Nanosecond ultralow power spin orbit torque magnetization switching induced by BiSb topological insulator

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Spin-orbit torque (SOT) magnetization switching has become one of the central topics of non-volatile, low-power, and ultrafast magnetoresistive random access memory (MRAM) [1]. Ultrafast SOT switching was first confirmed in Pt/Co bi-layers, followed by Ta/Co, and W/CoFeB/MgO stacks with perpendicular magnetic anisotropy (PMA) [2-4]. However, using heavy metals as a spin source requires very high current densities due to the limitation of their spin-to-charge conversion efficiency. Topological insulators (TIs) with spin-momentum locking surface states are promising for a spin current source thanks to their giant spin Hall angle. Thus, SOT-MRAM based on TIs has potential for both ultralow-power and ultrafast operation [5]. However, SOT switching using TIs has been studied so far in the thermal activation regime with relatively long pulse currents (≥ 10 ns). For practical application of SOT-MRAM, it is essential to study the SOT performance of TIs in the non-thermal regime with nanosecond pulse width when the switching time is limited by domain wall velocity.

In this work, we studied SOT magnetization switching induced by a $Bi_{0.85}Sb_{0.15}$ layer on a Si/SiO_x substrate in both thermal activation and non-thermal regime with current pulse width τ down to 1 ns. For this purpose, we deposited a stack of $Bi_{0.85}Sb_{0.15}$(10 nm)/[Pt(0.4 nm)/Co(0.4 nm)]$_2$/insulating buffer on a Si/SiO_x substrate by magnetron sputtering, as shown in Fig. 1(a). We fabricated a 1000 nm × 800 nm Hall bar for SOT measurements, where the Pt/Co multilayers have a large PMA of H_k^{eff} = 6 kOe. Figure 1 (b) shows the threshold switching current density J_{th}^{BiSb} as a function of τ at H_x = 1 kOe. The red dashed line is fitting by the thermal activation model (τ >> 10 ns), which yields a zero-Kelvin J_{th0}^{BiSb} = 2.5×10^6 A/cm^2 and a thermal stability factor Δ = 35. Meanwhile, the green dashed line is fitting for the non-thermal regime using $J_{th}^{BiSb}=J_{th0}^{BiSb}+Q/\tau$, which yields a larger J_{th0}^{BiSb} = 4.1×10^6 A/cm^2 but still smaller than those observed in heavy metals by nearly two orders of magnitude. Figure 1(c) shows SOT switching loops at various τ from 4 ns to 1 ns. We successfully demonstrate SOT-induced magnetization down to τ = 1 ns. We also found that the domain wall velocity of Pt/Co multilayers driven by BiSb is as fast as 470 m/s at a modest J^{BiSb}=1.6×10^7 A/cm^2. Figure 1(d) demonstrates deterministic SOT switching in our device by multi pulses (J^{BiSb}=1.3×10^7 A/cm^2, τ = 3 ns) at H_x = -1 kOe and +1 kOe. These results demonstrate the potential of BiSb for ultra-fast operation of SOT-based spintronic devices.

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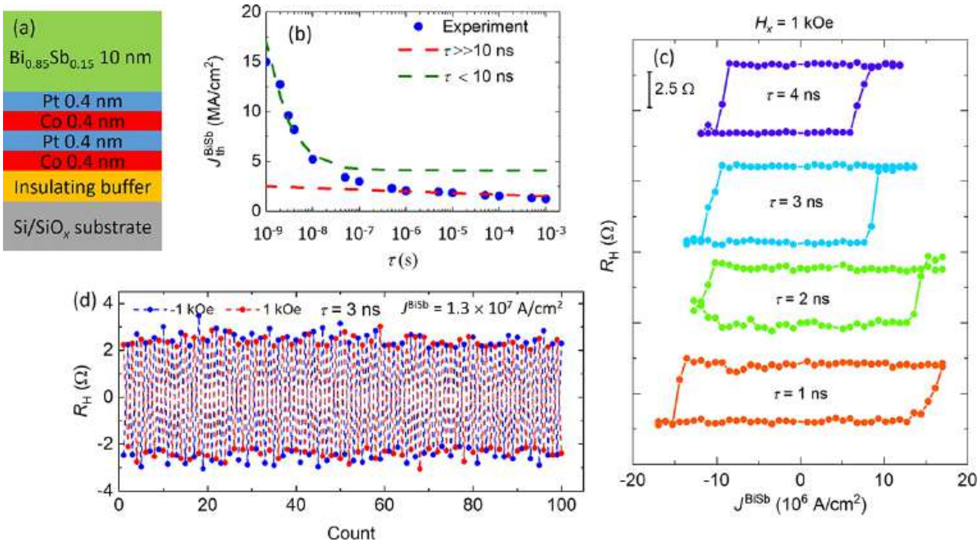

Fig. 1. (a) Schematic structure of our stack for nanosecond ultralow power SOT switching using BiSb. (b) Threshold switching current density J_{th}^{BiSb} as a function of pulse width τ at H_x = 1 kOe measured in a 1000 nm × 800 nm Hall bar device. The red dashed line is fitting by the thermal activation model (τ >> 10 ns), and the green dashed line is fitting for the non-thermal regime using $J_{th}^{BiSb}=J_{th0}^{BiSb}+Q/\tau$. (c) SOT switching loops at various τ from 4 ns to 1 ns. (d) Deterministic multiple switching at J^{BiSb}=1.3×10^7 A/cm^2, τ = 3 ns, and H_x = ±1 kOe.