Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp1210-1211

# Observation of the D'yakonov-Perel' spin relaxation in epitaxial Pt thin film and its electrical manipulation

Jeongchun Ryu, Shoichi Takasuna, Kohei Yoshizumi, Makoto Kohda and Junsaku Nitta

Department of Materials Science, Tohoku University
6-6-02 Aramaki-aza Aoba, Aoba-ku, Sendai 980-8579, Japan
Phone: +81-22-795-7317
E-mail: salsberry@dc.tohoku.ac.jp

**Abstract**

**We investigated spin relaxation mechanism in epitaxial Pt thin films and figured out that the dominant spin relaxation is caused by the D'yakonov-Perel' mechanism. Furthermore, magneto - conductance was manipulated by applying an external gate voltage, which indicates that the Rashba spin – orbit interaction plays a role.**

## 1. Introduction

For realization of functional spintronic devices, electrical spin manipulation is one of the essential technologies. Even though the D'yakonov-Perel' (DP) mechanism originated from the Rashba spin – orbit interaction (SOI) has been well established in Ⅲ – V semiconductor hetero - structures [1, 2], there are disadvantages, for example, the long spin precession length and limitation of operating temperature. To overcome those problems, spin manipulation in metals with strong SOI has been raised. However, further understanding of spin relaxation mechanism in thin metal films is required. Here, we report that in epitaxial Pt thin films, the spin relaxation is induced by the DP mechanism and magneto conductance can be manipulated by an external gate voltage.

## 2. Spin relaxation mechanism in Pt

Understanding the spin relaxation mechanism in thin metal films, closely related to SOI, is important for electrical manipulation of spin. Two dominant mechanisms of spin relaxation are considered in thin metal films: the Elliott-Yafet (EY) mechanism associated with the momentum scattering by impurities or disordered system and the DP mechanism originated from the Rashba SOI [2, 3]. These two mechanisms can be distinguished from relationship between momentum scattering time $\tau_p$ and spin relaxation time $\tau_{so}$ [4] : Since the EY mechanism is based on the scattering, the more scattering chances make the faster spin relaxation. As a result, $\tau_{so}$ is proportional to $\tau_p$. On the other hand, the behavior in DP mechanism is opposite to that in the EY mechanism, meaning that frequent momentum scattering events suppress spin relaxation. Therefore $\tau_{so}$ is in inversely proportional to $\tau_p$. While the dominant spin relaxation in bulk metals is mainly caused by the EY mechanism [5], it is expected that the Rashba SOI at the metal / insulator interface generate spin relaxation due to the DP mechanism in ultra - thin films[6].

## 3. Sample fabrication

Each epitaxial Pt layer was deposited on MgO (111) substrates by Radio-Frequency sputtering with a different thickness: $d$ = 3 nm, 4 nm and 6 nm. All samples were covered with an AlO layer (0.6 nm) in order to induce the Rashba SOI originated by the structure inversion asymmetry at the interface. For Understanding a crystallographic structure of Pt / MgO film along the growth direction, we measured X-ray diffraction (XRD) and Reflection High Energy Electron Diffraction (RHEED). As shown in Fig. 1, Pt film has a single crystal structure oriented along the [111] direction. For applying an external electric field effectively in Pt, we deposited an electric double layer on the top of AlO / Pt layer.

To evaluate the SOI in thin Pt films, we focus on quantum correction of the conductance, i.e. weak antilocalization (WAL). If strong SOI exists, negative magneto conductance is observed around zero magnetic fields. As a result, we can obtain the spin relaxation time $\tau_{so}$ which reflects the strength of SOI.

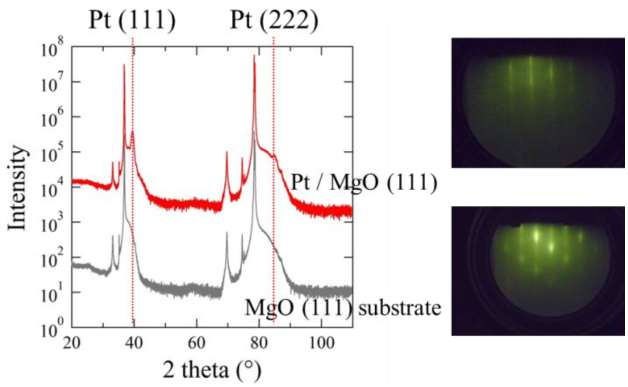


Fig.1. XRD and RHEED patterns of Pt / MgO film and MgO substrate.

## 4. Results and discussion

First of all, the Pt thickness dependence of WAL is shown in Fig. 2. Since Pt has strong SOI, all samples show WAL. The results are analyzed by two theories of quantum correction of the conductance both proposed by Iordanskii - Lyanda-Geller – Pikus (ILP) [7] and Hikami – Larkin - Nagaoka [8]. Even though the experimentally obtained results are well matched to both theories, it is considerable that magneto - conductance in thin metal should be fitted to

ILP theory because ILP theory is taking into account the DP mechanism, otherwise HLN theory only consider the EY mechanism. The estimated Rashba parameters in Pt thin films are about 10 times larger than those in semiconductors such as InGaAs [9]. In addition, these values we estimated are comparable to the calculated value [10].

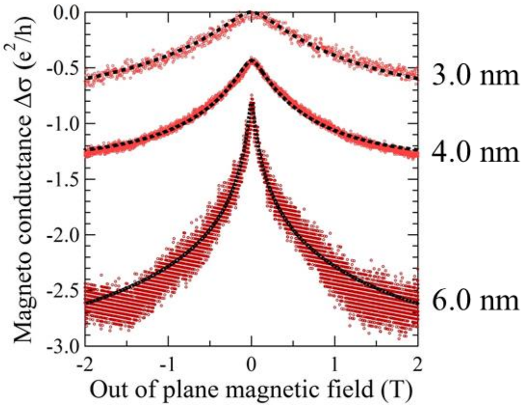


Fig. 2. WAL curves depending on Pt thickness measured at *T* = 1.6K. Dark dotted lines are best fitted results based on ILP theory.

Furthermore, to figure out the dominant spin relaxation mechanism in epitaxial Pt films, we investigated the relationship between $\tau_p$ and $\tau_{so}$ depending on Pt thickness (Fig. 3). The inversely proportional relationship indicates that the dominant spin relaxation in epitaxial Pt films is induced by the DP mechanism.

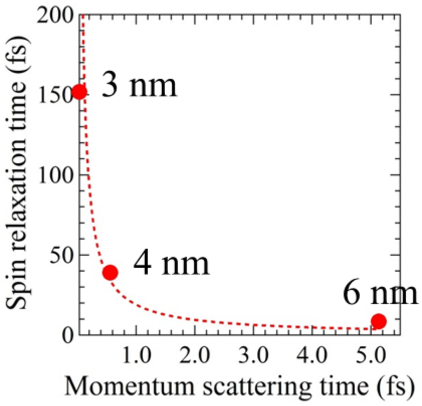


Fig. 3. Relationship between $\tau_p$ and $\tau_{so}$. Dotted line shows the DP mechanism in thick Pt films.

For appearing the DP mechanism in the Pt films, two reasons are considered: One is that the crystal orientation along [111] direction in epitaxial Pt film suppresses the EY mechanism a lot, thus it enhances the effect of the Rashba SOI at the interface largely. The other can be explained by the Pt thickness dependence. Since the Rashba SOI is originated from structure inversion asymmetry, accordingly the effect increases with decreasing Pt thickness, which means the asymmetric MgO / Pt / AlO interface dominates over the bulk Pt effect.

As the Rashba SOI is tunable by an electric field [1], we applied gate voltage through the electric double layer on 3 nm thickness epitaxial film and measured its WAL. As shown in Fig. 4, the signals of WAL are manipulated depending on gate voltage, which suggests possibility of gate - controlled spin relaxation time and spin precession angle.

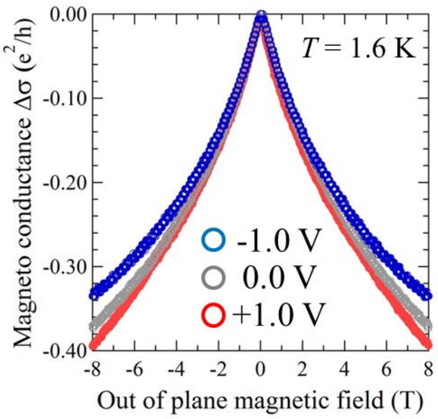


Fig. 4. WAL in 3 nm thickness of epitaxial Pt film depending on external gate voltage.

## 4. Conclusions

In conclusion, we demonstrated the DP mechanism induced by the Rashba SOI appears dominantly in epitaxial Pt thin films. Moreover, we succeeded to manipulate WAL by applying an external gate voltage. This proposes that the possibility of gate - controlled spin states in metals. The quantitative analysis correlated to manipulation of spin relaxation time will be discussed in the conference.

## References

[1] J. Nitta *et al.*, Phys. Rev. Lett. **78**, 1335 (1997).
[2] E. I. Rashba, Fiz. Tver. Tela (Soviet Physics-solid state), **2**, 1224 (1960).
[3] R. J. Elliott, Phys, Rev. **96**, 266 (1954).
[4] S. Maekawa, *Concepts in spin electronics*, , Oxford (2006).
[5] Y. Niimi *et al.*, Phys. Rev. Lett. **110**, 02685 (2013).
[6] M. Miron *et al.*, Nature Mater. **9**, 230 (2010).
[7] S. V. Iordanskii *et al.*, JETP Lett. **60**, 206 (1994).
[8] S. Hikami*, et al.*, Prog. Theor. Phys. **63**, 707 (1980).
[9] V. A. Guzenko *et al.*, Appl. Phys. Lett. **88**, 032102 (2006).
[10] A. Bendounan *et al.*, Phys. Rev. Lett. **78**, 1335 (1997).