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Dissertation Outline

Title: Integration of BiSb topological insulator and ferromagnetic multilayers for magnetic storage devices

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In this dissertation, we have demonstrated the feasibility of integrating BiSb topological insulator (TI) into two magnetic storage devices, i.e., spin-orbit torque (SOT) reader for hard disk drive (HDD) applications and SOT-magnetoresistive random access memory (MRAM).

In Chapter 1, we reviewed the development of computing technology in parallel with the emergence of memory technologies. The demand for artificial intelligent computing has stimulated the research for new memory technologies with ultralow power consumption, high speed of operation, and ultrahigh bit density.

In Chapter 2, we introduced the fundamentals of spin-orbit physics and emphasized the charge-to-spin conversion via the spin Hall effect (SHE) and the spin-to-charge conversion via the inverse SHE in non-magnetic materials. Furthermore, we presented TIs and their properties that can provide strong SHE. Finally, we focused on the conductive BiSb TI with a giant SHE that can be the spin Hall layer in many memory devices and its recent development.

In Chapter 3, we introduced the sputtering technique, and the Hall bar patterning process used to fabricate the devices in this dissertation. We also presented the superconducting quantum interference device, X-ray reflectivity, and diffraction measurements that were used to characterize the samples.

In Chapter 4, we have demonstrated a proof-of-concept BiSb-based SOT reader. With the use of BiSb as the spin Hall layer, we have achieved an output resistance as large as 1.1 Ω and an extracted giant inverse spin Hall angle of 61. This output value has exceeded the minimum requirement to obtain a signal-to-noise ratio of 28 dB for the HDD reader application. With such a large inverse spin Hall angle, our device can produce an output voltage of 15 mV with 9.4 kA/cm^2 even at room temperature. This performance is approximately two million times stronger than that of the Pt-based SOT reader, which indicates the potential of BiSb to serve in the SOT reader for beyond 4 Tb/in^2 HDD technologies.

In Chapter 5, we have successfully developed a perpendicular magnetized anisotropy (PMA) stack by inserting a CrO_x interfacial layer in between bottom BiSb and the trilayers of Ta/CoFeB/MgO on c-plane sapphire. Our findings provide a strategy to optimize the spin Hall angle and the PMA effective field for ultralow power SOT-MRAM cache memory. The CrO_x layer suppresses Sb diffusion, which can degrade BiSb performance via the intrinsic mechanism while providing a relatively good spin transparency. With a thin CrO_x of 1 nm, a relatively large spin Hall angle of 2.5 ~ 2.8 can be obtained, whereas the thicker CrO_x can enhance the PMA effective field significantly. The latter is suitable for low-level cache memories with long bit retention time related to the strong PMA effective field, while the former devices are promising for high-level cache memories thanks to the large spin Hall angle. Furthermore, we have also demonstrated the SOT magnetization switching by a small current density of 3.1 MA/cm^2 with a pulse width of 50 μs, which is an order of magnitude smaller than that in HMs.

In Chapter 6, we have investigated the feasibility of integrating bottom BiSb with a high-temperature process beyond its melting point on an amorphous oxidized silicon substrate. By introducing the combination of an oxide buffer, an additional oxide seed layer, and a protection layer, we can anneal BiSb at 400^0C in ultrahigh vacuum before sputtering the FM multilayers. The XRD spectra show that BiSb has been melted and recrystallized into a single phase from the as-grown polycrystalline. Furthermore, the transport measurement has shown that we have successfully realized PMA and a large spin Hall angle. We have also demonstrated SOT magnetization switching with a small current density. This work has proved the capability of integrating BiSb with complementary metal-oxide-semiconductor electronics using the back-end-of-line process, which opens a pathway to realize BiSb-based SOT-MRAM and other magnetic storage applications.