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Title(English)	Research on a pure spin current source using YPtBi topological semimetal and its device applications
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子 系 電気電子 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ 工学 ）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Topological materials, such as topological insulators (TIs), have great potential for ultralow power spin-orbit torque (SOT) spintronic devices thanks to their giant spin Hall effect (SHE) originated from their topological surface states (TSSs). However, the giant spin Hall angle ($\theta_{SH} > 1$) is limited to a few chalcogenide-based TIs with toxic elements and low melting points, making them challenging for device integration during the silicon Back-End-of-Line (BEOL) process. In this thesis, we have focused on a half-Heusler alloy topological semimetal (HHA-TSM), YPtBi, and evaluated the SHE in YPtBi, to overcome this difficulty.

In Chapters 1 and 2, we introduce the background and fundamental physics for spin Hall and ferromagnetic materials. These fundamental phenomena, especially, the Berry phase effects play important roles in this thesis.

In Chapter 3, we propose a generalized angle-resolved second harmonic technique to disentangle the magneto thermoelectric effects and SOT effective fields even in strong perpendicular magnetic anisotropy systems, which is used to precisely evaluate the SHE in YPtBi.

In Chapter 4, we evaluate the SHE in the YPt alloy which is one of the components of YPtBi. Although the SHE in the YPt alloy has the intrinsic contribution, the maximum value of θ_{SH} was 0.08 despite its higher resistivity than that of Pt. This result highlights the importance of the contribution of TSS in YPtBi to the giant SHE.

In Chapter 5, we synthesize YPtBi thin films by using co-sputtering at various substrate temperatures. According to the X-ray diffraction and X-ray fluorescence measurements, YPtBi thin films are stable up to 600°C which is high enough for BEOL process. To evaluate the SHE of YPtBi, we conduct the second harmonic measurement in CoPt/YPtBi heterostructures. By tuning the electric conductivity of YPtBi and the spin transparency at the CoPt/YPtBi interface, we successfully realize a giant θ_{SH} up to 4.1, which is much higher than those of each element of YPtBi or their non-topological alloys. We find that θ_{SH} is inversely proportional to conductivity which can be explained by the intrinsic mechanism of the SHE. Furthermore, θ_{SH} disappears when YPtBi thickness is 4 nm, indicating that the SHE is governed by TSS, which disappears below 4 nm due to interference of the top and bottom TSS, as well known in other TIs. We then demonstrate SOT magnetization switching in the CoPt/YPtBi heterostructures. Thanks to the giant SHE originated from TSS, a small threshold

current density of about 1×10^6 A/cm^2 is observed, which is one order magnitude smaller than that in heavy metals.

In Chapter 6, we evaluate the stoichiometry effect on the SHE in YPtBi. To understand the stoichiometry effect, we investigate the SHE while changing the composition ratio of Y/Pt from 0.5 to 1.9. We find that the θ_{SH} – conductivity relationship is similar to that observed in samples with exact stoichiometry, indicating that the SHE in YPtBi is robust against the change of its stoichiometry.

In Chapter 7, we investigate the SHE in YPtBi grown at low temperature. Although we observe the giant SHE in YPtBi in Chapters 5 and 6, the growth temperature was 600ºC, which was too high for BEOL process. To realize the giant SHE even at low temperature growth, we deposit YPtBi down to 300ºC using low Ar pressure. We then successfully obtain a giant θ_{SH} up to 8.2 by recovering the spin transparency at the CoPt/YPtBi interface and demonstrate efficient SOT magnetization switching by ultralow current density of ~10^5 A/cm^2 in YPtBi grown at 300°C with the Ar gas pressure of 1 Pa.

In Chapter 8, we investigate the SHE in YPtBi grown on SiO_2/Si substrates. We demonstrate high SOT performance of sputtered YPtBi films grown on SiO_2/Si substrates using buffer layers. We find that a 1 nm-thick Ta buffer layer realizes high quality YPtBi with large θ_{SH} of 1.3 and high conductivity of 1.4×10^5 $\Omega^{-1}m^{-1}$, which is comparable to the most conductive topological insulator BiSb grown on SiO_2/Si substrate.

In Chapter 9, we theoretically propose a bias-field-free spin Hall oscillator (SHO). We find the oscillation condition with no bias-field, and derive analytical solutions for typical parameters such as oscillation frequency, driving current, and so on, which are useful to design bias-field-free SHOs. We also confirm that YPtBi can effectively reduce the driving current for the proposed bias-field-free SHOs.

In Chapter 10, we summarize the achievements in this thesis. Our work opens the door to the next generation spintronic devices with YPtBi having both giant θ_{SH} and high thermal stability.