Field-free spin orbit torque switching of perpendicular antiferromagnet/ferrimagnet structures for SOT-MRAM

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I. INTRODUCTION

The manipulation of magnetization using electrical approaches allows us to realize energy-efficient and high performance spintronic devices. Conventional approach using a torque derived from spin-polarized current has created novel magnetic memory and logic devices, such as spin-transfer-torque magnetoresistive random access memory (STT-MRAM).[1] Recently, a new magnetization switching mechanism has emerged which is known as spin-orbit torque (SOT) switching. An in-plane current injected into a nonmagnetic layer (NM)/ferromagnet (FM) heterostructure with NM having large spin-orbit coupling, generates spin-current in the vertical direction. SOT induced magnetization switching has attracted much attention. Field-free SOT induced magnetization switching has been realized and demonstrated for in-plane magnetized MTJs. For memory applications, materials with perpendicular magnetic anisotropy (PMA) have advantages in terms of better thermal stability, improved scalability and faster switching.[1] However, SOT induced magnetization switching for materials with PMA requires breaking the symmetry with an in-plane field, which is an obstacle for practical applications. Up to now, a few efforts have been made to realize field-free SOT induced magnetization switching of materials with PMA in a bilayer system, either using a thin Co(Fe), CoFeB layer with interfacial PMA, or using Co/Ni multilayers.[2-8] All of these stacks are ferromagnets with large saturation magnetization (M_s). Recently, SOT induced switching has also been realized in TbFeCo with bulk PMA.[9] Here, we show a novel composite stack of CoFeB/Gd/CoFeB layers combined with antiferromagnetic PtMn as spin Hall channel, which show the good bulk PMA and low M_s.[10] Current induced SOT switching has been demonstrated in the absence of external magnetic field with reduced switching current density both in a bilayer and in a perpendicular magnetic tunnel junction (MTJ) structure.

II. EXPERIMENTAL DETAILS

Films were deposited onto a thermally oxidized silicon wafer at room temperature (RT) in a six-target Shamrock sputter tool. The layer structure of the bilayer film is (from bottom to top) Ta 5/$Pt_{50}Mn_{50}$ (PtMn) 10/$Co_{20}Fe_{60}B_{20}$ (CoFeB) 0.6/Gd 1.2/CoFeB 1.1/MgO 2/Ta 2 (thickness in nm). For the MTJs, the layer structure is Ta 5/PtMn 10/CoFeB 0.6/Gd 1.2/CoFeB 1.1/MgO 2/CoFeB 1.4/Ta 5 (in nm). The thickness of each layer was optimized to achieve a good PMA. All the films were patterned into Hall-bar devices using a standard photolithography and ion milling process to perform SOT switching measurement. Then the Hall bar devices were annealed at 300 °C for half an hour under a field of 5 kOe along the current channel direction to set an in-plane exchange bias. All measurements were performed at RT. The width of the current channel in the Hall bar devices was either 6 μm or 12 μm.

III. RESULTS AND DISCUSSIONS

The hysteresis loops with sweeping fields in the out-of-plane and in-plane directions for an un-patterned bilayer film after the same annealing condition were measured, as shown in Fig. 1(b), and show a good PMA and weak in-plane exchange bias (H_{ex} ~ 22 Oe), induced from the PtMn/CoFeB interface. The M_s is as low as ~ 370±20 emu/cm^3, because the CoFeB and Gd layers are antiferromagnetically exchange-coupled with each other. Field-free SOT switching was observed in this bilayer structure, as shown in Fig. 1(c), where the switching current density was about ~ 9.6×10^6 A/cm^2. The spin Hall angle of PtMn was determined to be ~ 0.084±0.005 by performing a second harmonic Hall measurement. Besides, SOT induced switching was also observed in a perpendicular MTJs with good tunneling magnetoresistance (TMR) at zero external magnetic field, as shown in Fig. 2(b-c). Our structures are well compatible with perpendicular MTJs due to the use of CoFeB, which could realize field-free three-terminal perpendicular MTJs and lead the application of novel SOT-MRAM.

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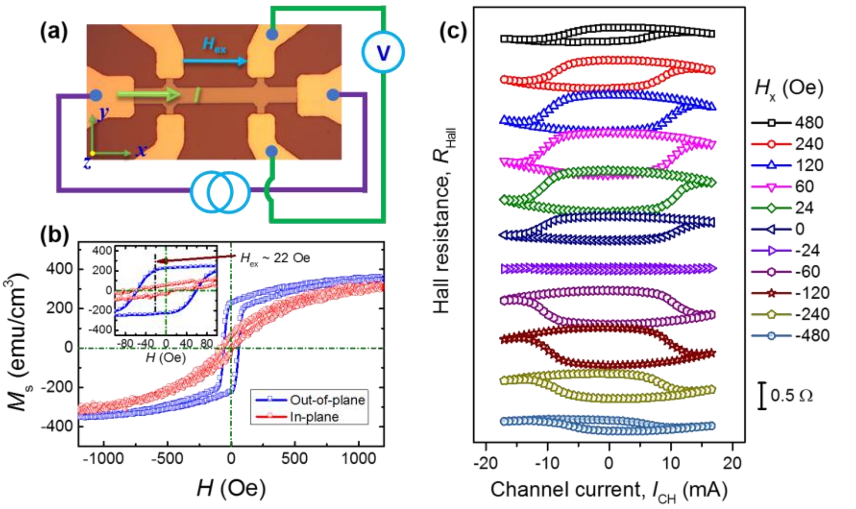

Fig. 1. SOT switching of CoFeB/Gd/CoFeB layers with PtMn spin Hall channel. (a) An optical micrograph of the fabricated Hall bar device and measurement configuration. (b) Out-of-plane and in-plane hysteresis loops of un-patterned CoFeB/Gd/CoFeB film with same field annealing condition, which shows M_S is about 370±20 emu/cm^3 and in-plane exchange bias field is about ~ 22 Oe. The inset is the enlarged hysteresis loops, to show the clear exchange bias field. (c) The Hall resistance (R_{AHE}) with sweeping channel current under various in-plane external magnetic field (H_x) for a 6-μm-wide Hall bar device in our CoFeB/Gd/CoFeB stacks.

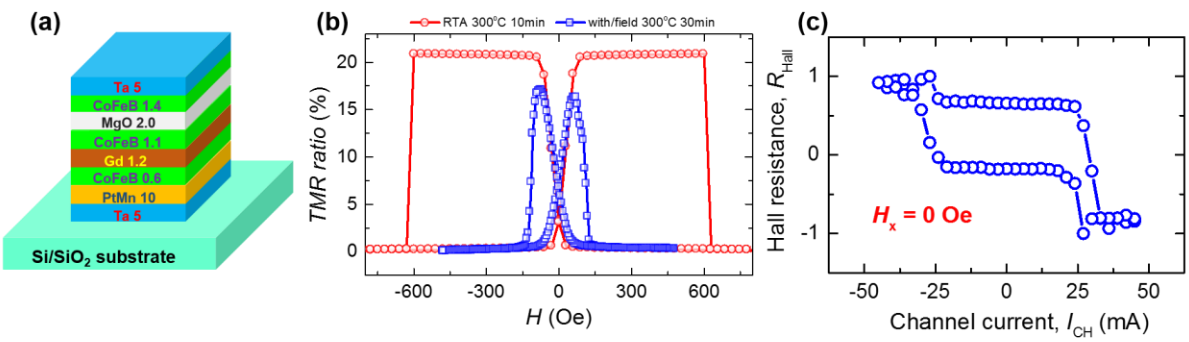

Fig. 2. SOT switching in a perpendicular MTJs. (a) Schematic of perpendicular MTJ structure used in our experiment. (b) Typical tunneling magnetoresistance (TMR) loops with perpendicular magnetic field after different annealing conditions. (c) Field-free SOT switching a perpendicular MTJ stack in a Hall-bar device.