Mott Spin Polarimeter with Spherical Acceleration Electrodes

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Abstract

We designed a compact Mott spin polarimeter with spherical acceleration electrodes. The acceleration electrode geometry of the polarimeter has been optimized for 1KeV to 7KeV incident electrons and is designed for ease in changing the target Au films. To evaluate characteristics of the polarimeter, a static electron lens system that consists of three static lenses was constructed and an NEA-GaAs photoemitter was used as a spin polarized electron source. With the present system, the observed spin polarization of photoemitted electrons is about 20%.

1. Introduction

Spin polarization analysis of electrons or atoms enable us to investigate the surface magnetic properties of materials(1). Photoemitted electrons have been used to define the spin polarized band structure of ferromagnetic materials for about two decades(2). Spin-resolved secondary electron microscopy (Spin SEM) was developed as a useful tool for mapping spin polarization of secondary electrons emitted from magnetic sample surfaces, i. e., for visualizing the fine magnetic domain structure of the surfaces(3). Recently the spin SEM study of spin configuration of magnetic multi-layer films attracts much attention(4). The spin polarized analysis of field emitted electrons reveals surface magnetic structure of a sharpened magnetic tip(5). Auger electrons, which are generated by impinging of spin polarized or unpolarized electrons/atoms on the magnetic sample surface, can also be resolved into two different spin components(6). Spin dependent electron diffraction and electron/atom scattering via exchange interaction have been studied as techniques for surface magnetic investigations(1).

The electron spin analyzer commonly used in surface spin analyses mentioned above is the Mott polarimeter. The Mott polarimeter counts left-right asymmetry of

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Mott scattered electrons by a heavy atom (usually gold) at appropriate scattering angle[7]. This polarimeter is more convenient than other spin analyzers except for the fact that it operates at high voltage (commonly 100 kV), because the spin analyzers using low energy electron diffraction or scattering requires ultra high vacuum condition to prepare clean surfaces of analyzer targets[8].

We are planning to develop a scanning tunneling microscope (STM) with spin resolution to observe ultra fine surface magnetic structures up to the atomic scale[9]. Such an STM is called spin-polarized STM (SP-STM). For realizing the SP-STM, it is important to prepare a tip which apex is magnetically well defined. Field emission microscopy (FEM) with spin resolution is only the method to do it.

We designed and developed a Mott polarimeter operated in the lower voltage region (40kV) for the spin-polarized FEM (SP-FEM). Our polarimeter has spherical acceleration electrodes that make it easy to handle, and those are optimized for the SP-FEM. Its characteristic was demonstrated with an NEA treated GaAs photo-emitter. Needless to say, our Mott polarimeter can be used for other surface spin analyses.

2. Principle of Mott Polarimeter

The spin dependent part of the Hamiltonian of an electron scattered by Coulomb potential V(r) is[1]

$$H_{ls}=\frac{1}{2m^2c^2}\,\frac{1}{r}\,\frac{dV}{dr}(\mathbf{s}\cdot\mathbf{l}) \tag{1}$$

where r is the distance between the electron and a scattering center atom, s is the spin of the electron. $\mathbf{l}=\mathbf{r}\times\mathbf{p}$ where p is the momentum of the electron. An electron sees different potential from that of the electron scattered into opposite scattering angle in the scattering plain (one is scattered clockwise in scattering plane, and another is scattered counterclockwise as depicted in Fig. 1). Therefore the differential scattering cross sections of these electrons are different and the left-right scattering asymmetry is observed. The differential cross section is

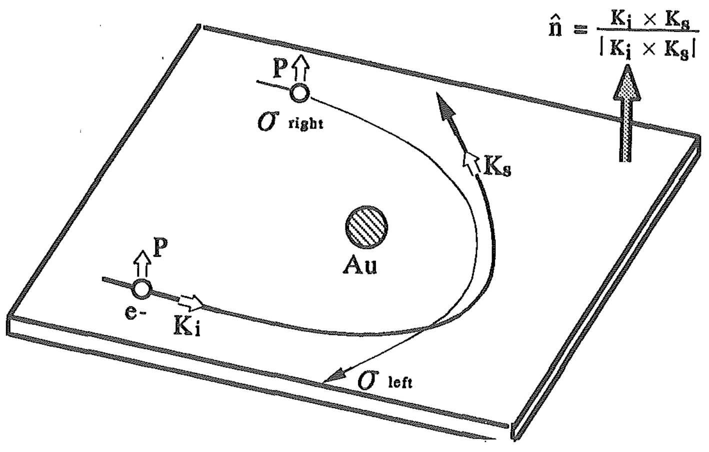

Fig. 1 Spin dependent scattering geometry of an electron by Coulomb field of Au atom.

$$\sigma(\theta, \phi)=(|f|^2+|g|^2)\ [1-S(\theta)\mathbf{P}\cdot\hat{\mathbf{n}}], \tag{2}$$

where f and g are scattering amplitudes, $S(\theta)$is the Sherman function, $\mathbf{P}$ is the spin polarization of the incidnet electron, $\hat{\mathbf{n}}$ is the normal of the scattering plane, and θ is the scattering angle.

When the spin polarization $\mathbf{P}$ is perpendicular to the scattering plane, that is, $\phi=90°$ and $\phi=270°$ ($-P_t\sin\phi=\mathbf{P}\cdot\hat{\mathbf{n}}$), left and right differential cross section ($\phi=90°$ corresponds to the scattering to the right) are

$$\sigma_{right}=\sigma(90°, \theta)=(|f|^2+|g|^2)(1-PS(\theta)), \tag{3}$$
$$\sigma_{left}=\sigma(270°, \theta)=(|f|^2+|g|^2)(1+PS(\theta)). \tag{4}$$

The number of electrons scattered into these directions are proportional to the above cross sections.

$$N_{right}\propto\sigma_{right}, \tag{5}$$
$$N_{left}\propto\sigma_{left} \tag{6}$$

Therefore the left-right asymmetry of the number of the scattered electrons is

$$A=\frac{N_{left}-N_{right}}{N_{left}+N_{right}}=PS(\theta) \tag{7}$$

The Mott polarimeter has two scattering electron counters to evaluate A located in appropriate direction θ. By measuring A, P is obtained with the theoretically calculated $S(\theta)$. Numerically calculated Sharman functions are shown in Fig. 2. This calculation uses an approximation proposed by G. Holzwarth and H. J. Meister[6]. Since the performance of the Mott polarimeter is mainly defined by $S(\theta)$, the angle of the detector is chosen to be 120°.

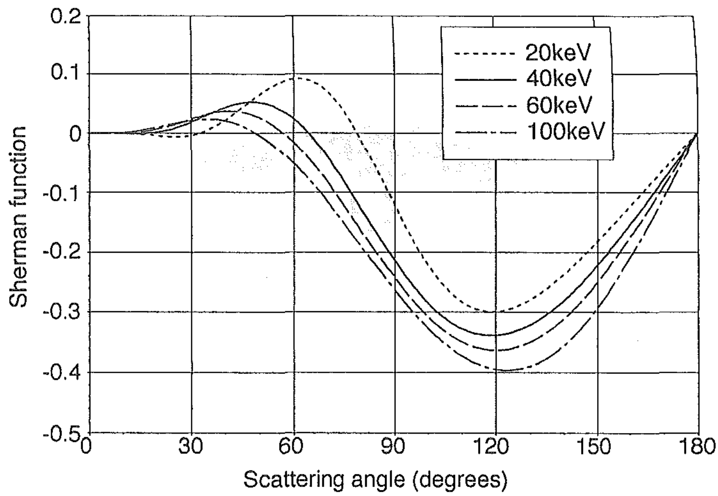

Fig. 2 Numerically calculated Sharman function including a screening field. Scattering angle dependence of the Sharman function with colliding energy of 20KeV, 40KeV, 60KeV, 100KeV is calculated.

3. Electrode Design

A conventional Mott polarimeter operates in about 100KeV energy region, however, the recently developed Mott polarimeter with cylindrical or spherical acceleration electrodes can operate with less than 40KeV[(7),(8)]. Since their electron counting systems can be located at ground potential, any special signal transfer system between ground to high voltage region is not necessary. We employed the spherical acceleration electrode that was proposed by Gray et al.[(8)] Schematic diagram of our spherical Mott analyzer is depicted in Fig. 3.

The concentric electric field between two half spherical electrodes accelerates incident electrons. The outer electrode is connected to the ground and high positive voltage (~40keV) is applied to the inner electrode. The accelerated electron impinges onto Au target thin films (its thickness is typically about 500 Å to a few thousands Å.) located at the center of the electrodes. Electrons that pass through the films are captured in the Faraday cage behind the target. The target is biased at −300V with respect to the inner electrode, to prevent ionized gas from escaping out the inner region. The escaped ions are accelerated by the field between the inner and the outer hemisphere and detected as a background signal. The Faraday cage is also biased at +300V to attract the passed electrons. Since the field diaccelerates the scattered electrons, inelastically scattered electron which loses large energy is retarded not to go into the detector aperture. And for retarding the electron more efficiently, there is a retarding electrode with the small aperture before the detector (channeltron). The two acceleration electrodes and the guard ring that compensate the field distortion at the end of the spherical field, are mounted on a ceramic base plate that is supported by a ICF253 flange. Since the target holder and the Faraday cage component are mounted on the isolated insulator base, the target can be changed by pulling the base without breaking the whole system down into parts.

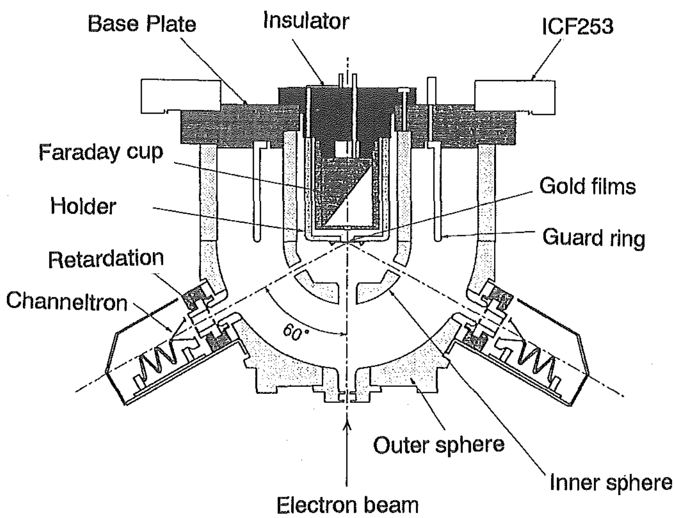

Fig. 3 Schematic diagram of the Mott polarimeter.

Geometry and shape of its acceleration electrodes are optimized for our experimental purpose. Design of the electrodes are done with a charged particle simulation (EGUN2e[12]). Fig. 4 shows the results of the electron trajectory simulation with optimized electrode geometry. The outer electrode is set to ground potential, 30KV is

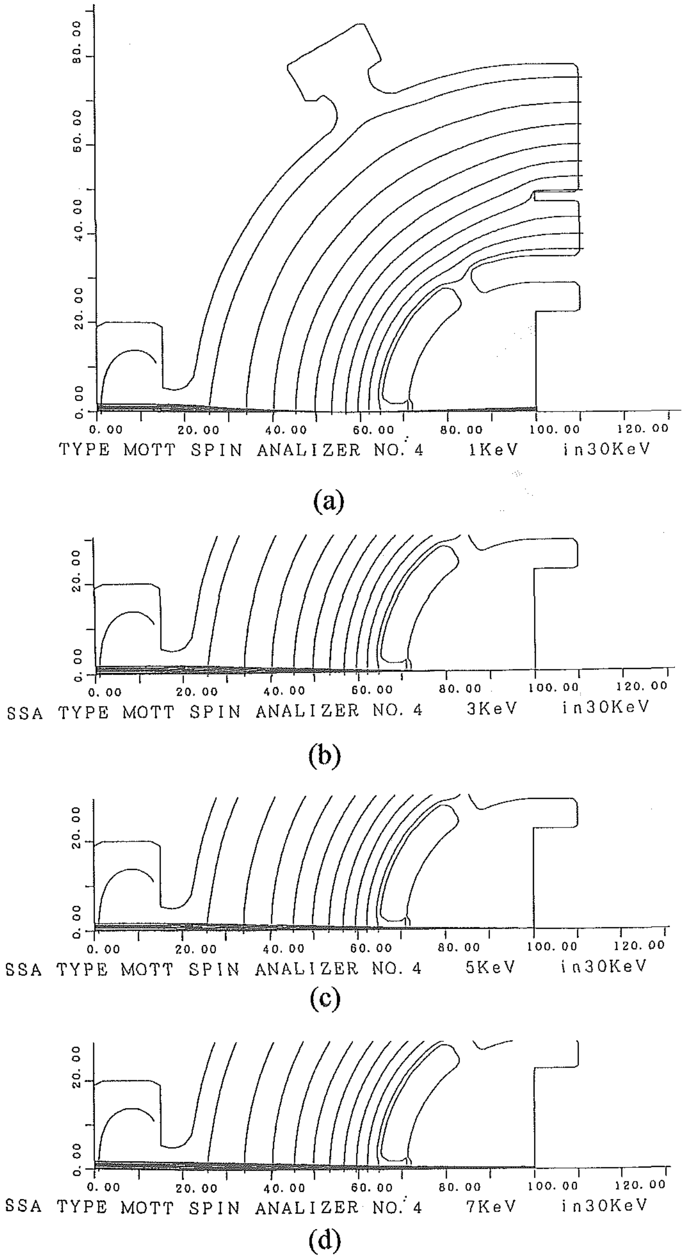

Fig. 4 Electron trajectory simulation of the spherical Mott polarimeter. The outer electrode is connected to the ground and the inner electrode is biased at 30KV. The electron trajectory is calculated where the incident electron energy is (a) 1KeV, (b) 3KeV, (c) 5KeV, and (d) 7KeV.

applied to the inner electrode, and 15KV is applied to the guard-ring. Electron trajectories of collimated electron beams (beam waist is 4mm in diameter) of 1KeV, 3KeV, 5KeV and 7KeV are simulated. In each case the electrode acts as a focusing lens and the best focusing characteristic was taken at the 5KeV incident energy. The beam waist size at the target can be maintained less than 0.2mm in diameter with the energy range from 3KeV to 7KeV. This energy range is appropriate for spin analysis of the field emitted electrons.

If the energy of the incident electron is changed, the potential of the retarding electrode must be changed. It is realized by using the electronic circuits shown in Fig. 5. In this system the incident energy range from 500eV to 5KeV is acceptable.

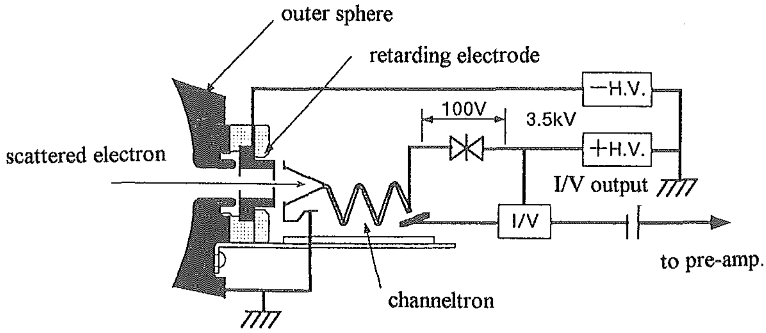

Fig. 5 Schematic diagram of the electron detection system.

4. Experimental System

We made the Mott polarimeter based on the designing concept mentioned above, and we set up measurement system to check its characteristics. Fig. 6 shows the scat-

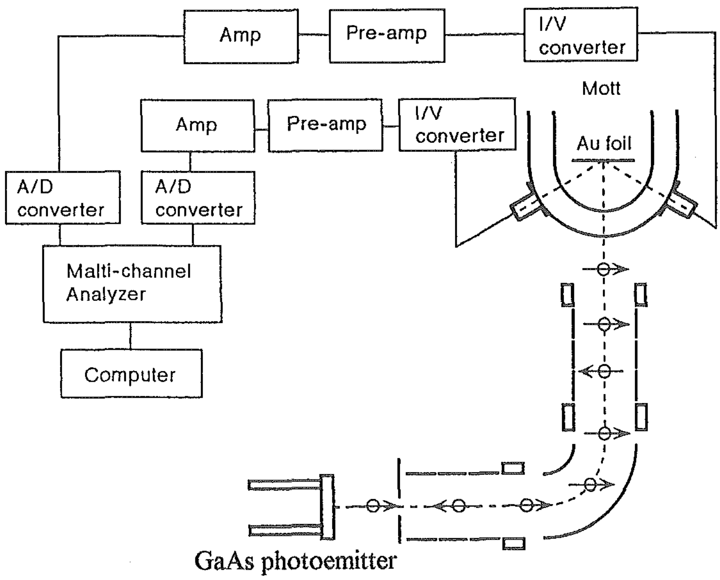

Fig. 6 Schematic diagram of the static lens system and the electron counting system.

tered electron counting electronics system and the static lens system. We used a GaAs photoemitter with a negative electron affinity (NEA) surface as a spin polarized electron source. The lens system is composed three kinds of static lenses. Lens 1 is the uni-potential lens to collimate the electron beam. Lens 2 is the 90° deflector lens, which acts as a 90° spin rotator. For the spin polarization of photoemitted electron is parallel to its propagation direction which cannot be detected by the polarimeter, the electron spin polarization is to be converted to the perpendicular direction. The spin polarization direction is conserved in the static electric field if there is no static magnetic field. Lens 3 is the bi-potential inzel lens to compensate the beam broading caused by the lens 2. There is an x-y deflector at the end of the lens 1 and there are two x-y deflectors at the each end of the lens 3. These deflectors are used to correct the beam propagation direction. We designed the lenses and found appropriate voltage table of each lens electrode for several kinds of the passing electron energy using the computer orbit simulator. Table 1 shows the electrode potential table of these lenses at the passing energy of 3KeV. The values calculated by the simulator are well consistent with the experimentally obtained values.

Table 1 Lens set up voltage obtained by the numerical calculation and the experiment.

	Lens 1 (uni-potential)			Lens 2 (deflector)		Lens 3 (bi-potential)			
	Electrode 1	Electrode 2	Electrode 3	inner	outer	electrode 1	electrode 2	electrode 3	electrode 4
calculated value	0	−2.60	0	2.67	−1.60	0	0	−1.50	0
experimental value	0	−2.48	0	2.66	−1.60	0	0	−1.40	0

(KV)

Photoemitted electrons are excited by circularly polarized light. We have already reported experimental details elsewhere[13].

The detected electrons are counted using a multi-channel analyzer and the counted left-right asymmetry is calculated by a personal computer.

5. Results and Discussions

The left-right counting asymmetry contains spurious asymmetry caused by miss alignment of the electrodes or by difference of electron counting efficiency of the left and right electron detectors. This asymmetry factor δ can be obtained by measuring an unpolarized electron beam. With the GaAs photoemitter, unpolarized electrons can be easily created by pumping with linearly polarized light. From equation (7) with the correction of the experimental factor, P can be expressed as following equation.

$$P=\frac{1}{S_{eff}(\theta)}\,\frac{N_{left}-\delta\cdot N_{right}}{N_{left}+\delta\cdot N_{right}}, \tag{8}$$

where S_{eff} is the experimentally corrected Sharman function[14] that depends upon the target thickness. S_{eff} can be caluculated numerically with a multiple scattering model and the numerically evaluated S_{eff} is −0.295 and −0.315 with Au films of 700 Å and 200 Å, respectively[15]. In out system, the measured systematic asymmetry δ was about

0.8.

With right circularly polarized light of circularly polarization of +76% and the 700 Å target films, we observed $PS_{eff}=0.055$, then $P=18.6\%$.

In our system the electron detector is a ceramic channeltron (Murata EMW-6081B) and we found that its counting efficiency is depend upon the number of the incident electrons. This means that the systematic asymmetry changes when the quantum efficiency of the photoemitter decreases. The life time of the simple GaAs photoemitter made in our laboratory is about 1 hour, then the precious measurement of the spin polarization is difficult. Further improvement in the electron detecting system is necessary.

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