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. Using a positron source (^{68}Ge-^{68}Ga) produced through a nuclear reaction, we have developed a spin-polarized positron beam. 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.

Spin-polarized electron momentum distributions of Heusler alloys.

Spin-up (down) positrons preferentially annihilate with spin-down (up) electrons into two-photons. Positrons and electrons having parallel spins annihilate into three-photons with a considerably smaller probability as compared to that of two-photon annihilation. Hence, in condensed matters, only two-photon annihilation is normally considered as annihilation events. The Doppler broadening of annihilation radiation (DBAR) spectrum (energy spectrum of two-photon annihilation) represents the electron momentum distribution. If both positrons and electrons are spin-polarized, the DBAR spectrum exhibits an asymmetry upon their spin-reversal. We demonstrated that through this asymmetry, the ferromagnetic band structures of Fe, Co, Ni and Gd can be studied [1]. Here, we further apply the above method to the Heusler alloys which are anticipated to have 100% spin polarization at the Fermi level. Figure 1 shows the change of the DBAR spectra under a magnetic field (1 T) obtained for Co_2MnAl (CMA), Co_2MnSi (CMS) and NiMnSb (NMS). These show different electron momentum distributions in magnetic field. The majority spin electrons of CMA have more d-like character. Replacing Al with Si, CMS tends to exhibit a little s-like character. In the case of NMS, the majority spin electrons are more s-like.

Current-induced spin polarization on metal surfaces.

Current-induced spin polarization (CISP) on non-magnetic material surfaces has attracted much attention due to the rapid development of spintronics devices and their underlying physics. Spin current arises from the spin-orbit (SO) interaction between the conduction electrons and nuclei, which then causes CISP. The Rashba SO interaction, which originates from space-reversal symmetry-breaking at a surface, gives rise to CISP near surfaces and interfaces. Recently, markedly large spin Hall effect and Rashba effect are observed for Pt and Au. Thus, it is particularly interesting to use newly developed surface-sensitive tools to investigate CISP on Pt and Au surfaces. Spin-polarized electrons can be detected through self-annihilation of positronium, which is a bound state of a positron and an electron. When positronium is emitted into vacuum, positrons pick up surface electrons near the Fermi level. The detection limit of spin polarization is low (0.1%) for normal positron spin polarization (~30%). These are major advantages for studying surface spin phenomena. Figure 2 shows the three-photon annihilation intensity of positronium generated on Pt and Au surfaces as a function of successive current reversal. The oscillations observed for the Pt surfaces indicate the occurrence of CISP. From the amplitudes of the oscillations, the spin polarizations were more than 1 %. Possible reasons for this large CISP on the Pt surfaces are currently considered in relation to the Rashba effect and the ferromagnetism associated with the outermost surface state [2].

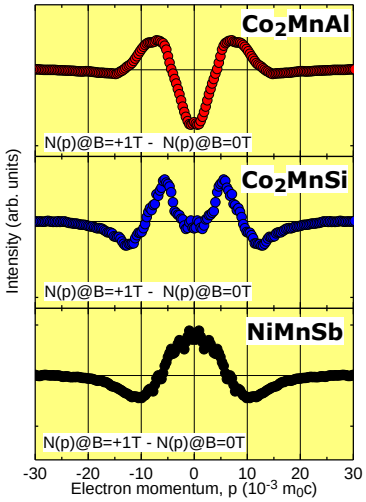

Fig.1 Change of DBAR spectra in a magnetic field (1T) obtained for the Co_2MnAl, Co_2MnSi and NiMnSb samples.

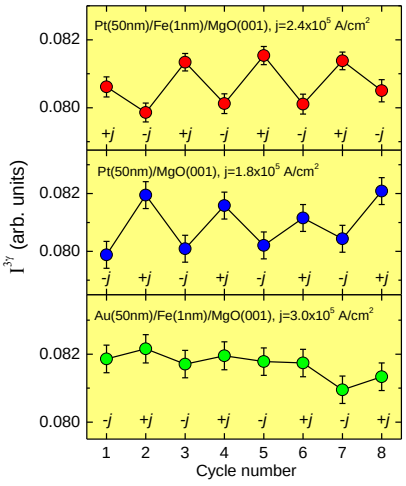

Fig.2 Three-photon annihilation intensity upon successive current reversal observed for the Pt and Au surface. (j_+) and (j_-) denote the direction of current applied for the sample. Current and positron spin polarization directions are perpendicular to each other.

References

[1] A. Kawasuso *et al.*, Phys. Rev. B **85**, 024417 (2012).
[2] A. Kawasuso *et al.*, J. Mag. Mag. Mat. **342**, 139 (2013).