Research Group for Spin-Polarized Positron Beam

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The research objectives of Spin-Polarized Positron Beam Research Group are to promote spintronics study using a highly spin-polarized positron beam. We have been developing spin-polarized positron beams using ^{68}Ge-^{68}Ga and ^{22}Na sources. To establish the foundation of spin-polarized positron annihilation spectroscopy (SP-PAS), we first conduct a fundamental study on elemental ferromagnets from both experimental and theoretical viewpoints. Subsequently, using SP-PAS method, we approach spintronics materials and novel spin phenomena.

Current-induced spin polarization on metal surfaces.

Spintronics is promising to go beyond the traditional electronics. Current-induced spin polarization (CISP) at surface and interface plays a critical role in spintronics. The spin Hall effect (SHE) and the Rashba effect are the representative phenomena producing CISP due to spin-orbit coupling (SOC). In the last fiscal year, using a spin-polarized positron beam, we studied the CISP on the outermost metal surfaces using a spin-polarized positron beam [1].

Positrons implanted into a sample diffuse back to the surface and emitted into vacuum as positronium which is the positron-electron bound state like hydrogen. Two spin states, singlet (S=0) and triplet (S=1), are possible. These decay into two and three gamma quanta, respectively. The annihilation probability shows asymmetry upon flipping the mutual polarization vector of positrons and electrons. From this, the electron spin polarization at the outermost surface can be determined. Since two-gamma annihilation of positronium overlaps the free positron-electron annihilation, three-gamma annihilation event is used for observing the surface electron spin polarization.

Figure 1 shows the three-gamma annihilation probability of positronium observed for the Au, Cu, Pt, Pd, Ta and W surfaces as a function of successive current reversal. The Au and Cu surfaces show no significant CISP. In contrast, the Pt, Pd, Ta, and W surfaces exhibit large CISP and the CISP of Ta and W are opposite to those of Pt and Pd. The sign of the CISP obeys the same rule in SHE suggesting that SOC is mainly responsible for the CISP. Figure 2 shows the spin polarizations of the above surfaces per input charge current density of $j_c=10^5$ A/cm^2.

According to the spin diffusion theory, the energy width of polarized electrons in the density of states is given by the shift of chemical potential: $\Delta\mu=2\theta_{SH}\lambda_S j_c \rho$, where λ_S is the spin diffusion length, θ_{SH} is the SHE angle and ρ is the resistivity. For θ_{SH}=10%, λ_S=10 nm, ρ=50 μΩcm and $j_c=10^5$ A/cm^2, one finds $\Delta\mu$=1 μeV. The typical density of states at E_F is 10^{23} cm^{-3}eV^{-1}, and hence the excess spin density will be 10^{17} cm^{-3}. Assuming that positrons pick up electrons located from E_F to E_F-1 eV, the observable electron spin polarization will be 10^{-4}%. The above huge CISP is hardly explained as the diffusive SHE.

The spin density induced by the Rashba effect is given by $<\delta s_y>=4\pi e D_{2D} E \tau \alpha_R/\hbar$, where e is the elementary charge, D_{2D} is the two-dimensional density of states, E is the applied electric field, τ is the electron relaxation time and α_R is the Rashba parameter. Assuming $\alpha_R=3\text{x}10^{-10}$ eVm, $D_{2D}=10^{14}$ cm^{-2}eV^{-1}, τ=10 ps, E=1 kV/m, one finds the spin polarization of the order of 5%. Thus, if the relaxation time is long enough, the above-observed huge CISP can be explained by the Rashba mechanism rather than the diffusive SHE. This settles a controversy, that which of these two mechanisms dominates the large CISP on metal surfaces.

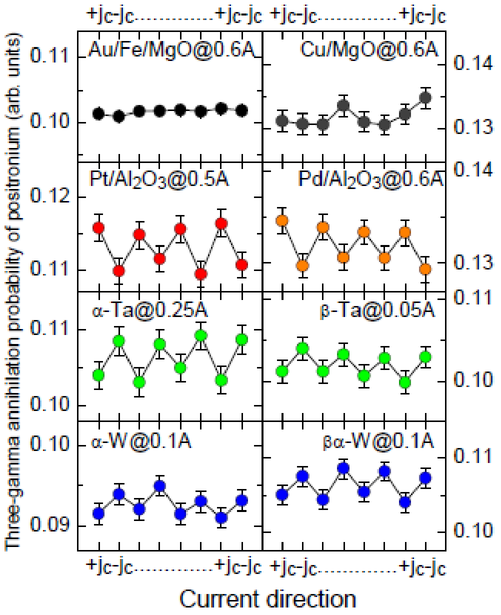

Fig.1 Three-gamma annihilation probability of positronium upon successive current reversal observed for the Au, Cu, Pt, Pd, α-Ta, β-Ta, α-W and β-W surfaces. (+j$_C$) and (-j$_C$) denote the direction of current applied for the sample.

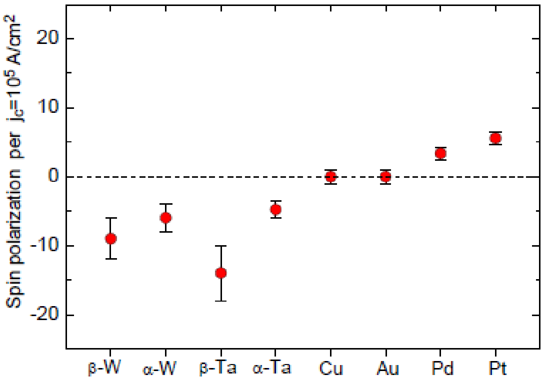

Fig.2 Spin polarizations per input charge current density of 10^5 A/cm^2 obtained for the Au, Cu, Pt, Pd, α-Ta, β-Ta, α-W and β-W surfaces.

References

[1] H. J. Zhang, S. Yamamoto, Y. Fukaya, M. Maekawa, H. Li, A. Kawasuso, T. Seki, E. Saitoh and K. Takanashi Scientific Reports 4, doi:10.1038/srep04844 (2014).