T2R2 東京科学大学 リサーチリポジトリ
Science Tokyo Research Repository

論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Terahertz time-domain spectroscopy on ordered magnetic alloys
著者(和文)	MaoHuiling
Author(English)	Huiling Mao
出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第12612号, 授与年月日:2023年12月31日, 学位の種別:課程博士, 審査員:佐藤 琢哉,藤澤 利正,納富 雅也,平原 徹,村上 修一
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第12612号, Conferred date:2023/12/31, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

Powered by T2R2 (Science Tokyo Research Repository)

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Physics 系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ Science ）
学生氏名： Student's Name	Mao Huiling	審査員主査： Chief Examiner	Takuya Satoh

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

A spintronic terahertz emitter, a class of new spintronics devices, radiates a single cycle terahertz (sc-THz) electromagnetic pulse from a magnetic metal/heavy metal bilayer. The fundamental concept of the emitter is outlined as follows: excitation of a magnetic metal with femtosecond laser pulses induces the pulses of a spin current in the magnetic metal, which subsequently enter a heavy metal layer and are converted into pulses of a charge flow via the inverse spin Hall effect. In spintronics, heavy metals are generally regarded as spin-to-charge converters with high conversion efficiency. In contrast, the capability of magnetic materials as a spin-to-charge converter has been disregarded because of relatively small conversion efficiency, in contrast to the importance of a spin current source. With these backgrounds, we aim to experimentally explore the possibility of magnetic materials given THz emitting layers by replacing a pure heavy metal layer with a magnetic one incorporating heavy metal elements. With this approach, we attempt to purse the question of whether the spin Hall effect and its inverse effect could be intentionally controlled in magnetic materials. Details of relevant backgrounds are compiled in Chapters 1 to 3, together with the objectives of this thesis.

In Chapter 4, a study on THz spectroscopy with antiferromagnetic $L1_2$-ordered Mn_3Ir layers is compiled. In the (111) planes, Mn atoms configure a Kagome lattice, inside which the Mn spins form an all-in/all-out magnetic order. The noncollinear spin configuration, with the assistance of the spin-orbit coupling, leads to the sizable anomalous Hall effect. We prepared a permalloy(Py)/Mn_3Ir multilayer on a MgO(111) substrate by DC sputtering at a substrate temperature of 600℃. The analysis of the x-ray diffraction measurements showed that the $L1_2$-order parameter of the Mn_3Ir layer is 0.33. We performed THz time-domain spectroscopy on the prepared multilayer and reference stacks, a Py single layer, Pt/Mn_3Ir multilayer, and Py/Pt multilayer, by employing the electro-optic effect of a THz crystal. The THz waveforms from the Py/Mn_3Ir were successfully measured, in contrast to much weaker THz intensities from the Py single layer and Pt/Mn_3Ir multilayer. Therefore, the THz waves from the Py/Mn_3Ir result from converting the spin currents from the Py layer to electric currents inside the Mn_3Ir layer. Furthermore, we estimated the spin Hall angle of the Mn_3Ir layer as a function of frequency by referring to the THz waveforms measured in the Py/Pt multilayer. The estimated values of spin Hall angle are approximately constant at 0.035 within a frequency range of 0.3-2.2 THz. The unexpectedly small spin Hall angle might result from the opposite signs of the spin Hall effect between $L1_2$-Mn_3Ir and disordered Mn_3Ir.

In Chapter 5, a study on THz spectroscopy in ferromagnetic disordered/ordered FePt alloy layers is compiled. Being encouraged by the successful observation of sc-THz emission in the Py/antiferromagnetic Mn_3Ir bilayers (Chapter 4), we have raised the following question of whether the spin Hall effect and its inverse effect could be altered by the incorporation of heavy metal elements in ferromagnetic layers. Referring to the critical contribution of ordering heavy metal ions in the layers, we have prepared disordered and ordered ($L1_0$) FePt layers with the fixed compositions of Fe and Pt for THz-emitting layers. Consequently, the structure of bilayers consists of Fe/Pt. Particular interest given THz emission with these samples has been to study the influence of order/disorder in FePt on the spin- and inverse-Hall effects through THz emission spectroscopy. The crystal ordering of FePt can be controlled by the deposition conditions, such as temperature, substrate orientation, etc. $L1_0$-FePt alloys are essential as a recording medium for hard disc drives. We deposited FePt alloys on MgO(001) substrates by DC sputtering at room temperatures and annealed the alloys at temperatures of 200℃, 300℃, 400℃, 500℃, 600℃ and 700℃. Also, we prepared a reference Fe single layer, Fe/Pt multilayer, and Pt/Fe multilayer on MgO(001) substrates. The $L1_0$ ordering parameters of the FePt alloys estimated by the x-ray diffraction measurements rapidly increase from 0 to 0.7 between 400℃ and 500℃, along with which the easy axis of magnetization transits from in-plane to out-of-plane directions. Conventional THz time-domain

spectroscopy measured the THz emission properties of these FePt alloys. Surprisingly, we observed the intense THz waves from the disordered FePt without annealing, about 8 times as large as the Fe/Pt multilayer. The THz emission from the FePt alloys originates in the spin-to-charge conversion because we observed no detectable signal in the single Fe layer and the polarity inversion of THz emission of the multilayers according to the stacking order of Fe and Pt. Furthermore, we measured the emissions of THz waves from the FePt alloys, which disappear across the transition point of the easy axis of magnetization.

Our results demonstrate how incorporating heavy metals into magnetic materials affects the THz emission properties in association with the variations of the magnetic properties. Our study on Mn_3Ir in the antiferromagnetic system reveals detailed spin configurations, offering a quantitative method to assess spin-to-charge conversion efficiency. The spin Hall angle (θ_{SH}) remains relatively constant at approximately 0.035 across a frequency range of 0.3–2.2 THz. Our investigation into FePt reveals an unexpected relationship between structural ordering and enhanced THz emission, suggesting that even disordered FePt could enhance THz emission. By considering material composition, structural ordering, and spin-charge dynamics, we can deepen our understanding of spin-to-charge conversion phenomena in the THz spectral range, paving the way for practical applications to enhance the performance of spintronic devices.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

注意：論文要旨は、東工大リサーチリポジトリ（T2R2）にてインターネット公表されますので、公表可能な範囲の内容で作成してください。
Attention: Thesis Summary will be published on Tokyo Tech Research Repository Website (T2R2).