New compact classical 40 kV Mott polarimeter

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A compact classical electron spin detector based on Mott scattering is described. This Mott polarimeter has an efficiency of $\approx 5.6\times 10^{-4}$, a maximum counting rate of 500 kcps and bulk size 15 cm$\times$25 cm. The design of the polarimeter goes back to the classical Mott detector, operating from 100 to 120 kV but it can be combined with conventional analyzers due to its compactness. In this Mott polarimeter an electrostatic acceleration voltage up to 40 kV can be applied and the detectors are energy sensitive silicon diodes operated in reverse bias with variable discriminator threshold. The detectors with the amplifiers are floated on the top of acceleration voltage to allow a field-free travel of the electrons from the scattering gold foil to the detectors. Such features reduce the polarimeters sensitivity to slight motion or changes in the shape of the incoming beam. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1535736]

I. INTRODUCTION

The most common method for the measurement of the spin polarization of electrons is Mott scattering.[1,2] There is the wide spectrum of different kinds of Mott polarimeters.[3–9] Other types of polarimeters are not discussed here because they are not real competitors to Mott detectors for numerous parameters. In this article we describe a new classical polarimeter built in the Surface Magnetism Group at St. Petersburg Technical University based on the experience and equipment held in our team.[10,11] We will first recall the main requirements, to be considered for the design of a new polarimeter:

(1) The polarimeter must measure two spin components of electrons with any energy at the same time.
(2) It must be a self-sufficient device. The polarimeter should be ready to operate within a few minutes after switching on the power. No adjustment of the spin detector before and during operation should be needed. The polarimeter should run without variation of any parameters during several years in any pressure.
(3) The measured polarization must represent the real polarization of the electrons and must not depend on shape, position, density, and intensity of the beam. In other words, the polarimeter should be insensitive to those parameters of the beam, which can vary during an experimental run.
(4) The polarimeter must be compact, fully ultrahigh vacuum compatible and should be bolted on a flange not larger than CF100.
(5) Obviously the efficiency of the polarimeter should be as high as possible. This point deserves particular attention in the design of a modern experiment.

In Mott detectors, the polarization is calculated from the measured asymmetry of the electron scattering on the gold foil:

$$A=(N_L-N_R)/(N_L+N_R), \quad (1)$$

with the absolute statistical error (high limit)

$$\Delta A=1/\sqrt{N_L+N_R}, \quad (2)$$

where N_L and N_R are the counts in the left and in the right channels, respectively.

The polarization is then given by

$$P=A/S, \quad (3)$$

where S is the effective Sherman function, namely the asymmetry which is measured for a fully polarized beam.

The absolute statistical error of the polarization is

$$\Delta P=1/S\sqrt{N_L+N_R}=1/\sqrt{\varepsilon N_0}, \quad (4)$$

where N_0 is the number of incoming electrons and ε is the efficiency of the polarimeter:

$$\varepsilon=S^2(N_L+N_R)/N_0. \quad (5)$$

We note that for the calculation of the efficiency and for comparing different polarimeters it is necessary to count the electrons only in two channels, while four detectors are used in most polarimeters to cover two polarization components.

From Eq. (4) it can be seen that the absolute error of the polarization is given by the number of incoming electrons. Therefore, if we know the efficiency of a polarimeter we can calculate in advance the number of incoming electrons needed to allow for a certain statistical error. For example, in the hypothetical case of 100% efficiency, 10^4 incoming electrons are necessary to measure the polarization of an electron beam with $\Delta P=0.01$ (1% of polarization).

In practice, we believe that a large number of tasks can be solved successfully if the efficiency of polarimeter will be about 10^{-3}. It can be seen from Eq. (4) that 10^7 incoming electrons are necessary in this case to measure the polarization of electrons with $\Delta P=0.01$. For example, the polarization of an electron current $I=1$ pA will be measured in about

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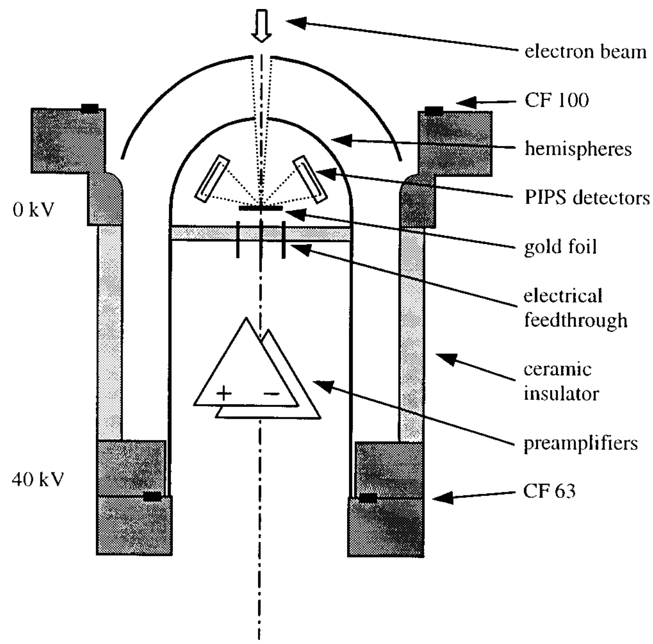

FIG. 1. Schematic of Mott polarimeter.

1 s. This is the order of magnitude of an Auger electron's current after scattering a primary beam with a current of several μA on a solid.

In order to satisfy all these conditions we decided to choose the classical polarimeter scheme with spherical accelerating field as proposed by Landolt.[6]

The reason for this choice are twofold: First, it was found that only the classical polarimeter in which the scattered electrons are moving in field free space can keep the necessary stability and insensitivity against changes of the beam parameters.[11] Second, the emergence of the new elements of the electronics industry allows one to build a very compact classical Mott detector. It is apparent that for the selection of those electrons that were scattered elastically by the gold foil it is necessary to use energy sensitive detectors. The detectors with large area used before (in conjunction with the preamplifiers) had low resolution and high intrinsic noise. Therefore the classical Mott detectors did not offer the possibility to separate well the signal from the noise for electrons energies well below 100 kV. Nowadays, new detectors with a small dark current and new low noise transistors are available. Based on such transistors new preamplifiers were developed, providing successful solutions to the problems.

II. POLARIMETER DESIGN

The starting point for the design of the new polarimeter was our old classical Mott detector,[10] which was built approximately 5 years ago and has proven to be a very effective, reliable, and stable device.[12,13] The design of the new polarimeter consists in a scaled down copy of such detector with only one ceramic insulator (Fig. 1). The inner part of the new polarimeter is assembled within a flange CF63 and is the exact (but shortened) copy of the old one.

The electrons, the polarization of which is to be measured, are accelerated in the field between two hemispheres. After scattering on the gold foil they are counted by passivated implanted planar silicon (PIPS) barrier detectors. It is very important here that the electrons move in a field free space. The thickness of the gold foil is 800 A on a thin free standing formvar film. The active area of the detectors is $10\times 10\ \mathrm{mm}^2$ and the distance between the centers of the gold foil and the detectors is 17 mm.

Inside the polarimeter (on the atmospheric side) are four preamplifiers. Each preamplifier includes: (i) a section sensitive to the incoming charge, (ii) a voltage preamplifier, (iii) a quasi-Gauss shaper scheme, and (iv) an active filter with Bessel characteristic.

From the atmospheric end a cylindrical aluminum box is mounted which lies also on the high potential. The box contains the discriminators, fiber-optic transmitters, a transformer and a power supply for $+-5$ and $+50$ V. The voltages come from an ac signal with an amplitude of 10 V, which is supplied by the high voltage (40 kV) power supply.

The complete new Mott polarimeter has maximal sizes: length 25 cm, diameter 15 cm. The protection shield (if necessary) increases the length and the diameter over 3 and 5 cm.

The counting signals are brought to ground potential by a fiber-optical system. To provide the voltages for the polarimeter a special compact stabilized power supply for 50 kV was made, with sizes: $30\times 26\times 18\ \mathrm{cm}^3$.

III. TESTS AND CALIBRATION OF THE POLARIMETER

A. High voltage tests

The device was tested up to a voltage of 55 kV. At this voltage the polarimeter was kept for several hours without any problems. However all performance tests were carried out with a voltage of 40 kV.

B. Signal-to-noise tests

Since all electronics is put to high voltage, it is difficult to use a pulse analyzer. Therefore signal-to-noise tests were carried out by a more simple, traditional method. The number of counts of electrons as a function of discrimination level was measured in each channel. The results are shown in Fig. 2(a) after derivation. One can see that the signal and noise are well separated. Therefore a discrimination level of 50–60 a.u. gives 100% efficiency of counting for elastic electrons. In this case the intrinsic noise of the electronics is 1 to 2 counts per second. The maximum count rate of the new Mott polarimeter is 500 kcounts/s.

C. Calibration of the polarimeter

1. Measurement of S

The calibration of the polarimeter was carried out by a method described in Ref. 10. It was shown that a classical Mott detector (in first approximation) can be calibrated by extrapolation to a high level of discrimination. The main idea of this method is based on the assumption that the measured pulse height spectrum is defined as the convolution of the real electron spectrum with an apparatus function (energy resolution of the PIPS detector-preamplifier system). Therefore at a high level of discrimination (sometimes this level is

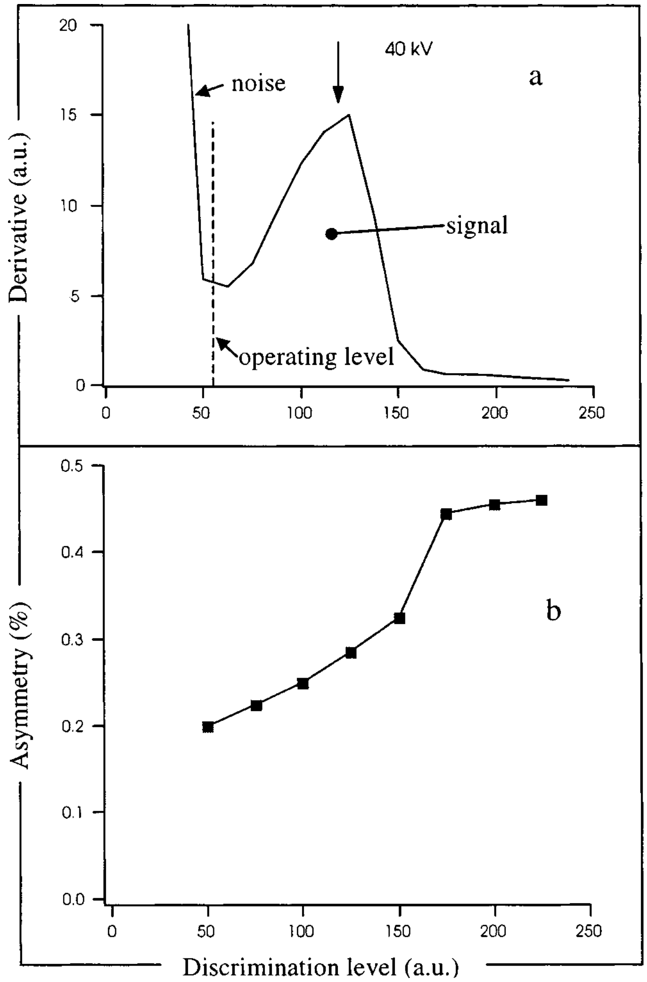

FIG. 2. (a) Derivative of the number of counts of electrons vs discrimination level for one channel. An arrow corresponds energy 40 kV. (b) Asymmetry of scattering vs discrimination level.

twice as high as the one used in standard operation) the asymmetry is defined only by elastically scattered electrons.

This method is similar to the method of calibrating a retarding potential Mott polarimeter based on extrapolation to zero energy loss.[14] For the calibration it is necessary to use a very stable source of polarized electrons. The polarization can be small and obscure. For the calibration the asymmetry of scattering A as a function of discrimination level should be measured and the curve must be well saturated to accept the asymmetry for the calculation of the effective Sherman function S based on atomic data for the specific geometry of scattering.

As a source of polarized electrons we used the scattering of unpolarized electrons on the surface of a single crystal of $FeNi_3$ (110). The schematic of the experiment is shown in Ref. 11. The sample was irradiated with a beam of unpolarized electrons with an energy of 500 eV. The electron gun was situated under the angle of 90° with respect to the axis of the Mott polarimeter. The scattering plane was horizontal. The sample was shaped as a picture frame, the sides of which are oriented along the easy axis of magnetization. Around one side of the frame a magnetizing coil of seven loops was wound. The operating side of the frame was magnetized in the direction perpendicular to the plane of beam scattering (vertical). The secondary electrons were injected into the Mott detector by means of a simple electron optical system.

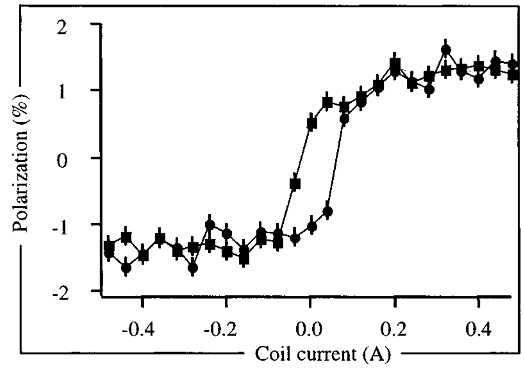

FIG. 3. Hysteresis loop measured by spin polarized secondary electron emission (SPSEE) method from contaminated $FeNi_3(110)$ sample.

It was found that the clean surface of the $FeNi_3$ crystal is sensitive to contamination. However the already contaminated surface gave a small but very stable polarization for many hours. To remove the possible errors introduced by spin–orbit interactions and an apparatus asymmetry, hysteresis loops were measured during the whole calibration procedure (Fig. 3). The presence of a loop with nonzero coercive field assures the magnetic origin of the measured asymmetry. The time for measuring a full loop as shown in Fig. 3 (50 points) is 12 min with the statistical error bars as shown in the graph and with a count rate of 400 kcounts/s.

In Fig. 2(b) the measured curve of the asymmetry of scattering as a function of discrimination level is shown. It can be seen that at the operating level of discrimination (55 a.u.) the asymmetry of scattering is minimal and reaches the value of approximately 0.21%. The time of measurement of the asymmetry with a statistical error equal to the size of the points, in the graph, at this discrimination level, was 8 min, with a count rate of 400 kcounts/s. When the discrimination level was increased, the asymmetry of scattering also increased and reached saturation at the value of asymmetry of 0.45%. The measuring time necessary for the asymmetry to reach the same statistical error at the level of 225 a.u. was already 14 h. But as mentioned previously our source of polarized electrons gave a very stable polarization for many hours. We note also that the efficiency ε has a very wide maximum around the operating level of discrimination (55 a.u.).

This asymmetry of 0.45% was accepted as the value for pure elastic scattering where a Sherman function of $S = 0.32$ is calculated for our geometry from atomic data.[15] At the operating level of discrimination (55 a.u.) the effective Sherman function that is calculated from these numbers then becomes

$$S = 0.32 \times 0.21/0.45 \approx 0.15.$$

2. Measurement of the ratio $(N_L + N_R)/N_0$

To measure the ratio $(N_L + N_R)/N_0$ the unit consisting of four detectors and a gold foil was replaced by another unit consisting of only one detector lying in the place of the gold foil. This unit was installed by opening the CF63 flange.

Since the pumping to a pressure of 10^{-7} mbar is very quick the procedure was repeated several times. For both configurations the counts were measured in all detectors with unchanged parameters of the gun's power supply. The measured ratio $(N_L+N_R)/N_0$ for the operating level of 55 a.u. was ≈ 0.025.

Thus the Mott detector provides an efficiency $\varepsilon \approx 5.6 \times 10^{-4}$ for one projection of spin.

This value is a factor 2 below the discussed (10^{-3}), however a new unit with 8 PIPS detectors which will cover practically the whole space above and below the gold foil is already in preparation. According to our calculations we then will reach an efficiency $\varepsilon \approx 9 \times 10^{-4}$ in this case.

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