Terahertz Emission Based on Spin Current from Ferromagnetic Heterostructures

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1. Introduction

Modern spin-based electronics (spintronics) store and process the information via the spin degree of the freedom. The processing of spin dynamics in spintronic devices is frequently relevant to the spin currents. The femtosecond laser pulse provides a novel stimulus for exciting ultrafast spin current transient on subpicosecond timescales in metallic magnetic heterostructures [1]. In this work, we demonstrate the terahertz (THz) emission related with spin current in ferromagnetic heterostructures which contains a ferromagnetic metal layer and a non-magnetic layer. The spin current transient is temporally probed in a contactless way on the basis of inverse spin Hall effect and electric dipole radiation, which give rise to a terahertz emission [2]. The non-magnetic layer thickness dependence of the emission amplitude is studied. This research provides new insights in excitation and detection of spin currents in terahertz regime.

2. Experiment

In the present experiments, we studied heterostructures made of a single cobalt layer and a single platinum layer deposited on the 0.5-mm-thick fused silica substrate by electron beam evaporation under ultrahigh vacuum condition at room temperature. The thickness of Co layer is 10 nm, while the thickness of Pt cap ranges from 0.5 to 5 nm. The samples are kept in the saturated magnetization state via applying an external static magnetic field (~150 mT) and excited by linearly polarized laser pulses with 100 fs duration and 800-nm centre wavelength under a normal incidence scheme. The diameter of the laser beam is loosely focused to 2 mm. The pumping power is 40 mW. The THz emission is detected by electrooptic (EO) sampling using a 1-mm-thick <110>-oriented ZnTe.

Absorption of a femtoseond laser pulse drives Fermi-level electrons to higher bands, generating a non-equilibrium electron distribution. The majority- and minority-spin hot electrons are subjected to different spin-dependent conductivities. As a consequence, a net spin current from the Co into the Pt layer will be launched immediately. The polarized electrons moving along out-of-plane direction encounter spin relaxation due to spin-orbit coupling, deflecting spin-up and spin-down electrons in inverse directions, which is known as inverse spin Hall effect (ISHE). The transformation between spin current and charge current is given by $\mathbf{j}_c=\gamma\mathbf{j}_s\times\sigma$, where γ is the spin Hall angle. The charge current in plane acts as an electric dipole, causing a THz emission in the free space.

Figure 1 shows the waveforms of THz emission detected by EO sampling with various Pt thicknesses. The amplitude of THz emission is dramatically enhanced with a thicker Pt layer on account of the strong spin-orbit interaction in it. The inset depicts the relationship between the peak amplitude and the Pt thickness. The solid line gives the guide for eyes. The THz emission tends to be undetectable with decreasing the Pt thickness to null, which means the spin-orbit interaction mainly occurs in the Pt layer, with a negligible contribution from Co layer. Thicker Pt layer will be checked for an optimized heterostructure design in later experiments.

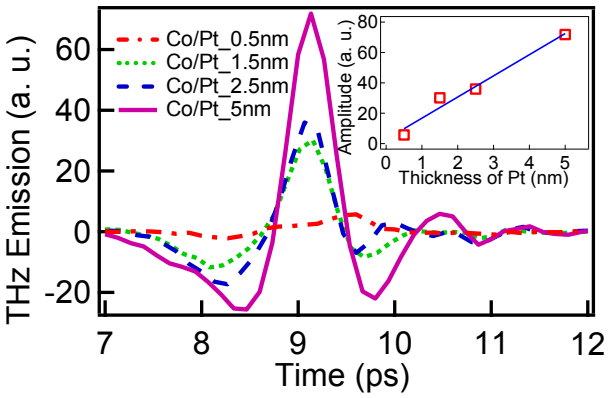

Fig. 1. Temporal waveforms of the THz emission from heterostructures. The pump power is 40 mW and the thickness of Co is 10 nm for all the measurements. The thickness of Pt layer ranges from 0.5 to 5 nm. The inset gives the relationship between the peak amplitude and the Pt thickness. The solid line gives the guide for eyes.

3. Conclusions

In conclusion, we have studied the ultrafast manipulation of spin current in the ferromagnetic Co/Pt heterostructure. The spin current transient is probed via the THz emission in an ultrafast and contactless way on the basis of inverse spin Hall effect. The THz emission is sensitive to the thickness of the cap Pt layer. This research paves the way towards manipulation of spin current and probing the temporal waveform of it in THz regime.

References

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[2] T. Kampfrath et al., Nature nanotechnology, **8**, (2013), 256.