Research Group for Spin-Polarized Positron Beam

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The research objectives of Spin-Polarized Positron Beam Group are to promote spintronics material study using a highly spin-polarized positron beam. Using a positron source (^{68}Ge-^{68}Ga) produced through a nuclear reaction, we develop a spin-polarized positron beam. After establishing the foundation of spin-polarized positron annihilation spectroscopy (SP-PAS) from both experimental and theoretical viewpoints, using SP-PAS method, we study spintronics materials and novel spin phenomena.

Construction of spin-polarized positron beam line using a ^{68}Ge-^{68}Ga source

To conduct spintronics study extensively, we need to have a spin-polarized positron beam. The performance required for the spin-polarized positron beam is as follows: (i) Higher spin polarization, (ii) Energy tunability from several eV to tenth keV, (iii) Polarization switchability between longitudinal and transverse directions. To fulfill the above requirements, we produced a ^{68}Ge-^{68}Ga source which emits highly spin-polarized positrons as compared to the conventional ^{22}Na source and constructed an electrostatic beam line as shown in Fig.1 [1]. The ^{68}Ge-^{68}Ga source was produced through a proton nuclear reaction ^{69}Ga(p, 2n)^{68}Ge. For an efficient production of ^{68}Ge-^{68}Ga, we first used an isotope-separated ^{69}Ga metal as a target material. However, melted Ga reacted with the capsule materials and eventually destroyed the capsule itself. We therefore replaced the ^{69}Ga metal with a GaN crystal and have been repeating irradiation experiment more than fifteen times since April/2010. The current activity of the ^{68}Ge-^{68}Ga source gets to approximately 300 MBq. Consequently, we succeeded to generate a spin-polarized positron beam with a flux of 5×10^3 e^+/sec and a polarization of more than 35 %. We also confirm that, by changing the energy selector between magnetic and electrostatic deflectors, the polarization direction can be changed between longitudinal and transverse. Using this spin-polarized positron beam, we could observe the magnetic-field-reversal asymmetry of the Doppler broadening of annihilation radiation spectra.

Spin Hall effect on a Pt(001) surface observed by spin-polarized positron annihilation

The spin Hall effect (SHE) is a phenomenon of electron spin flow, which occurs near non-magnetic conducting material surfaces under a direct current. The origin of SHE is thought to be the spin-orbit interaction between conduction electrons and nuclei. Conduction electrons with spins perpendicular to the charge current will be bent to the transverse directions for both the current and spin directions. Consequently, in-plane polarized electron spins appear near each surface surrounding the current axis. Recently, markedly large SHEs were reported in some metals, such as Pt and Au. Furthermore, direction of spin polarization is found to be different for different metal kinds. Experimental detection of metal SHE is normally done by using magnetotransport or ferromagnetic resonance measurements. These methods hardly determine polarization of electron spins appeared on metal surfaces due to SHE. In using a spin-polarized positron beam, we attempted to detect polarized electrons near the Pt(001) surface [2]. We found that the intensity of three-photon annihilation of spin-triplet positronium changes upon current reversal (Fig. 2) and the asymmetry in the intensity depends on angle between positron polarization and current directions as anticipated for SHE of Pt. The spin polarization of surface electrons near the Fermi level was evaluated to be more than 0.01 which is four orders of magnitude greater than that expected from a conventional spin diffusion theory. To explain the above experimental fact, some special surface effects such as the Rashba effect and surface ferromagnetism should be considered.

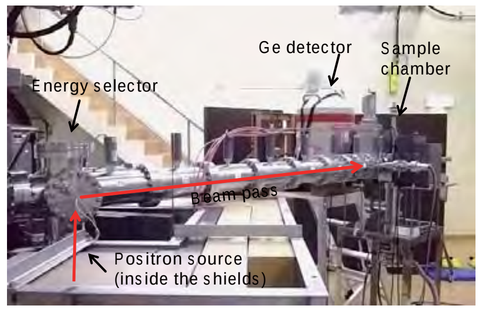

Fig. 1 Picture of newly developed spin-polarized positron beam line. The source part (surrounded by lead and concrete blocks) is directly connected to the proton irradiation chamber. The source strength is increased by repeating irradiation annually. The positron beam is lifted up from the positron gun, bent 90° and transported horizontally to the sample chamber. At the sample chamber, annihilation gamma rays are measured by a high-purity Ge detector.

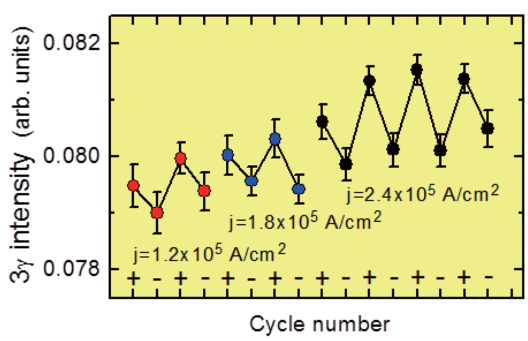

Fig. 2 Three-gamma annihilation intensity measured upon successive current reversal observed for the Pt(001) surface. (+) and (-) denote the direction of current applied for the sample. Current and positron spin polarization directions are perpendicular to each other. The oscillating behaviour of the three-gamma annihilation intensity upon current reversal means that spin-polarization of surface electrons is changed between parallel and anti-parallel with respect to the positron spin-polarization upon current reversal.

References

[1] M. Maekawa *et al*., Nucl. Inst. Meth. Phys. Res. B, submitted.
[2] A. Kawasuso *et al*., Phys. Rev. Lett., to be published.