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自旋軌道矩對鐵磁層/反鐵磁層結構的影響

The influence of spin-orbit torque on ferromagnet/antiferromagnet bilayer

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研究重點:

本論文研究自旋軌道矩(spin-orbit torque)如何影響及翻轉鐵磁層和反鐵磁層介面的交換偏壓(exchange bias)。在過去若要改變交換偏壓，需要在外加磁場下，升高溫度到達反鐵磁材料的阻隔溫度(blocking temperature)，耗時且費力(耗能源)。我們發現，利用自旋霍爾效應(spin Hall effect)，即電流通過重金屬層(鉑)，可以產生自旋電子流，此自旋電子流不但可以翻轉鐵磁層，同時也會對鐵磁層/反鐵層界面的交換偏壓產生擾動，使其跟隨鐵磁層產生翻轉。另一方面，我們也做實驗驗證，電流通過產生的熱效應並未達到反鐵磁材料的阻隔溫度，不是交換偏壓翻轉的主要因素。

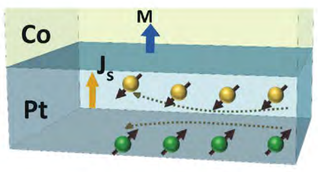
研究成果:

1. Introduction

Exchange bias (EB), a shift in the hysteresis loop of a ferromagnet arising from interfacial exchange coupling between adjacent ferromagnetic and antiferromagnetic layers, is an integral part of spintronic devices. Here, we show that spin-orbit torque generated from spin current, a promising approach to switch the ferromagnetic magnetization of next generation magnetic random access memory (MRAM), can also be used to manipulate the exchange bias. This implies that the ferromagnetic magnetization and exchange bias can be manipulated independently. Our work demonstrates that spin-orbit torque in ferromagnet/antiferromagnet heterostructures facilitates independent manipulations of distinct magnetic properties, motivating innovative designs for future spintronics devices.

Spin orbit torque

One of the origins for spin-orbit torque (SOT) is **spin Hall effect**



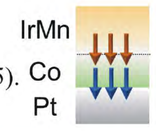
When a current flows through the heavy metal, the transverse spin current (J_s) will be generated with spin polarization in the orthogonal direction.

Antiferromagnet and exchange bias

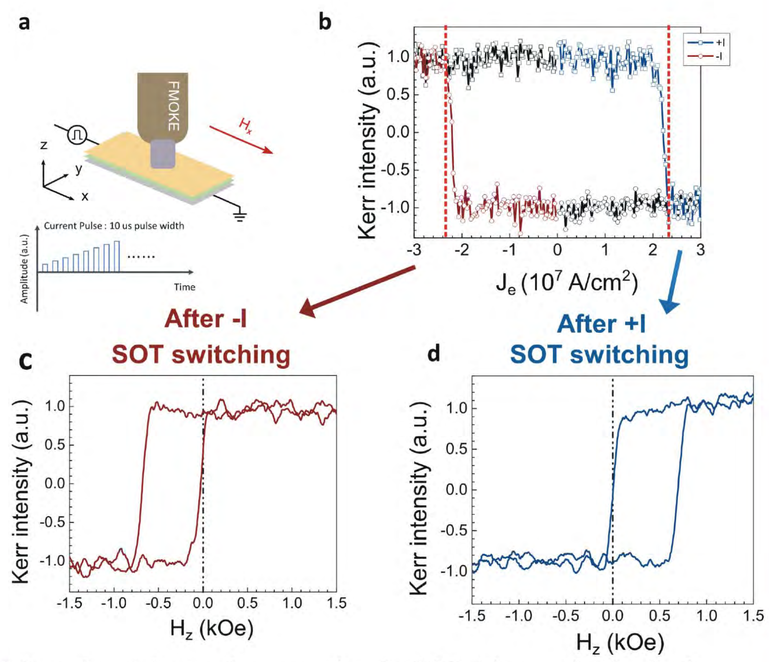
IrMn is an antiferromagnetic material. The exchange bias is formed when FM/AFM is put together.

Core component: Pt/Co/IrMn

We prepared the sample by DC sputtering. The film structure is Substrate//Ti(2)/Pt(2)/Co(1.2)/ IrMn(6, 8)/Ti (5). Unit: nm.

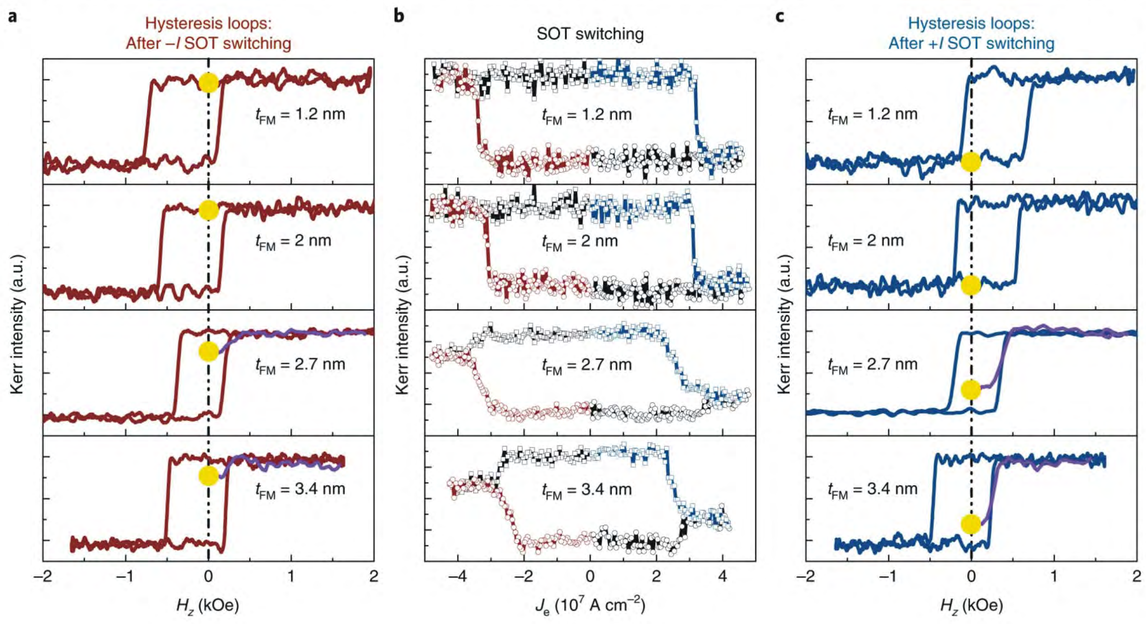


2. SOT-driven switching and the current-pulse-induced EB reversal



(a) Experimental setup for measuring the SOT-driven switching by focus-magneto-optical Kerr effect (FMOKE). (b) The SOT switching curve under the Hx = 300 Oe. The current pulse width = 10 us. (c)(d) The negative pulses (red line) reverse the magnetization from negative to positive and shift the easy axis loop to the left. The opposite behavior can be observed when we apply the positive pulses (blue line) through the wire.

3. Thickness dependence of exchange bias reversal in SOT switching



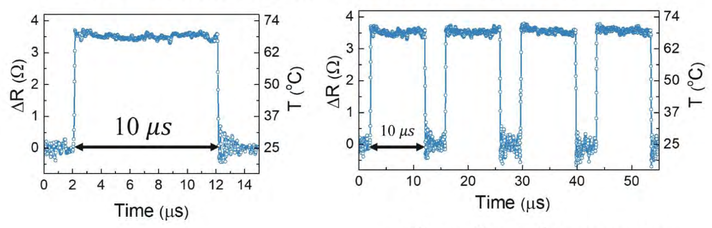
(a–c) Samples with the heterostructure Pt(2)/[Co(t_{Co})/Ni(t_{Ni})]n/IrMn(8) and different FM thickness are investigated. The hysteresis loops after SOT switching with −I and +I current pulses are shown in a and c, respectively, and the corresponding SOT switching curve is shown in b. The in-plane Hx= 300 Oe is applied for SOT switching. The initial magnetization after SOT switching is denoted by yellow circles in a and c and the purple lines represent the initial curves. However, for thicker FM layer (t_{FM} = 2.7 nm), although concurrent SOT switching is still observed, the FM switching is incomplete due to multi-domains. Finally, for t_{FM} = 3.4 nm, the FM layer is too thick for spin current to reach the AFM/FM interface so the exchange bias remains intact after SOT switching of the (incomplete) FM magnetization

4. Discussion

I. Joule heating effect: Pt (2)/Co(1.2)/IrMn(6) (nm)

Time-resolved resistance measurement (TRRM)：

The Joule heating alone is not enough to switch the exchange bias, because the **temperature during the pulse region is below the blocking temperature**.

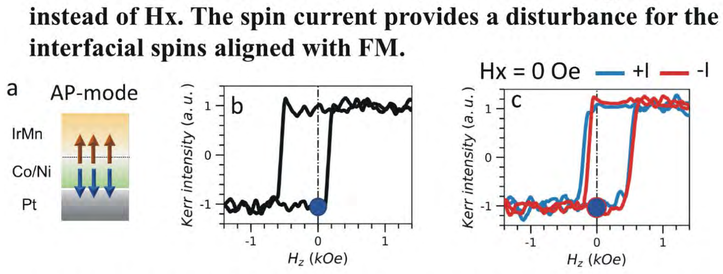


$$\Delta R = R - R_0$$
$$T = T_0 + \gamma \Delta R = 67.5 \pm 1.7°C$$
$$\gamma = 12.27\ K/\Omega, where\ \gamma = dT/dR$$

The estimated temperature (67.5°C) at critical switching current is below the blocking temperature (90°C)

II. Effects of Hx on SOT-driven switching and EB reversal.

The reversal of interfacial spins depends on FM magnetization, instead of Hx. The spin current provides a disturbance for the interfacial spins aligned with FM.



(a) The FM magnetization and the interfacial spins between AFM and FM layers in the sample Pt(2)/[Co(0.2)/Ni(0.8)]$_2$/IrMn(8) are initially configured in antiparallel directions for AP-mode switching. (b) The initial EB is evident by the shifted M-H curve. (c) In the absence of longitudinal magnetic field, either +I or –I current pulse will reverse the EB direction (shifted loop to the right).

研究生活及心得：

感謝中技社給予的肯定，是對我在研究路途上的一大鼓勵。同時也要感謝指導教授賴志煌老師在研究過程中的指導，讓我學習到做研究的精神和做事的態度。另外也要謝謝合作的老師，林秀豪老師，帶我從不同面向看研究以及做研究的熱誠。以及謝謝實驗室夥伴的互相的幫忙和支持，和一路上做研究上許多人的幫忙。

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