Terahertz emission from ferromagnetic Co/Pt heterostructures

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1. Introduction

The terahertz emission based on the spin current in the ferromagnetic heterostructure Co/Pt is demonstrated. The spin current launched by the NIR femtosecond laser pulse is injected from Co to Pt layer and converted into the in-plane charge current due to the inverse spin Hall effect, which gives rise to the terahertz emission into the free space. The inverse spin Hall effect occurs within a nano-scale thickness range, and the appropriate thickness has not been reported. We studied the Pt-layer thickness dependence in the experiment. Our model that includes the effect of the spin current transport in the bulk material and the spin loss at the interface of the heterostructure quantitatively reproduces the experimental results.

2. Experiments and Results

Cobalt (Co) and platinum (Pt) were deposited on the 0.5-mm-thick fused silica substrates as the Ferromagnetic (FM) and non-magnetic (NM) layers. The thickness of the FM layer is 10 nm for all samples. The thickness of the NM layer ranges from 0.5 to 20 nm. During the experiment, the samples were kept in the saturated magnetization state by an external static magnetic field \( \mathbf{M} \approx (\sim 150 \text{ mT}) \) along y. Fig. 1(a) illustrates the principles of the THz emitter based on the spin current. All samples were excited under a normal incidence scheme by laser pulses from a Ti:Sapphire amplified laser with 100-fs duration, 1-kHz repetition rate, and 800-nm central wavelength. The diameter of the laser beam was loosely focused to ~2 mm on the sample. A net spin-polarized current \( \mathbf{J}_s \) from the Co layer into the Pt layer will be launched immediately after the excitation of the laser pulse [1, 2]. According to the inverse spin Hall effect (ISHE), \( \mathbf{J}_c \) is converted into an in-plane charge current \( \mathbf{J}_e \) along x axis. It is described by \( \mathbf{J}_c = \gamma \mathbf{J}_s \times \mathbf{n} \), where \( \gamma \) is the spin Hall angle and \( \mathbf{n} \) is the unit vector in the spin polarization direction. \( \mathbf{J}_e \) acts as an electric dipole, causing a THz emission polarized in the x direction towards the free space. The focused THz emission is detected by electro-optic sampling using a 1-mm-thick (110)-oriented ZnTe crystal.

The amplitude of the THz emission sensitively depends on the Pt layer thickness as shown in Fig. 1(b). The relation between the THz amplitude and the Pt-layer thickness is summarized in Fig 1(c). The theoretical model including the effect of the spin current transport in the bulk material and the spin loss on the interface quantitatively explains the impact of the layer-thickness on the terahertz emission from the ferromagnetic heterostructure [3]. The solid (dotted) curve in Fig. 1(c) demonstrates the fit with (without) taking into account the interfacial spin loss. The calculation with taking into account the interfacial spin loss successfully reproduced the experimental results. Because the interfacial spin loss sensitively depends on the metal layer thickness, the dotted curve clearly deviates from the experimental data, especially in the small Pt thickness range. The discrepancy proves that the interfacial spin loss need to be carefully addressed for the design of efficient FM/NM heterostructure THz emitter. In more complex heterostructures such as the stacked and arrayed heterostructures, there are more interfaces so that the analysis on the interfacial spin loss is even more important. Our model can be conveniently extended for more complicated heterostructures via analyzing spin diffusion inside all the NM layers and the spin loss at all the interfaces in an analogous way. Furthermore, our model reveals that THz emission can be enhanced by increasing the spin injection efficiency. One possible way can be interface engineering using multilayers with a smaller spin memory loss.

References