2018 年 9 月

Study on the Spin Conversion Induced by Surface Acoustic Waves

表面弾性波により誘起されたスピン変換現象に関する研究

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Keywords: spin conversion, surface acoustic wave, magnon-phonon coupling, inverse Edelstein effect, Rashba spin orbit coupling

Introduction:

Since last century, spin conversion, the key concept of Spintronics, has been vigorously investigated in order to gain deeper understanding of spin dynamics and enriching the functionalities of electronic devices. It describes various intriguing phenomena taking place at the nanoscale between electricity, light, sound, vibration, heat and etc., based on the interconversions mediated by spin [1]. However, among the above, the interaction between spin and sound-vibration prevails not well explored.

In the presence of magnetic materials, mechanical oscillation energy can be transferred to spin via magnon-phonon coupling. When surface acoustic waves (SAWs) are passing across ferromagnetic layers, periodic elastic deformation induced by SAWs drives precession magnetization dynamics, well known as acoustic ferromagnetic resonance (A-FMR) [2], generating spin current flow into adjacent nonmagnetic layers (see Figure 1.).

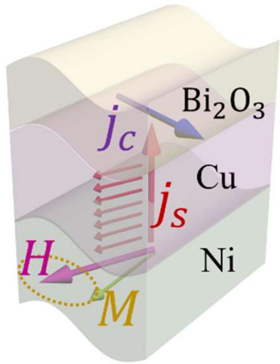

Figure 1. Schematic of acoustic spin pumping (ASP) mechanism

The generated spin current is usually converted to electrical charge current by inverse spin Hall effect (ISHE). Alternatively, recent reports showed efficient spin to charge current conversion at interfaces with spatial inversion asymmetry between two nonmagnetic materials [3, 4]. Spatial inversion asymmetry induces a built-in electric potential and spin orbit coupling at surfaces and interfaces, the so-called Rashba spin orbit coupling. Here, the spin to charge conversion mechanism is known as inverse Edelstein effect (IEE) [5]. In this Thesis, we study the spin to charge conversion in a hybrid device which combines magnon-phonon coupling via SAWs and inverse Edelstein effect (IEE).

Methods and Results:

Our hybrid devices consist of Ni(10nm)/Cu,Ag(20nm) /Bi_2O_3(20nm) trilayer structure deposited on $LiNbO_3$ substrates at the center of a pair of Ti(5nm)/Au(20nm) interdigital transducers (IDTs). By applying RF voltage at the input IDTs, Rayleigh type SAWs are launched along x-axis (see Figure 2.), driving acoustic ferromagnetic resonance in Ni and injecting spin current into the adjacent nonmagnetic layer, Cu (Ag). Then, due to the inversion spatial symmetry breaking at the interface between Cu (Ag) and Bi_2O_3 [3, 6], the system converts spin current into charge current via IEE, inducing a magnetic field dependent voltage V, detected in longitudinal and transverse geometries.

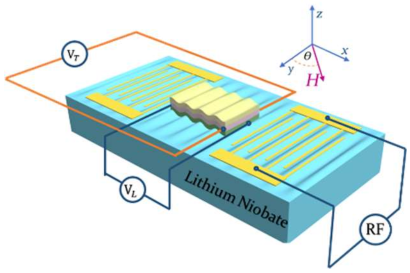

Figure 2. Illustration of experiment setup

We first characterize the absorption of SAWs by using a vector network analyzer (VNA), while varying the in-plane external magnetic field angle. Absorption of SAWs is characterized by measuring the transmission coefficient $|S_{21}|$ as function of in-plane static magnetic field magnitude and angle θ. Figure 3 (a, d) show the magnetic field angle dependence (θ) at the resonance peak of the absorption of SAWs due to A-FMR excitation. We observe a fourfold butterfly shape signal with first maximum located at θ = 45°, which agrees well with the theoretic prediction.

The driving of A-FMR produces a spin current which can be converted into charge current when a spin-orbit interaction is present. We extend our study to the full in-plane magnetic field angle dependence with voltage detection in both, transverse and longitudinal geometries. For transverse geometry we detect the voltage perpendicular to the SAWs wavevector k (V_T in Figure 2), while for the longitudinal geometry we detect the voltage parallel to the SAWs wavevector k (V_L in Figure 2). Figure 3 (b, e) shows the magnetic field angle dependence (θ) of the transverse IEE voltage V_T for Ni/Cu/Bi_2O_3 and Ni/Ag/Bi_2O_3. Figure 3 (c, d) shows the magnetic field angle dependence (θ) of the longitudinal IEE voltage V_L for Ni/Cu/Bi_2O_3 and Ni/Ag/Bi_2O_3.

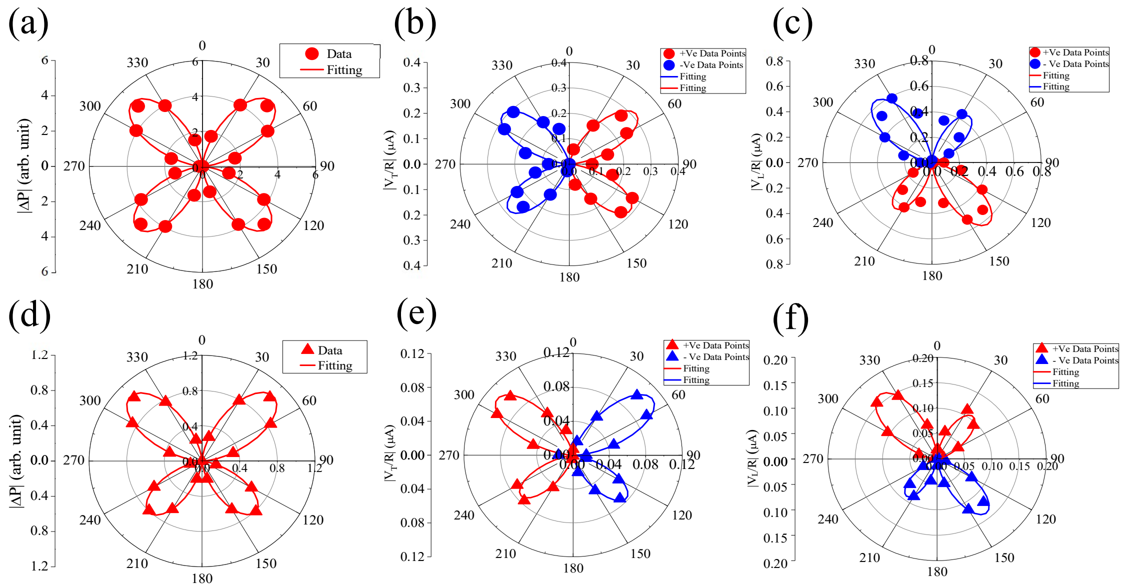

Figure 3. Polar graph of damping of SAWs due to excitation of acoustic ferromagnetic resonance measured on (a): Ni/Cu/Bi_2O_3 and (d): Ni/Ag/Bi_2O_3, varying applied magnetic field angle θ; Polar graph of transverse signal measured on (b): Ni/Cu/Bi_2O_3 and (e): Ni/Ag/Bi_2O_3, varying applied external magnetic field angle θ. Polar graph of longitudinal signal measured on (c): Ni/Cu/Bi_2O_3 and (f): Ni/Ag/Bi_2O_3, varying applied external magnetic field angle θ.

Summary and Perspectives:

In this thesis, we demonstrate the spin to charge current conversion via magnon-phonon coupling and inverse Edelstein effect at the hybrid device Ni/Cu(Ag)/Bi_2O_3. The generation of spin current ($J_s \approx 10^8 A/m^2$) due to magnon -phonon coupling reveals the viability of acoustic spin pumping as mechanism for the development of Spintronic devices. Full in-plane magnetic field angle dependence of power absorption and combination of longitudinal and transverse voltage detection reveals symmetric and asymmetric components of acoustic spin pumping voltage induced by Rayleigh type surface acoustic waves. We assign the asymmetric contributions to the interference between longitudinal and shear waves and anisotropic charge distribution at our hybrid device.

In fact, magnon-phonon coupling is not the only route for transferring mechanical oscillation to spin.

In the absence of magnetic materials, spin rotation coupling (SRC) [7] brings new possibilities of spin current generation via mechanical excitation, free of magnetic fields and spin orbit interaction. In the future, we will focus our study on direct experimental demonstration of SRC by using optical characterization method (magneto optical Kerr effect, MOKE), as schematically depicted in figure 4. The success of this project will bring us the fundamental new method of generation of spin current, advancing the understanding of spin conversion phenomena, and giving new insight towards future electronic devices.

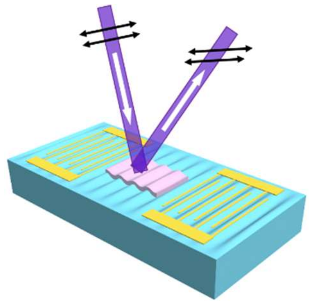

Figure 4. Schematics of optical characterization of SRC

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Publications:

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2) J. Puebla, F. Auvray, M. Xu, B. Rana, A. Albouy, H. Tsai, K. Kondou, G. Tatara, Y. Otani. Direct optical observation of spin accumulation at nonmagnetic metal/oxide interface. *Applied Physics Letters, 111 (2017) 092402.*

3) F. Auvray, J. Puebla, M. Xu, B. Rana, D. Hashizume, Y. Otani. Spin accumulation at nonmagnetic interface induced by direct Rashba–Edelstein effect. *Journal of Materials Science: Materials in Electronics, (2018) 1-7.*

Oral presentation:

1) ○M. Xu, J. Puebla, F. Auvray, B. Rana, K. Kondou, and Y. Otani. Characterization of Coupling between Mechanical Angular Momentum and Electron Spin. *23rd International Colloquium on Magnetic Films and Surfaces. Santa Cruz CA. 2018 July.*

2) M. Xu, J. Puebla, F. Auvray, B. Rana, K. Kondou, and Y. Otani. Acoustic Spin Pumping at Rashba Interfaces. *2018 The Physical Society of Japan Meeting. Noda, Japan. 2018 March.*

Poster presentation:

1) ○M. Xu, F. Auvray, J. Puebla, B. Rana, H. Tsai, K. Kondou, and Y. Otani. Generation of spin currents by surface acoustic waves, *Autumn Meeting of the Physical Society of Japan. Iwate, 2017 September.*

2) ○M. Xu, F. Auvray, J. Puebla, B. Rana, H. Tsai, K. Kondou, and Y. Otani. Inverse Rashba-Edelstein effect induced by acoustic spin pumping, *RIKEN-NIMS 1st Materials Innovation Core Workshop. Tokyo, 2018 January.*

3) ○M. Xu, F. Auvray, J. Puebla, B. Rana, H. Tsai, K. Kondou, and Y. Otani. Generation of spin currents by surface acoustic waves, *The 11th Condensed-Matter-Science Cross-Area Workshop. Chiba, 2017 November.*