Possibility of the RKKY interaction on the spin Hall effect

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Spin-related interactions such as spin-orbit interaction (SOI) and Zeeman interaction are of crucial for fundamental and application aspects in spintronics so far. Especially SOI is very important in spintronics for generating, detecting, and manipulating spins solely by electrical means. Thus the pursuit for the spin-related interaction is required to realize further spin manipulation for future spintronics.

In 1991, Parkin had found artificial antiferromagnetic coupling in FM/NM/FM multilayer structure, so called interlayer-exchange coupling via Ruderman-Kittel-Kasuya-Yoshida (RKKY) interaction using the conduction electrons [S. S. P. Parkin, *Physical Review Letters* **67**, 3598 (1991)]. Here FM and NM mean ferromagnet such as Co or Fe, and non-magnet such as Ru or Cu. Based on the Fermi wavelength and the strength of the coupling in the NM layer, the exchange coupling shows an oscillatory behavior as a function of the NM layer thickness. Considering this phenomenon, it is expected to control the spin Hall effect (SHE) through the coupling caused by the RKKY interaction between the spins $\boldsymbol{\sigma}$ and the magnetization $\mathbf{M}$ as shown in Fig. (a).

We experimentally studied the coupling in Pt(5 nm)/Ru(1 nm)/Co(5 nm)/AlO_X(2 nm) system using the spin-torque ferromagnetic resonance (ST-FMR) technique. Figure (b) shows the detected voltages for several applied powers of the rf current. Surprisingly we found that the detected resonant field decreases with increasing the power (Fig. (c)). This is definitely opposite behavior compared with a case caused by heating effect of the power. For the measurement, we now apply 45 deg-aligned magnetic field to the sample strip for maximum sensitivity. So this decrease of the resonant field seems to be originated from an enforcement of the alignment of the magnetization to 90 deg direction via the RKKY interaction in the Ru spacer. In this meeting, we report the Ru thickness dependence for making sure of the Friedel oscillation and the detailed mechanism in this system.

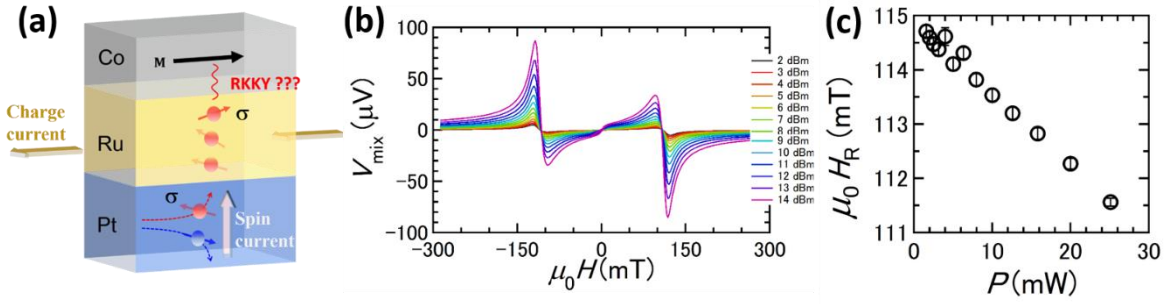

Figure (a) Schematic image for Pt/Ru/Co trilayer, spin current generation in the Pt layer via SHE, and the RKKY interaction between the generated spin $\boldsymbol{\sigma}$ and the magnetization $\mathbf{M}$ in the Co layer as a coupling image. (b) ST-FMR signals at 12 GHz in case of the Pt(5 nm)/Ru(1 nm)/Co(5 nm) trilayer as a function of the applied field for each applied power case. (c) Detected resonant field in the Co layer as a function of the applied power.