Positron and Spintronics

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When both positrons and electrons are spin-polarized, electron-positron momentum distribution exhibits asymmetry upon their mutual spin reversal. Annihilation of positronium formed on metal surface also shows spin-reversal asymmetry. These properties are demonstrated to be useful in studying ferromagnetic band structure and surface magnetism, respectively. Here, we call positron annihilation spectroscopy, which particularly uses the spin dependent annihilation process, spin-polarized positron annihilation spectroscopy (SP-PAS). In the spintronics field, SP-PAS will be a potential tool in revealing spin-related phenomena, such as magnetoresistance, current-induced spin polarization, spin-injection, vacancy-induced magnetism, half-metal band structures and so on. To promote spintronics study with SP-PAS, spin-polarized positron beam is needed. In this talk, I will report the development of spin-polarized positron beam, some fundamental aspect of SP-PAS and its applications to spintronics study performed so far.

陽電子とスピントロクス

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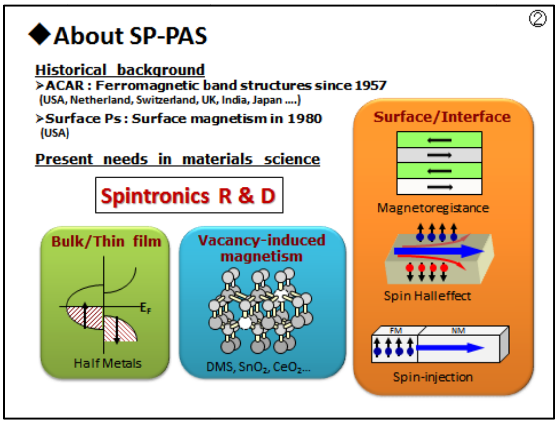
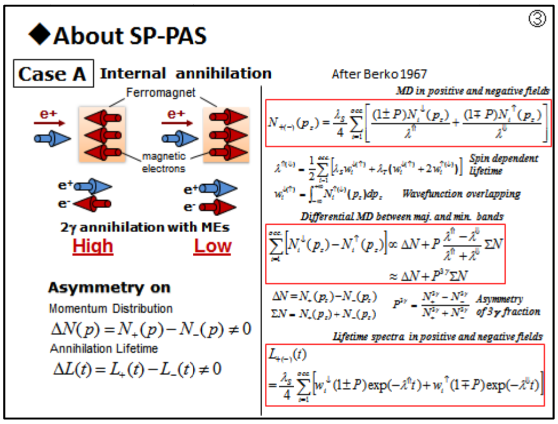
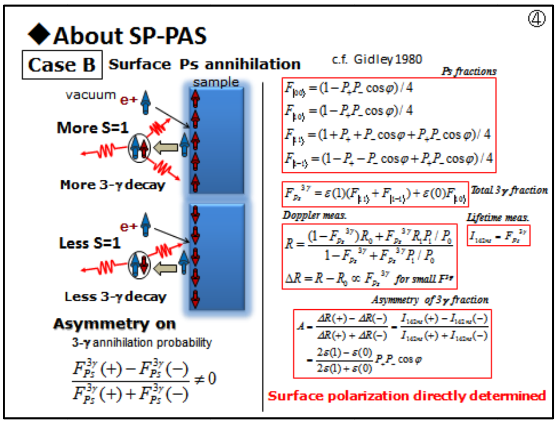
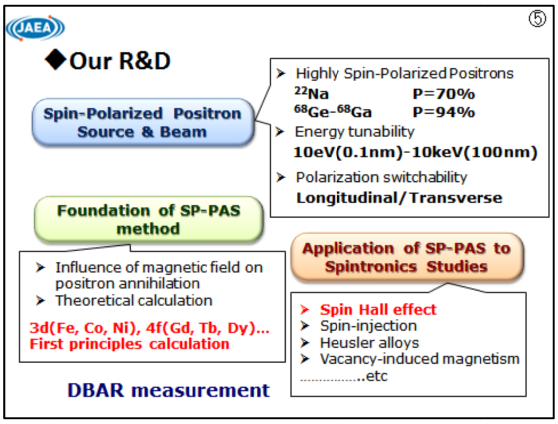
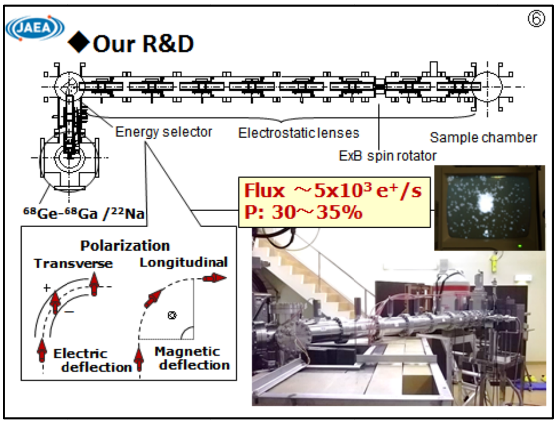
陽電子と電子の両方がスピン偏極している場合、電子ー陽電子運動量分布は互いのスピン反転に対して非対称性を示す。金属表面で形成されるポジトロニウムの消滅も、同様にスピン反転非対称性を示す。これらの特性は、強磁性バンド構造や表面磁性の研究に有用であることが示されている。ここで、スピンに依存した陽電子消滅過程を利用する陽電子消滅法を特にスピン偏極陽電子消滅法と呼ぶことにする。近年急速に進展しているスピントロニクス分野において、スピン偏極陽電子消滅法は各種のスピン現象（磁気抵抗、電流誘起スピン分極、スピン注入、空孔誘起強磁性、ハーフメタルバンド構造など）を解明する上で、有用なプローブになると期待される。スピン偏極陽電子消滅法を用いてスピントロニクス研究を推進するためには、スピン偏極陽電子ビームが必要である。本講演では、スピン偏極陽電子ビームの開発、及び、スピン偏極陽電子消滅法の基礎とこれまで講演者等が行った幾つかの応用研究について報告し、将来の展開を模索したい。

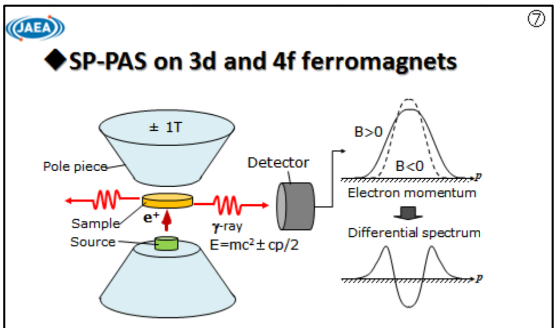




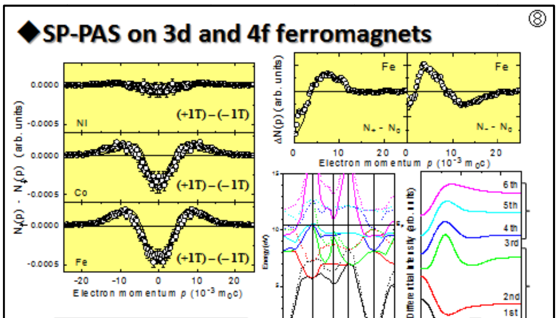




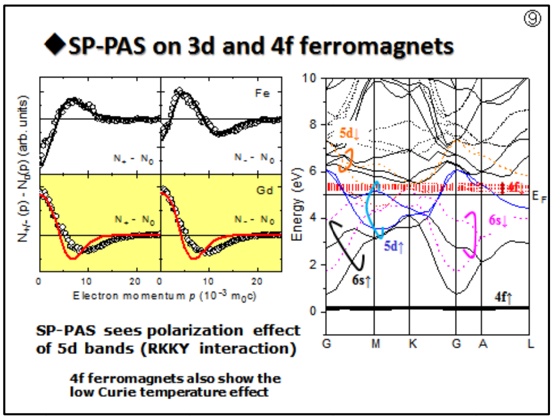


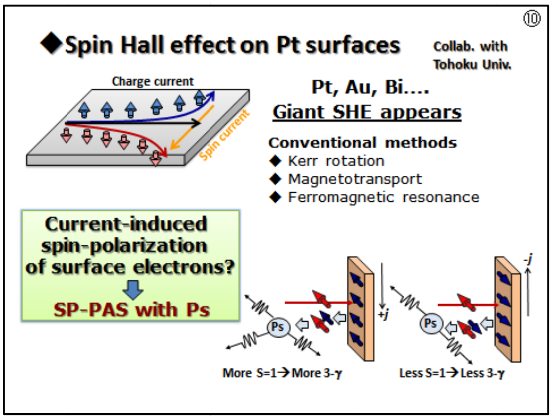


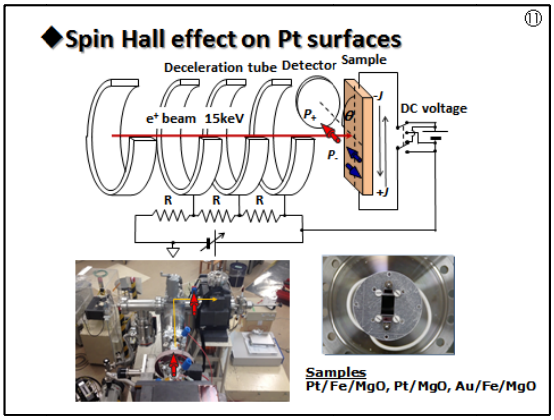
$$N_+(p_z) - N_-(p_z) = \frac{P}{2}\sum_{i=1}^{occ}\left[\frac{N_i^{\downarrow}(p_z)}{\lambda^{\uparrow}} - \frac{N_i^{\uparrow}(p_z)}{\lambda^{\downarrow}}\right]$$

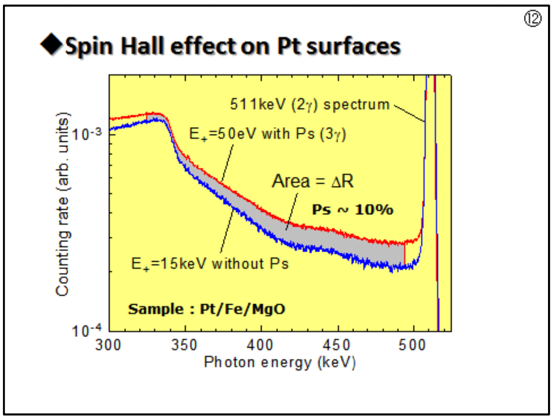


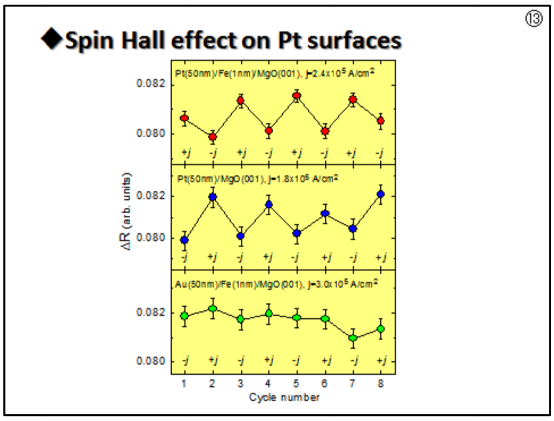
	Fe > Co > Ni
Intensity	2.2 :1.6 :0.4
M_S (μ_B)	2.2 :1.7 :0.6

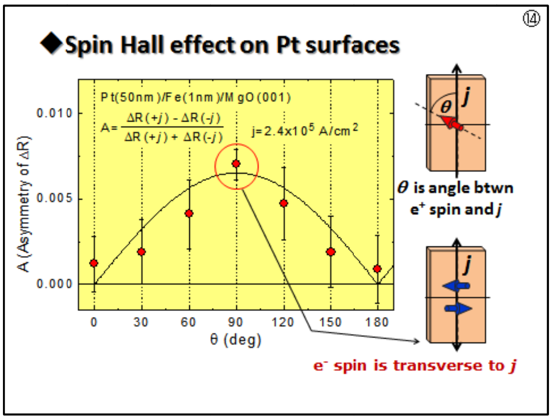

⑨
◆SP-PAS on 3d and 4f ferromagnets
Fe
Gd
N+ - N0
N- - N0
Electron momentum p (10^-3 m0c)
Energy (eV)
5d↓
5d↑
6s↓
6s↑
4f↑
EF
G M K G A L
SP-PAS sees polarization effect
of 5d bands (RKKY interaction)
4f ferromagnets also show the
low Curie temperature effect

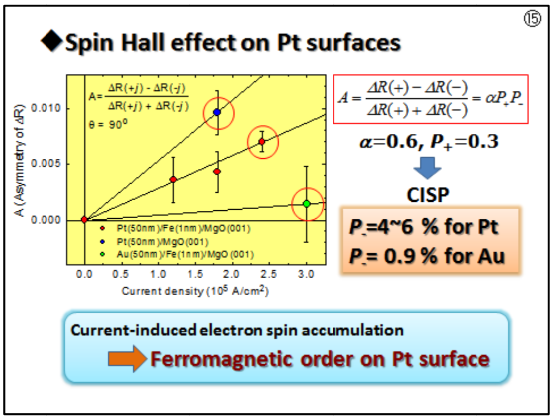

⑩
◆Spin Hall effect on Pt surfaces
Collab. with
Tohoku Univ.
Charge current
Spin current
Pt, Au, Bi....
Giant SHE appears
Conventional methods
◆ Kerr rotation
◆ Magnetotransport
◆ Ferromagnetic resonance
Current-induced
spin-polarization
of surface electrons?
SP-PAS with Ps
Ps
+j
-j
More S=1→More 3-γ
Less S=1→Less 3-γ

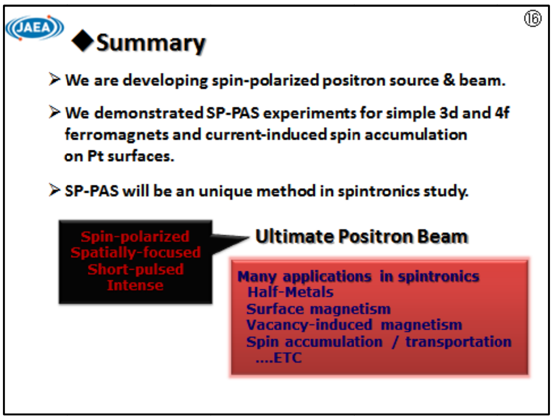

⑪
◆Spin Hall effect on Pt surfaces
Deceleration tube
Detector
Sample
e+ beam 15keV
DC voltage
R R R
Samples
Pt/Fe/MgO, Pt/MgO, Au/Fe/MgO


⑫
◆Spin Hall effect on Pt surfaces
511keV (2γ) spectrum
E+=50eV with Ps (3γ)
Area = ΔR
Ps ~ 10%
E+=15keV without Ps
Sample : Pt/Fe/MgO
Counting rate (arb. units)
Photon energy (keV)
300 350 400 450 500


⑬
◆Spin Hall effect on Pt surfaces
Pt(50nm)/Fe(1nm)/MgO(001), j=2.4x10^5 A/cm^2
Pt(50nm)/MgO(001), j=1.8x10^5 A/cm^2
Au(50nm)/Fe(1nm)/MgO(001), j=3.0x10^5 A/cm^2
ΔR (arb. units)
Cycle number


⑭
◆Spin Hall effect on Pt surfaces
Pt(50nm)/Fe(1nm)/MgO(001)
A = (ΔR(+j) - ΔR(-j)) / (ΔR(+j) + ΔR(-j))
j=2.4x10^5 A/cm^2
A (Asymmetry of ΔR)
θ (deg)
θ is angle btwn
e+ spin and j
e- spin is transverse to j


⑮
◆Spin Hall effect on Pt surfaces
A = (ΔR(+j) - ΔR(-j)) / (ΔR(+j) + ΔR(-j))
θ = 90°
Pt(50nm)/Fe(1nm)/MgO(001)
Pt(50nm)/MgO(001)
Au(50nm)/Fe(1nm)/MgO(001)
A (Asymmetry of ΔR)
Current density (10^5 A/cm^2)
A = (ΔR(+) − ΔR(−)) / (ΔR(+) + ΔR(−)) = αP+P-
α=0.6, P+=0.3
CISP
P-=4~6 % for Pt
P-= 0.9 % for Au
Current-induced electron spin accumulation
Ferromagnetic order on Pt surface


⑯
JAEA
◆Summary
➢ We are developing spin-polarized positron source & beam.
➢ We demonstrated SP-PAS experiments for simple 3d and 4f ferromagnets and current-induced spin accumulation on Pt surfaces.
➢ SP-PAS will be an unique method in spintronics study.
Spin-polarized
Spatially-focused
Short-pulsed
Intense
Ultimate Positron Beam
Many applications in spintronics
Half-Metals
Surface magnetism
Vacancy-induced magnetism
Spin accumulation / transportation
....ETC