# Spin-resolved photoelectron spectroscopy

## Application Notes

Spin-resolved photoelectron spectroscopy experiments were performed in an experimental station consisting of an analysis and a preparation chamber. The preparation chamber is used for substrate cleaning, as well as for the preparation and magnetization of ferromagnetic thin films. It is equipped with several e-beam evaporators (Fe, Co, Ni), gas inlets, a LEED optics, and a magnetic coil. The latter is made of Cu-wire with 1mm diameter. The analysis chamber is equipped with an dual anode x-ray source (Al-Kα & Mg-Kα), a HeI UV-source UVS 300 and a PHOIBOS 150 analyzer with mini-Mott spin detector (MCD-6/spin).

A W(110) single crystal surface served as a substrate for the preparation of the ferromagnetic films. It was cleaned by a standard procedure involving several oxygen treatment cycles at 1800ºC and final flashes at 2500ºC. The cleanliness of the W(110) surface was verified by LEED and x–ray core-level spectroscopy showing a well ordered and contamination free surface.

Thin films of Fe, Co, or Ni were deposited in situ on the freshly prepared W(110) substrate, which was kept at room temperature. Thin film smoothness was improved by post annealing the sample at 400° C. During the thin film preparation the pressure was kept below 5´$10^{-10}$ mbar. The resulting ferromagnetic thin films are clean and show a high crystalline quality as can be deduced from the corresponding LEED images shown in Figure 1.

The ferromagnetic films were magnetized by pulsed magnetic fields of approximately 500 Oe. The magnetic field was applied along the corresponding easy magnetization axis of the ferromagnetic film which leads to a single domain state of the film. Table 1 lists film thickness, the crystallographic direction of the easy magnetization axis of each film and the corresponding crystallographic direction of the W(110) substrate.

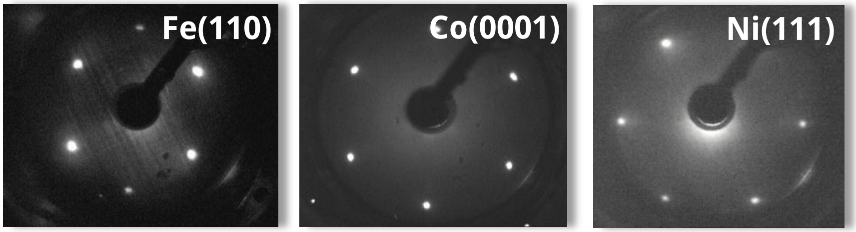

Figure 1: LEED images of Fe(110), Co(0001), and Ni(111) films grown on W(110).

| | Thickness / Å | Easy magnetization axis | Direction in W |
|---|---|---|---|
| Fe(110) | 50 | $<1\bar{1}0>$ | $<1\bar{1}0>$ |
| Co(0001) | 100 | $<1\bar{1}00>$ | $<001>$ |
| Ni(111) | 100 | $<1\bar{1}0>$ | $<001>$ |

Table 1: Film thickness, crystallographic direction of easy magnetization axis and the corresponding direction in the W substrate.

The overall principal scheme of the photoemission experiment is shown in Figure 2. Spin-polarized electrons are excited by the UV-light sample and travel through the hemispherical energy analyzer, where they are dispersed in energy and finally hit the mini-Mott detector. Here, the HeI emission line (21.2 eV) from the UVS 300 source is used to excite valence band electrons. The angle between UV light and the sample surface was 20° and electrons were collected around the surface normal. All spectra were measured at room temperature which is far below the Curie temperature of the investigated ferromagnetic films. The energy and angular resolution of analyzer were set to 100 meV and 2°, respectively.

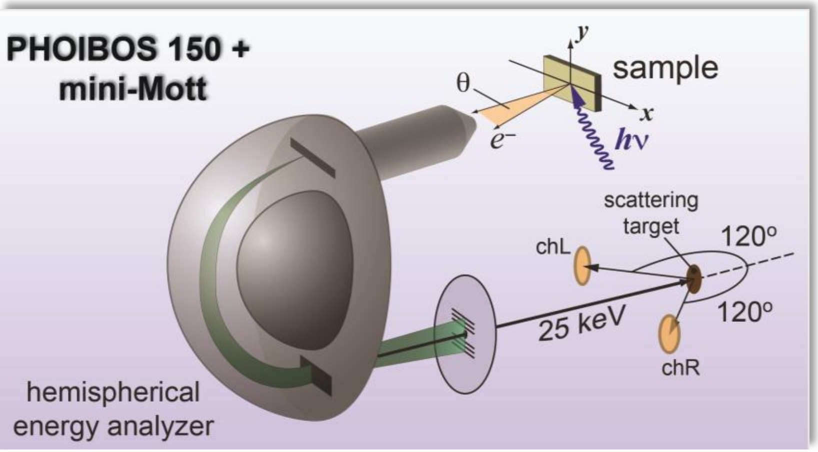

Figure 2: The principal scheme of spin-resolved photoelectron spectroscopy experiment.

The detector consists of 6 front channeltrons allowing the measurements of total spin-integrated signal, and a spin-detector for spin-resolved measurements. In the spin-detector the electrons are accelerated to an energy of 25 kV and scatter on a Th target. Due to the high kinetic energy of the incoming electrons the scattering potential of the nucleus is not symmetric, which is a result of spin-orbit interaction during the scattering process. For example, for spin-up electrons the probability to scatter to the left is higher compared to the probability to scatter to the right. Calculations show that the maximum asymmetry in the scattering, that is, $A=I_L/I_R$, is achieved for scattering angles of 120° with respect to the direction of incoming beam.

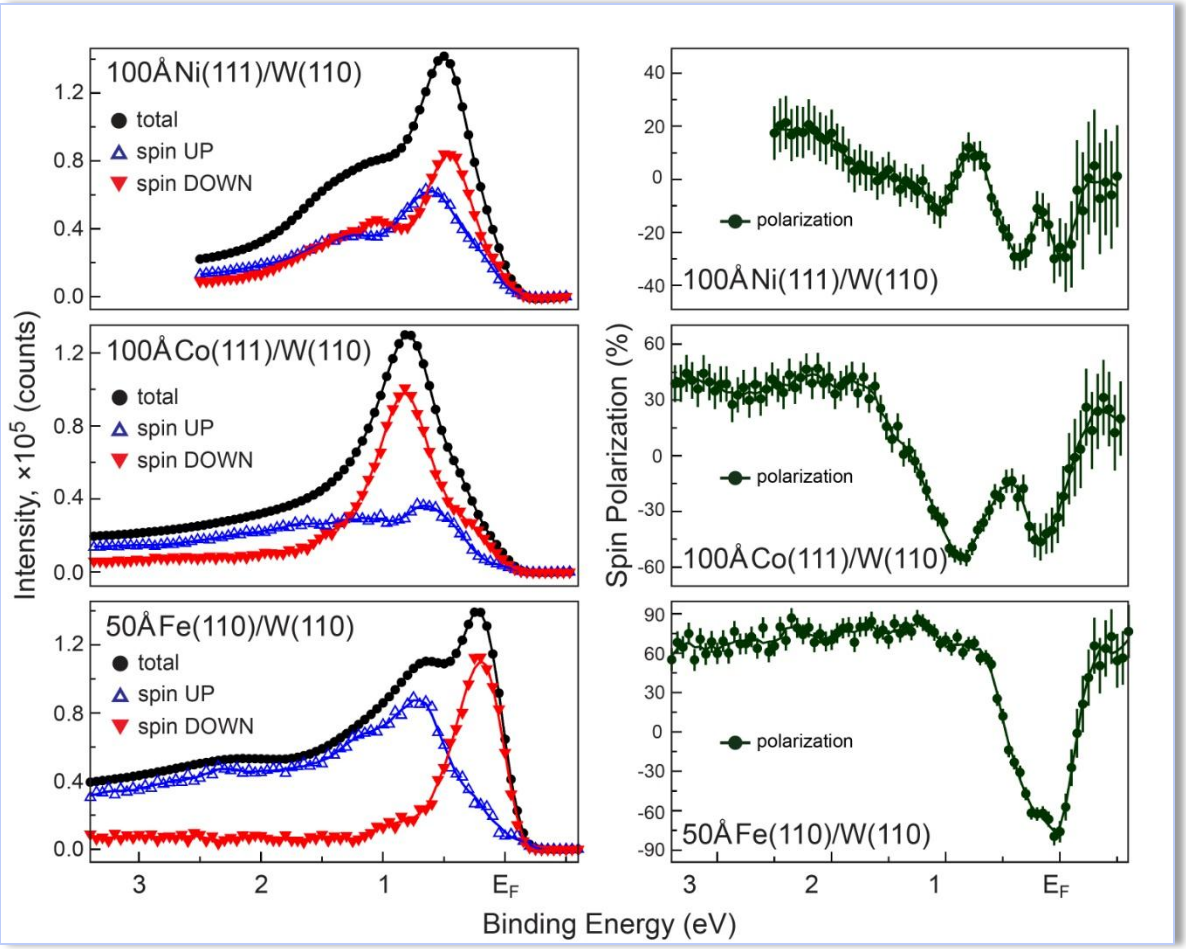

Figure 3: Spin-integrated, spin-resolved photoelectron spectra (left column) and the corresponding spin polarization (right column) as a function of binding energy measured for Fe(110), Co(0001), and Ni(111) thin films.

The elastically scattered electrons are detected by 2 pairs of channeltrons which are placed in the vertical and horizontal planes allowing simultaneous measurements of two orthogonal components of the electron spin. The energy window around the elastic peak and the scattering energy are two main factors which define the efficiency of the spin detector. The so-called effective Sherman function, $S_{eff}$, determines the sensitivity of detector for spin separation, while the figure of merit ( FOM) characterize the efficiency of the spin detector.

One of the main sources of error in the calculation of spin polarization on the basis of experimental data is the asymmetry induced by the experimental set-up. In order to remove this error spin-resolved measurements on ferromagnetic samples have to be performed two times for two opposite directions of magnetizations. In case of experiments where spin-orbit effects are studied on non-magnetic sample the circularly polarized light is recommended and two measurements with opposite helicities have to be done.

Figure 3 (left column) shows spin-integrated as well as spin-resolved photoelectron spectroscopy spectra for thin ferromagnetic Fe(110), Co(0001), and Ni(111) films. The corresponding spin polarization as a function of binding energy (Figure 3, right column) was calculated on the basis of raw data for “left” and “right” spin channels using the following formula:

$$P = \frac{1}{S_{eff}} \frac{\sqrt{I_L^+ I_R^-} - \sqrt{I_R^+ I_L^-}}{\sqrt{I_L^+ I_R^-} + \sqrt{I_R^+ I_L^-}} .$$

Here, $I_L$ and $I_R$ are two sets of intensities of “left” and “right” channels measured for “+” and “-” magnetization directions. The corresponding intensities for spin-up and spin-down channels are calculated by using

$$I_\uparrow = I_0(1+P)\,,\; I_\downarrow = I_0(1-P)\,,$$

where $I_0$ is the total intensity of all spin channels. The statistical error in the calculation of the spin polarization is:

$$\Delta P = \frac{1}{S_{eff}\sqrt{4I_0}} .$$

The spin-resolved photoelectron spectroscopy spectra and the calculated spin polarizations are compared with previously measured data using a classical Mott spin-detector operated at scattering voltage of 100 kV [1-3]. The previously obtained value of -80% spin polarization for the Fe(110)/W(110) measured in similar conditions allows to estimate the Sherman function in our experiments. It is equal to $S_{eff}$=0.12 when the energy window of elastically back-scattered electrons in the spin-detector is set to 1200 eV.

References:

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Further reading:

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