Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp553-554

K-7-01

Magnetic phase transition induced tunneling anisotropic magnetoresistance in FeRh-based junctions

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Abstract

Magnetic tunnel junctions (MTJs) with only one ferromagnetic electrode exhibit tunneling anisotropic magnetoresistance (TAMR) dependent on the anisotropic density of states, but no room temperature performance so far. In this talk we will present an alternative approach to obtaining TAMR in α'-FeRh-based MTJs driven by the magnetic phase transition of α'-FeRh and resultantly large variation of the density of states in the vicinity of MgO tunneling barrier, referred to as phase transition tunneling anisotropic magnetoresistance (PT-TAMR). The MTJs with only one α'-FeRh magnetic electrode show a PT-TAMR ratio up to 20% at room temperature. Both the polarity and magnitude of the PT-TAMR can be modulated strongly by interfacial engineering at the α'-FeRh/MgO interface. Besides the fundamental significance, our finding might add a different dimension to magnetic random access memory and antiferromagnet spintronics.

1. Introduction

CsCl-ordered FeRh (α'-FeRh) films, show a first order phase transition from antiferromagnetic (AFM) to ferromagnetic (FM) order, which can be driven by temperature or magnetic field above room temperature [1]. Such an AFM–FM transition means a strong variation of magnetic ground state accompanied by a large DOS variation at the Fermi level [2,3]. Thus, it would be fundamentally transformative if the magnetic phase transition of α'-FeRh was used to drive the tunneling effect. Basically, the AFM–FM transition itself is associated with an obvious change of resistance, but the current-in-plane geometry is not capable for implementing high density storage, thus demanding the experimental exploitation of MTJs structure with current-perpendicular-to-plane geometry as the basis of memories with a cross bar structure. Furthermore, considering the low lattice misfit between MgO and α'-FeRh, a MgO (001) substrate is commonly chosen for the deposition of epitaxial α'-FeRh [3,4], while epitaxial growth of MgO tunneling barrier is highly expected on the top of α'-FeRh bottom electrode, which would be beneficial for achieving sizeable tunneling effect. The experiments below demonstrate an α'-FeRh magnetic phase transition TAMR (PT-TAMR) with the ratio up to 20% at room temperature in MTJs with only one α'-FeRh magnetic electrode, and the polarity and magnitude of PT-TAMR are profoundly dependent on the design of the α'-FeRh/MgO interface.

2. General Instructions

α'-FeRh(30 nm)/MgO(2.7 nm)/γ-FeRh(10 nm) sandwich films were grown on MgO(001) substrates by magnetron sputtering. Correspondingcross-sectional *Z*-contrast scanning transmission electron microscopy (STEM) image is shown in Fig. 1(a). The typical resistance-area (RA) product of the α'-FeRh/MgO/γ-FeRh junctions as a function of temperature (RA–T) is presented in Fig. 1(b). The curves were recorded with a bias voltage of 5 mV. The most eminent feature is that a clear "first order" phase transition emerges in the RA–T curves, reflecting that the magneto-transport in the MTJs is controlled by the magnetic phase transition of the α'-FeRh bottom electrode, accompanied by a PT-TAMR ratio of ~20%, higher than our previous TAMR (< 1%) in IrMn-based junctions [5].

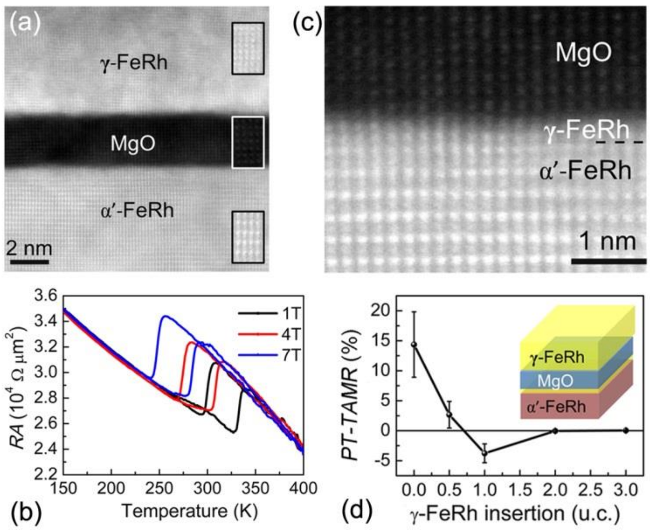

Fig. 1. (a) Cross-sectional z-contrast STEM image of the stack films. (b) Resistance-area (RA) product of the α'-FeRh/MgO/γ-FeRh junctions as a function of temperature. (c) high resolution STEM Z-contrast image with one unit cell-thick γ-FeRh naturally superimposed at the α'-FeRh/MgO interface. (d) A summary of the PT-TAMR ratio as a function of the thickness of γ-FeRh insertion.

A closer inspection of the RA–T curves shows that a low resistance state–high resistance state (LRS–HRS) switching (defined as the positive polarity) is associated with the

AFM–FM transition, different from the HRS–LRS switching (the negative polarity) in the α'-FeRh electrode, hence exhibiting an opposite polarity for the junction and the electrode. The total DOS of one Fe and one Rh atom in the nearest neighbor of α'-FeRh/MgO interface, reflecting the critical role of the interfacial magnetic layer on the tunneling effect. Remarkably, the DOS of the AFM state overwhelms its FM counterpart at Fermi level, accounting for the lower tunneling resistance in the AFM state compared to the FM case, i.e. the positive polarity.

Figure 1(c) shows that one unit cell-thick γ-FeRh is naturally superimposed at the α'-FeRh/MgO interface. This unintendedly ultrathin layer is most likely generated by a part of Fe diffusion into the MgO barrier, which was supposed to occur at their interface, and then the Rh-rich composition makes it transform from ordered α'-FeRh to disordered γ-FeRh. To check the influence of the emerging γ-FeRh thickness on the PT-TAMR behavior, 0.5 to 3 u.c.-thick γ-FeRh grown at room temperature were intentionally inserted between α'-FeRh and MgO. As shown in Fig. 1(d), for the insertion of 0.5 u.c.-thick γ-FeRh, the positive polarity of RA–$\mu_0 H$ curve remains but with a PT-TAMR ratio of ~3.5%, much lower than the one without insertion. The scenario differs dramatically when the insertion is up to 1 u.c.-thick γ-FeRh, the PT-TAMR gets reversed from positive to negative. It is found that the PT-TAMR induced by the magnetic phase transition nearly vanishes when the insertion of γ-FeRh is increased to 2 u.c. or above, especially taking the natural existence of 1 u.c.-thick γ-FeRh into account. This tendency could be understood that the interfacial γ-FeRh near the MgO tunneling barrier, which dominates the tunneling effect, has no magnetic phase transition.

3. Conclusions

In summary, the PT-TAMR ratio up to 20% at room temperature in α'-FeRh/MgO/γ-FeRh junctions is driven by the magnetic phase transition of α'-FeRh in the vicinity of the MgO tunneling barrier. The oxygen diffusion into the naturally formed ultrathin (1 u.c.) γ-FeRh at α'-FeRh/MgO interface, making the α'-FeRh contact the oxides, leading to the DOS reversal at the Fermi level for the AFM and FM states. As a result, the junctions show the opposite polarity from the bulk α'-FeRh. Both the γ-FeRh insertion and annealing of stack films, which generate 2 u.c.-thick γ-FeRh at the α'-FeRh/MgO interface, exclude the effect of Fe-O hybridization on the DOS of α'-FeRh, making the junctions show the same polarity of the PT-TAMR as the α'-FeRh bulk, but with reduced magnitude. Thus, our work not only brings about a different approach for the strong PT-TAMR effect but also provides ideas how to manipulate it by designable interfacial engineering [6].

Acknowledgements

We would like to express sincere thanks to all the contributors to this work: J. F. Feng, Z. C. Wang, J. Zhang, L. Jin, B. Zhang, F. Li, M. Jiang, Y. Z. Tan, X. J. Zhou, G. Y. Shi, X. F. Zhou, X. D. Han, S. C. Mao, Y. H. Chen, and X. F. Han. This work was financially supported by the National Natural Science Foundation of China (Grant No. 51671110) and Ministry of Science and Technology of the People's Republic of China (Grant No. 2016YFA0203800).

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