Electrical field controlled spin transport in antiferromagnetic Cr_2O_3

Zhiyong Qiu

Electrical spin - the key element of spintronics - has been regarded as a powerful substitute for the electrical charge in the next generation of information technology, in which spin plays the role of the carrier of information and/or energy similar to the electrical charge in electronics. Controlling of spin transport in a solid is one of the most important issues. Here, we demonstrated that spin transport can be modulated by an electrical field in an antiferromagnetic insulator Cr_2O_3.

Introduction

From the discovery of giant magneto-resistance (GMR) [1, 2], spintronics, a new branch which studies at the cross of magnetism, electronics, and informatics, has become the hotspot of the science community [3, 4]. GMR is, therefore, considered as the start point of the modem spintronics. Since the beginning of the 21st century, spintronics has grown up to be a separate research field revolving around a more fundamental keyword 'spin current', which is respected to instead the ‘charge current’ as the carrier of information and/or energy in the next generation spin-based information process device [5]. Here, generation, modulation, and detection of a spin current are no doubt the three central issues [6]. However, it is still far from the achievement of a real applicable spin-device, in which efficient modulation of spin current is the urgent issue.

In our previous work, it is found that the magnetic-ordering parameters are strongly coupled with the transport spin in antiferromagnetic (AFM) systems [7, 8]. Spin susceptibility and Neel vector are identified to be the most important factors for spin transport in an AFM system. These results opened a new possibility to achieve modulate high efficient modulation of spin current in an AFM system.

In this work, we show that the transport of a spin current can be controlled by an applied bias electrical field in an antiferromagnetic insulator Cr_2O_3. This is attributed to the magnetoelectric effect of Cr_2O_3, which relates the coupling between the magnetic and the electric properties in Cr_2O_3. Also, a spin transistor is demonstrated in this work.

Experimental and set-up

As shown in Fig. 1 **a**, a three-terminal trilayer device is designed to consist of a heavy metal Pt layer, an AFM insulator Cr_2O_3 layer, and a permalloy (Py) layer. There are three electrodes in this trilayer device, one is on the Py layer and the other two are on the Pt layer. As shown in Fig. 1 **b**, spin currents are generated from Py and injected into Cr_2O_3 layer by microwave at the ferromagnetic resonance (FMR) condition which is known as spin pumping effect. Then, spin currents, transmitted through the Cr_2O_3 layer, can be converted into an electrical signal by means of inverse spin Hall effect and detected from both electrodes on the Pt layer. An applied voltage

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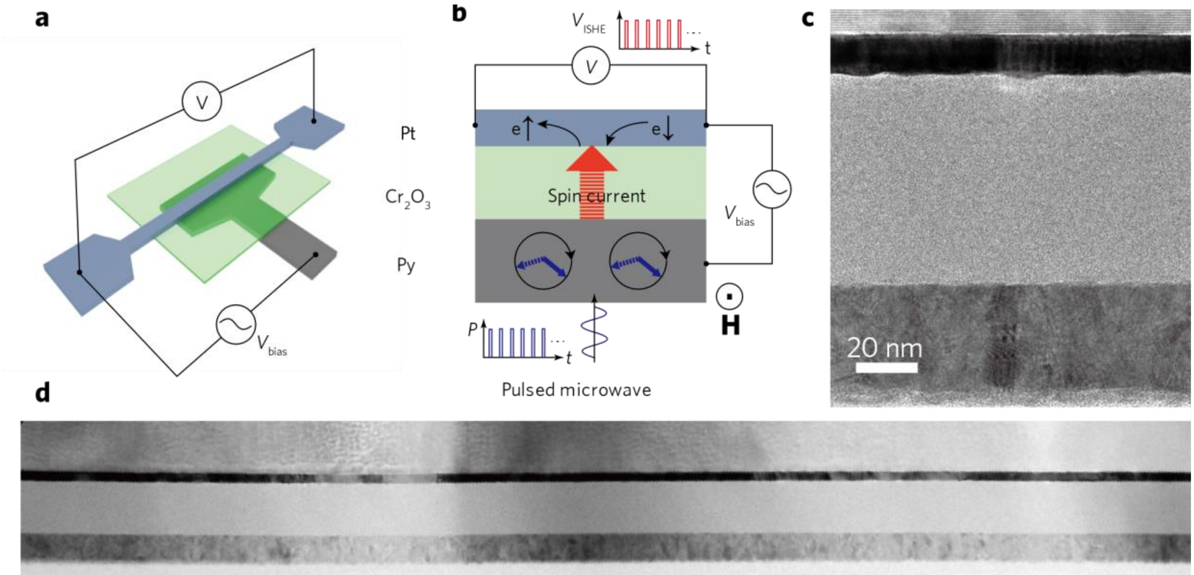

Figure 1. a. Set-up of spin transport experiment for the Py/Cr_2O_3/Pt trilayer device. Here, V_{bais} refer to the bias voltage between Py and Pt layers. **b**. Concept of this experiment. Spin current is generated by spin pumping effect from Py layer and injected into Cr_2O_3. Then spin current is detected by Pt layer on the other side of Cr_2O_3. The bias voltage V_{bais} is employ to control the spin transport. **c.** and **d.** show the cross section TEM image of Py/Cr_2O_3/Pt trilayer device.

between Pt and Py layers can create an out-plane electrical field in Cr_2O_3 layer, which will change the magnetic structure of Cr_2O_3 by means of magnetoelectric effect and affect the spin transport in the Cr_2O_3. Here, a pulsed microwave was used to excite the spin current in order to exclude any possible heating effects by a lock-in technique.

Both the Pt and Py layers are made from metallic targets by using an rf-sputtering system. The Cr_2O_3 layer is prepared from a sintered Cr_2O_3 target by using a pulsed laser deposition system. The trilayer device in this work behaves a continuous and well-controlled interface on a large length scale (Fig. 1 **c** and **d**). The Cr_2O_3 middle layer is more like a polycrystalline structure than a high quality single crystal-like structure (Fig. 1 **c**). The x-ray diffraction results show that the Cr_2O_3 layer displays (001)-preferential orientation.

Results and discussion

Figure 2 **a** shows spin pumping signals detected from Pt/ Cr_2O_3/Py trilayer device with various bias voltage Vbias at temperature T=300 K. At all conditions, spin pumping-like signals can be observed. At the FMR field, clear voltage peaks appear. The sign of the peak voltage VISHE is reversed by reversing the polarity of the applied magnetic field, showing that the voltage peak is due to ISHE induced by spin current pumped from the Py layer.

When a bias voltage V_{bias} is applied between Pt and Py layers, spin pumping voltage signal V_{ISHE} changed significantly (Figure 2 a). By applying a bias voltage V_{bias}=0.8 mV, the voltage peaks were suppressed by a factor of over 20%. In Fig. 2 b, the bias voltage V_{bias} dependence of spin pumping signal V_{ISHE} is shown. V_{ISHE} are suppressed with both positive and negative V_{bias}. V_{ISHE} shows an even symmetry to the applied bias voltage.

There seems a critical voltage at around 0.16 mV in our sample. When the bias voltage is lower than this critical voltage, the spin pumping signa is stable. When the bias voltage is higher than this critical voltage, the spin pumping signal steeply decreases first and then Slowly approach

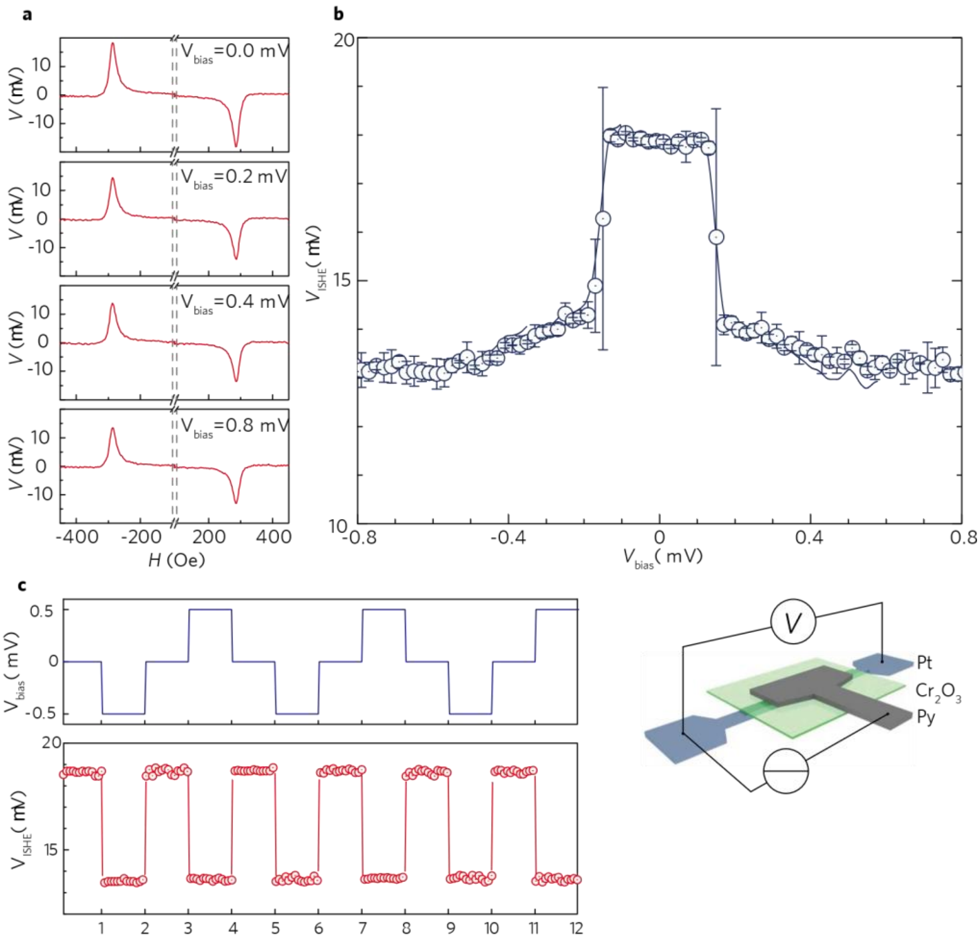

Figure 2. a. spin pumping signals in a Pt/Cr_2O_3/Py trilayer device at various bias voltages. **b.** The bias voltage V_{bias} dependence of inverse spin Hall voltage V_{ISHE}. **c.** Demonstration of a spin transistor.

saturation with increasing the bias voltage.

By using the trilayer device, a spin transistor is demonstrated in Fig. 2 **c**. When the bias voltage is periodically switched among 0 mV and ±0.5 mV, the spin pumping signal shows switching between high and low level, which suggest that the spin current transmission can be well controlled by an applied voltage in the Cr_2O_3.

Summary

Spin transport phenomenon in a AFM insulator Cr_2O_3 is systematically studied while an electrical field is applied. It is found that spin transmission can be well controlled by the applied bias voltage signal, and this effect can be a new approach for a spin transistor.

Reference

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