Room-temperature colossal spin Hall effect in topological insulator $Bi_{0.9}Sb_{0.1}$(012) thin films for ultra-low-power spin-orbit-torque switching

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Spin-orbit-torque (SOT) switching using the spin Hall effect (SHE) in heavy metals and topological insulators (TIs) has great potential for ultra-low power magnetoresistive random-access memory (MRAM). To be competitive with conventional spin-transfer-torque switching, a pure spin current source with large spin Hall angle (θ_{SH} >1) and high electrical conductivity ($\sigma > 10^5\ \Omega^{-1}m^{-1}$) is required. However, there is no spin Hall material so far that satisfies these two conditions simultaneously; heavy metals (β-Ta, Pt, W) show high $\sigma \sim 10^5$-$10^6\ \Omega^{-1}m^{-1}$ but small spin Hall angle (θ_{SH} ~ 0.08-0.4) [1-3], while topological insulators (TIs) have large θ_{SH} ~ 2-18.8 but low $\sigma \sim 10^3$-$10^4\ \Omega^{-1}m^{-1}$ [4,5]). Here, we report the colossal SHE effect in conductive TI $Bi_{0.9}Sb_{0.1}$(012) thin films (5-10 nm). We demonstrate that $Bi_{0.9}Sb_{0.1}$(012) thin films have large $\sigma \sim 2.5\times10^5\ \Omega^{-1}m^{-1}$and colossal θ_{SH} ~ 52 at room temperature [6,7]. Figure 1(a) compare the room-temperature θ_{SH}, σ, and spin Hall conductivity σ_{SH} of several heavy metals and TIs. In term of σ_{SH}, BiSb outperforms the nearest competitor (Pt) by a factor of 30, and other TIs by a factor of 100. Figures 1(b) and 1(c) demonstrate SOT switching in a 100 μm×50 μm Hall bar of $Bi_{0.9}Sb_{0.1}$(012) (5 nm)/$Mn_{0.45}Ga_{0.55}$ (3 nm) bi-layer with an applied in-plane magnetic field of ±3.5 kOe, respectively. The critical current density of 1.5×10^6 A/cm^2 for SOT switching of MnGa is one to two orders of magnitude smaller than those using Ta, Pt, or IrMn, confirming the colossal SHE in BiSb(012). Thus, BiSb(012) is the best candidate for the spin current source in SOT-MRAM and possibly the first industrial application of topological insulators.

(a)

	θ_{SH}	σ ($\Omega^{-1}m^{-1}$)	σ_{SH} ($\frac{\hbar}{2e}\Omega^{-1}m^{-1}$)
β-Ta (ref.1)	0.15	5.3×10^5	0.8×10^5
β-W (ref. 2)	0.4	4.7×10^5	1.9×10^5
Pt (ref. 3)	0.08	4.2×10^6	3.4×10^5
Bi_2Se_3 (ref. 4)	2-3.5	5.7×10^4	1.1-2.0×10^5
Bi_xSe_{1-x} (ref. 5)	18.8	7.8×10^3	1.1-2.0×10^5
$Bi_{0.9}Sb_{0.1}$ (this work)	**52**	**2.5×10^5**	**1.3×10^7**

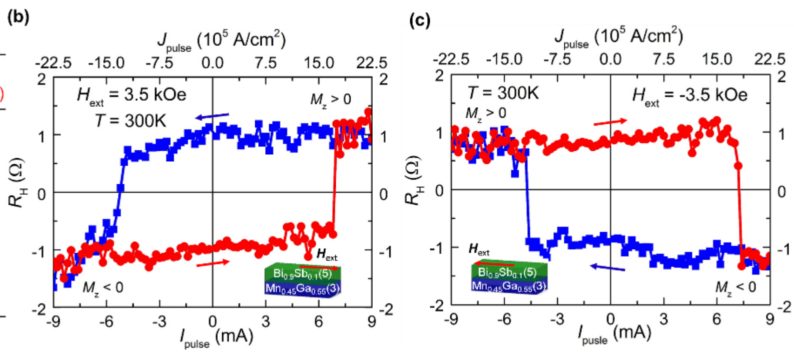

Fig. 1. (a) Room-temperature spin Hall angle θ_{SH}, electrical conductivity σ, and spin Hall conductivity σ_{SH} of several heavy metals and TIs. (b)(c) Room-temperature SOT switching in a 100 μm×50 μm Hall bar of $Bi_{0.9}Sb_{0.1}$(5nm)/$Mn_{0.45}Ga_{0.55}$(3nm) bi-layer under 100 ms pulse current and an in-plane H_{ext} of ±3.5 kOe, respectively.

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