



# A new analyzer for spin resolved electron spectroscopies

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## Abstract

We have developed a new instrument which performs simultaneously energy and spin-polarization analysis of an electron beam, to be used in spin resolved electron spectroscopies from magnetic surfaces and thin films. The device consists of a novel polarization detector with high efficiency and analyzing power coupled to a large commercial hemispherical energy analyzer (HEA). The spin polarimeter is based on the spin dependence of the low energy (4–6 eV kinetic energy) reflectivity from a magnetic target, namely a Fe(001)-*p*(1 × 1)O surface. We describe reliable target preparation procedures and the design of the electron-optical system transferring the electrons from the HEA exit slit to the polarimeter target. © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Electron spectroscopy; Spin polarization; Surface magnetism

Spin resolved electron spectroscopies are very fruitful in investigations of surface and ultrathin film magnetism [1]. To this aim sources and detectors of polarized electrons have been developed in the last decades. Spin-polarized electron sources are successfully realized by means of negative electron affinity photocathodes based on GaAs [2], AlGaAs/GaAs heterojunctions [3] and, more recently, strained semiconductor structures [4]. On the other hand, in the field of polarimetry, the situation is quite different. Actually, in addition to the traditional high-energy Mott detector [5], many other polarimeters have been developed in the last years, but with poor efficiency [6]. A key parameter of a spin detector is the analyzing power  $S$ , known as Sherman function in Mott polarimetry [5]. Typical  $S$  values are around 0.1–0.2 (see Ref. [6]), and this strongly influences the detector efficiency  $F$  ( $F = S^2 I / I_0$ , where  $I$  is the electron intensity actually used for the polarization measurement and  $I_0$  is the primary intensity). As a result with all the exception of one (see Ref. [7])<sup>1</sup> of the presently used polarimeters have  $F \leq 2 \times 10^{-4}$ , indicating that polarization measure-

ments are still much more demanding than intensity measurements.

We have recently developed a polarimeter [8,9] based on the spin-dependent electron scattering from Fe(001)-*p*(1 × 1)O, a well-ordered surface presenting very large spin-dependent effects [10]. Moreover, the presence of the surface oxide protects the system against contamination, so that a very stable device can be realized [8,9]. The measured efficiency is  $F \geq 6 \times 10^{-4}$ , while 10 times larger values are envisaged with optimization of the collection of the reflected beam [8,9]. It is also to be noted that  $F$  is not the only relevant parameter. In fact, systematic errors also play a relevant role in many experiments. For instance, apparatus asymmetries (possibly even uncontrolled) are present in any real system, posing serious problems when tiny polarization values are to be measured. In that case, the analyzing power is surely more important than the efficiency, since with a large spin asymmetry, i.e. large  $S$ , the measured signal would become more reliable. In our device, we find extremely large  $S$  values for electrons reflected at 3–6 eV kinetic energy, with maximum above 45%, i.e. roughly three times better than other polarimeters presently used [8,9].

In order to perform at the same time energy and polarization analysis of the electron beam, the polarimeter is coupled to a large commercial HEA (VSW HA-150), with the scattering target located after its exit slit (see Fig. 1). The Fe(001)-*p*(1 × 1)O target is prepared in a dedicated ultrahigh vacuum (UHV) system: a

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<sup>1</sup>The Authors report on a polarimeter with  $F = 3.8 \times 10^{-3}$  based on scattering from a clean Fe surface; the device is strongly affected by contamination problems.

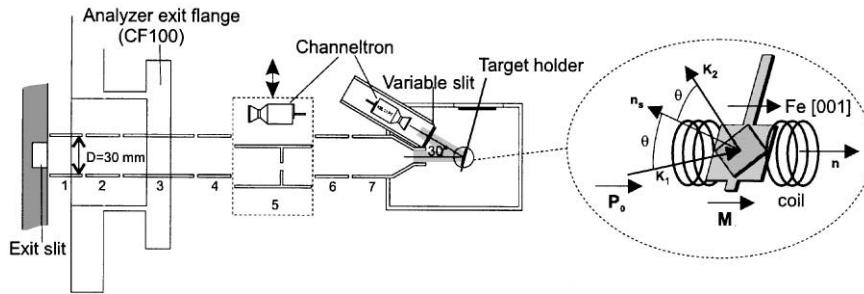


Fig. 1. Section view of final part of the energy and spin analyzer. The inset shows a sketch of the scattering geometry: the incidence angle is  $15^\circ$  off normal and the specularly reflected beam is collected. At each beam energy the reflected current is measured for parallel and antiparallel orientation of the beam polarization  $P_0$  and the target magnetization  $M$ , which can be switched by a current pulse through the coil.

clean Fe(001) surface<sup>2</sup> [11] is exposed to oxygen ( $p \sim 10^{-7}$  Torr) at  $\sim 450$  K for few minutes and then flash-heated at 900 K for few seconds. Next, by means of a vacuum interlock system, the target is transferred into another UHV chamber close to the HEA exit slit, without being exposed to air. Possible contaminants accumulated at the surface during the transfer process are removed by heating in  $O_2$ . The resulting surface is very stable: the analyzing power presents almost no deterioration after one week in UHV. Heat treatment in  $O_2$  as described above, refreshes the surface and restores the initial performance.

The low operating energy and the constraints related to the divergence of the impinging beam require an accurate design of the electron-optics coupling the polarimeter to the HEA. Fig. 1 shows a scheme of the adopted solution, consisting of a seven element decelerating column. The electrodes are cylindrical tubes made of a nonmagnetic alloy (Arcap AP4); the full system is shielded against spurious electric and magnetic fields, to avoid perturbation of the electron path and of the scattering geometry. The first five electrodes constitute an afocal system, which slows the electron beam down to 6 eV kinetic energy and forms an image of the HA exit slit corresponding to the pupil present in the fifth electrode. In this configuration, originally studied by Heddle [12], the image position results independent of the kinetic energy of the electrons emerging from the HA. The second part of the e-optics (electrodes 5, 6 and 7) is a three cylinder zoom lens: the last electrode determines the scattering energy, in the 4–6 eV range, while the sixth one allows to change the overall transmission as well as the

beam divergence and size at the target. The behavior of the transfer e-optics has been analyzed in detail via ray-tracing simulations using the Simion 3D program. As an example, for a pass energy of 44 eV, we found 44, 92.4, 16.3, 34.2, and 6 V for the voltages of the first five electrodes, respectively. In this case the maximum transmission (25%) was obtained for  $V_6 = 60$  V, with beam spot and divergence at the target around 4 mm and  $8^\circ$ , respectively. The low value of the maximum transmission achieved is due to the low operating energy and in turn to the small electron optical acceptance of our polarimeter (see also Ref. [6]). When spin analysis is not required, the standard energy analysis functions are preserved via a retractile channeltron mounted on a linear motion feed-through replacing the fifth electrode, as indicated in Fig. 1.

Experimental tests with a spin-polarized electron gun, including an accurate calibration and analysis of the efficiency dependence on the definition of the scattering geometry (cf. the movable slit in the scattering box of Fig. 1), are presently being carried out in our laboratory.

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<sup>2</sup>The Fe (001) surface is actually obtained by epitaxial growth of a thick Fe film on a clean MgO(001) substrate see Ref. [11]. Single crystal films are very useful, since they can be very easily magnetized in remanence. Moreover, the stray magnetic fields, originating from a tiny amount of magnetized material, tend to be negligible.