A Novel Spin-Resolved Photoelectron Spectrometer with a High-Efficiency Spin Polarimeter

High-energy and angle-resolved photoemission measurements with spin resolution have been realized by adopting a high-efficient spin-detector based on a very-low-energy electron diffraction-type spin-polarimeter. With an efficiency about 100 times greater than a conventional spin detector, a "Mott-type" spin polarimeter has been realized. Because of the high-efficiency, high-energy and angular resolutions (30 meV and ±0.7°) in angle-resolved photoemission measurement are now compatible with spin-resolution. The precise electronic structure of solids, including their spin structure, can be obtained by this method, and the new spin-resolved photoemission system will open new insights into spintronics.

Spintronics, in which electron spin is controlled and utilized, is a promising technique for next-generation electronic devices. In order to develop such techniques, a method to investigate the electron-spin structure of materials is strongly demanded. A spin-resolved photoelectron spectroscopy (SRPES) is one of the most powerful techniques to provide such information on solids. However, the efficiency of the spin detection used for the SRPES measurement was extremely low, and experiments were very time consuming. Because of this low efficiency, realizing high-energy and angular resolutions (ΔE < a few tens meV, and $\Delta\theta < 1°$) that are easily obtained in recent photoemission measurements was not compatible with spin detection, and the resolutions (ΔE ~a few hundreds meV, and $\Delta\theta$ ~a few degrees) of conventional SRPES measurement were not good enough to enable investigation into the precise spin structure of solids.

Here we report a newly developed SRPES system that overcomes the shortcoming of previous SRPES measurement systems. By adopting a spin-dependent very-low-energy electron diffraction (VLEED) [1], we have been achieved a system that is 100 times more efficient in spin detection than previous SRPES system using the Mott-type spin detector. The schematic image of the spin detector is shown in Fig. 1. We modified the standard photoelectron detector of a commercial hemispherical electron analyzer (PHOIBOS150, SPECS GmbH), and replaced three of the nine channeltrons with an electron lens that leads the electrons to the spin detector. The transferred electrons that are accelerated or decelerated to E_k = 6 eV are reflected by a ferromagnetic target, and detected by the channeltrons set beside the electron lens. By measuring the difference in intensity of the reflected electrons between the positively and negatively magnetized ferromagnetic target, one can obtain the spin-polarization of the incoming electron to the target.

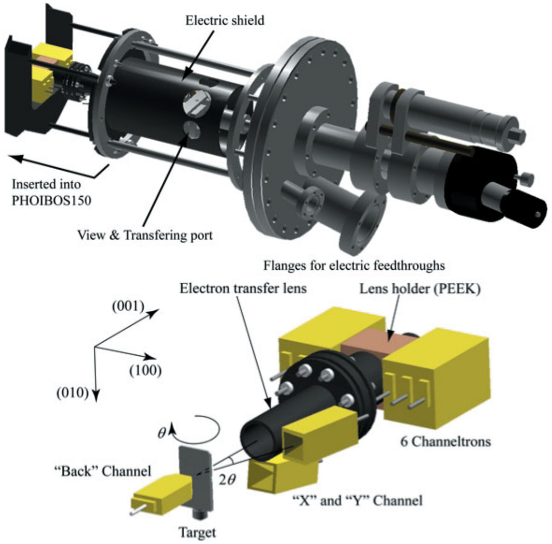

Figure 1
Design of a VLEED spin detector. Overview (top) and around the target (bottom).

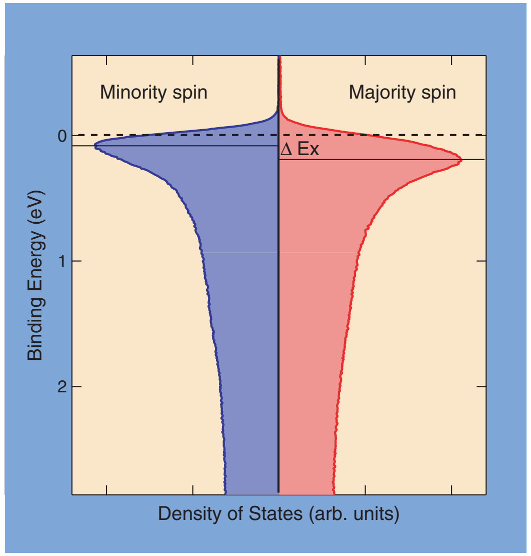

Figure 2
Majority and Minority spin sates of Ni(110) obtained by spin-resolved photoemission measurement. Exchange splitting (ΔEx) is clearly seen.

As the reflectivity of the low-energy electrons is much higher than that of the high-energy electrons that are utilized for the Mott scattering, one can measure the spin-polarization much more efficiently than with the Mott detector. The VLEED detector itself was developed 20 years ago [1] and has suggested its potential for efficient spin detection. The ferromagnetic target, usually Fe(001), however, is very easily deteriorated by residual gases, thus its lifetime is very short and it needs to be replaced every few hours. Because of the instability of the target, the VLEED detector did not become popular, despite its high efficiency.

We have conquered the problem by adopting a pre-oxidized Fe(001) surface, achieved using pure oxygen, that has been reported as a better candidate for spin detection [2]. We combined a VLEED detector using a Fe(001)p(1×1)-O target with a high-transmission large hemispherical analyzer. By the relatively higher Sherman function (~0.4) and high reflectivity of electrons (~0.1), a quite high efficiency – with a figure of merit of 10^{-2} order – has been achieved [3]. This value is about two orders higher than that of a typical Mott-type detector and provides the possibility to do SRPES measurement with high-energy and angular resolutions. Energy and angular resolutions of ΔE = 30 meV and $\Delta\theta$ = ±0.7° have been realized [3]. Figure 2 shows the observed SRPES data of ferromagnetic Ni(110) obtained with the VLEED. One can observe clearly the exchange splitting of the valence *d* band in the Stoner picture [4]. Because of the high efficiency, we can obtain SRPES data in a reasonable acquisition time (less than one hour per spectrum). The high performance of the new SRPES system achieves precise spin-structure analysis in spin-polarized materials derived from the spin-exchange, and spin-orbit interactions possible, and will contribute to the development of spintronics.

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