Hall signals due to non-zero Berry curvature. In addition, due to spin splitting caused by the spin orientation of Mn atoms in their Kagome structure, which can bring about a large magnetic spin Hall effect and z-direction spin current, which also accelerates the research and development of spintronic devices. Moreover, the previous work also found better spin transport properties in non-collinear antiferromagnetic Mn3Sn, such as large spin Hall angle, good thermoelectric transport properties, etc. In conclusion, the AFM materials have week magnetic moment, and robustness against external magnetic fields, which is beneficial to the research and exploration of AMTJ devices. The AMTJ will be ideal to design ultra-high-density, ultra-fast magnetic memory.

AFM materials represent the future spintronis. Firstly, the mechanism of TMR on antiferromagnetic/insulator/antiferromagnetic tunnel junctions is unclear. Significant experiment is very urgent to achieve. The electrical measurement device can be obtained

by lithography technology and ETCH technology. The material properties need to be characterized in detail, and the tunneling magneto-resistance of the device under different growth processes and different measurement temperatures is studied. On this basis, further explore the dependence of material property such as crystallinity, oxygen comoposition ratio and film thickness on TMR, reveal the underlying physical mechanism, and optimize parameters to obtain the maximum TMR value. Compared with traditional ferromagnetic materials, the physical mechanism behind antiferromagnetic tunneling magneto-resistance is more complex. So it is harder to reveal the physical mechanism related to antiferromagnetic spin in detail, including magnetic spin Hall effect, magnetic spin Hall. It is expected to obtain high-performance pure electronically controlled antiferromagnetic spin devices. Secondly, we need study the AFM spin-orbit torque random-access memory (ASOT-MRAM).

As the latest generation of magnetic chips, SOT-MRAM has the advantages of low power consumption, high speed, and high durability, and realizes the separation of read and write on the basis of traditional magnetic chips. It is the most ideal chip to realize the integration of storage and computing. Compared with ferromagnetic materials, antiferromagnetic materials have ultra-high speed and ultra-stability performance, so it will be very meaningful work to realize ASOT-MRAM. It is necessary to carry out research on SOT switching of different antiferromagnetic materials, and clarify the physical mechanism behind the current switching of the antiferromagnetic Neel vector. Most importantly, enhancing the Tunneling magneto-resistance of AMTJ will optimize the performance of antiferromagnetic SOT-MRAM. Thirdly, in the research of SOT-MRAM, the required auxiliary field is often provided by introducing a by the exchange bias of between the interface of ferromagnetic and antiferromagnetic hetorostructure. However, how to achieve field free SOT switching will be a huge challenge problem.

Two methods can be tried to realize the antiferromagnetic SOT-MRAM device under zero field:

1. By designing the wedge-shaped film to introduce the effective field by breaking the symmetry, to achieve field free SOT switching.

2. Providing the required auxiliary field by exchange bias.

Several features and innovations of the AMTJ are mainly in the following aspects:

A. It will realizes logic devices with ultra-high speed and ultra-small size through the proposed new type of magnetic chip. It is possible to achieve more than 100% TMR for AMT which will have smaller size and higher reading speed.

B. It is a new method to control AFM by tunneling effect and it is a new method to characterize AFM.

C. It will be possible to design the next-generation AFM MRAM by SOT controlling the AFM Neel vector.

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