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A LEED PROBE FOR SURFACE SPIN SYSTEMS*

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Abstract: Information about the spin structure of a surface is contained in diffracted LEED intensities via spin-orbit scattering or, in the case of ferromagnets, exchange scattering. Such information, for example, can be exploited for determination of surface magnetic structure or for profiling surface barrier potentials.

The influence of spin scattering on the measured LEED intensities can be enhanced by polarizing the incident electron beam. In the spin-polarized LEED system described here, the electron source is zero-electron-affinity GaAs + Cs - O - Cs, illuminated by circularly polarized light. After passage through a 90^{o} electrostatic deflector to convert the photoemitted electrons from longitudinal to transverse polarization, the beam passes a constant magnification lens before striking the sample at energies from 10 - 200 eV. Diffracted intensities are measured by a minicomputer-controlled Faraday cup. Data reduction, storage, and display occur via dedicated link between the minicomputer and an IBM 370. A synchronous method for measuring the scattered polarization and preliminary results are discussed.

INTRODUCTION

Unpolarized electrons scattered from solid surfaces may be partially polarized due to differences in the spin up - spin down scattering cross sections ("spin-orbit interaction"). In magnets this effect also occurs and is enhanced by exchange scattering. These scattered electrons contain, in their polarization, information about the spin structure of the solid.

Measurement of the degree of spin polarization is usually carried out (at 70 keV or higher energy) by Mott scattering /1/, a method which suffers from experimental complexity and low sensitivity. However, if the incident beam is polarized, spin scattering can be considerably enhanced. Furthermore, if the initial polarization state is known and is reversible, then one can determine the scattered polarization without the use of a polarization analyzer, as will be shown later. Thus, the use of polarized incident beams in LEED permits a more detailed structure analysis to be made.

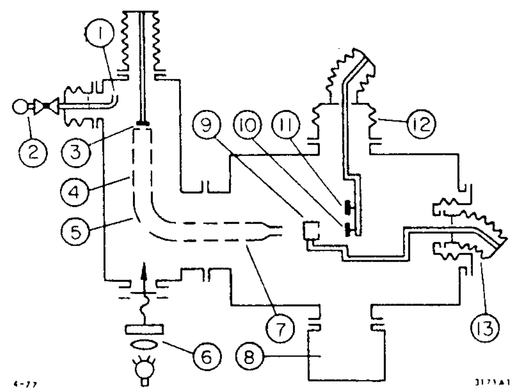

Fig. 1--Schematic diagram of polarized LEED (PLEED) system: (1) Cs tube, (2) Cs reservoir, (3) GaAs cathode, (4) condenser lens, (5) 90^{o} spherical deflector, (6) light source, linear polarizer, and photoelastic modulator, (7) field lens and drift tube, (8) sputter ion pump, (9) Faraday cup, (10) sample, (11) W crystal, (12) XYZ manipulator, (13) Faraday cup motions.

ELECTRON SOURCE

The experimental system is shown in Fig. 1. The electron source is liquid nitrogen-cooled, Zn-doped GaAs which has been cesiated and oxidized to near zero electron affinity. Illumination by circularly polarized light at an energy close to the band gap causes photoemission of longitudinally polarized electrons /2/. The electrons are condensed into a beam and electrostatically deflected 90^{o} to

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convert to transverse polarization. The beam is then focused and decelerated by a constant magnification lens system /3/. Use of this lens enables the electron coherence width to be held constant over the entire beam energy range. Properties of the electron source are summarized in Table I.

TABLE I

Electron Beam Properties

Beam energy range	10 - 200 eV
Beam current	0.1 μA
Beam size	1 mm diameter
Thermal energy spread /4/	0.1 eV
Beam divergence	.125^{o} - .55^{o} over 200 - 10 eV
Beam polarization	~ 50%, reversible
Coherence width	~ 200 Å, constant over energy range

Polarized light is produced using a xenon lamp and a Bausch and Lomb high intensity monochromator followed by a linear polarizer and a photoelastic modulator for alternating between left and right circular optical polarization, thereby reversing the electron polarization. Light reaches the GaAs through a transparent, conductive area in the spherical deflector. The illuminated cathode spot is 0.5 mm in diameter. The source chamber incorporates facilities for thermal cleaning of the source, a cesiator, and an oxygen leak valve. The source and processing system is isolated by an inline valve from the measuring system and has separate ion pumping.

SAMPLE HOLDER

The crystal manipulator is of the standard three translation axis type, also incorporating ±6^{o} tilt, ±90^{o} azimuthal rotation, ±180^{o} polar rotation, and electron bombardment or resistive heating of two crystals. The second of these is a W crystal used for measuring the polarization of the incident beam, using accurate low energy polarization data currently being obtained /5/.

DETECTION SYSTEM

The scattered-electron intensity detector is a Faraday cup of the retarding collector type incorporating a triaxial signal cable for optimum noise shielding. The entrance aperture is changeable, allowing angular apertures as small as 0.25^{o}, or as large as is necessary to accommodate the entire diffracted beam. Cup motion covers 2π sr of the sample surface independent of the beam incidence angles, by use of servo-motor-controlled rotary and linear feedthroughs. The control system is initially aligned using a three axis translation, plus tilt, manipulator.

Data acquisition is controlled by a Digital Equipment Corporation LSI-11 microcomputer. Information concerning the Faraday cup position is provided by shaft encoders on the feedthrough servo motors. This information and the diffracted intensity are read into the LSI-11 via a parallel bidirectional interface (Fig. 2). The cup position is computer-adjusted for maximum intensity, the intensity

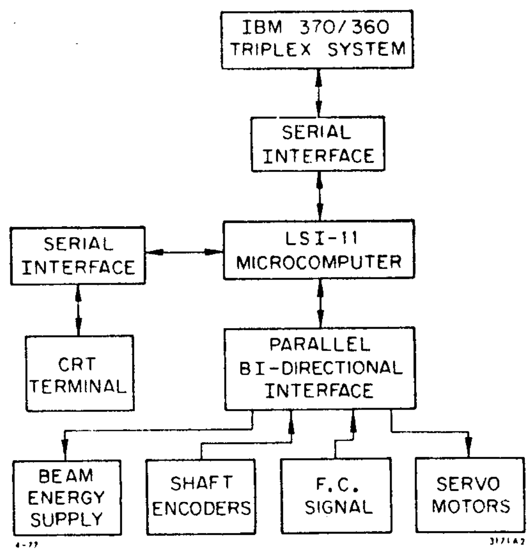

Fig. 2--PLEED computer operated detection and data processing system.

and position are noted, and then the incident beam energy is stepped for the next measurement. Measurements are sent by dedicated line to the SLAC Triplex system for data reduction, plotting, and storage. Interactive programming of the LSI-11 allows the operator to set the initial conditions and the range of the measurements on the local terminal, to which the processed data may also be recalled. If the polarization of the incident electron beam is known (calibrated using the W crystal), then the polarization function of the target may be determined by making a left-right asymmetry measurement of the diffracted beams in the scattering plane /1/. If P and P' are the incident and scattered polarizations, respectively, then, for normal incidence and P polarized normally to the scattering plane,

$$P' = \frac{P^2 + K}{P(1+K)}$$

where

$$K = \frac{N_L - N_R}{N_L + N_R}$$

and N_L, N_R are the numbers of electrons detected on the left and right, respectively.

To avoid any dc drift problems associated with the Faraday cup and to increase the speed of measurement, a method using synchronous detection has been devised. If the incident beam is spin reversed, then one can measure the left-right asymmetry without moving the cup. By using a photoelastic modulator, the spin reversal can be accomplished at fixed frequency, say 50 kHz, and a lock-in-amplifier will synchronously detect the difference $N_L - N_R$. The sum $N_L + N_R$ can be determined from the total dc collected. Thus, polarization-energy curves may also be processed and displayed by the LSI-11 system.

PRELIMINARY RESULTS

Construction and tests of the GaAs cathode source have been carried out in a separate system using a Mott analyzer to measure the beam polarization. Quantum efficiencies of 1-5% at 6328 Å have been routinely achieved using Zn dopings from 6×10^{18} to 4×10^{19} cm^{-3}. The GaAs samples are chemically cleaned and etched using a procedure described by Shiota et al. /6/. The samples were subsequently heated in vacuum to near the congruent melting point of GaAs (650 °C). Using this method, the cathodes could be repeatedly thermally cleaned and reactivated without loss of efficiency or polarization.

Polarization measurements with the cathode at 77K were made using 750 Å-thick Au foils at 70 keV beam energy with the asymmetry detectors 120° apart. The exciting light source was a dye laser, operating at 1.76 eV, whose circular polarization could be varied by rotating a quarter-wave plate. The left-right asymmetry ratio as a function of plate angle (which reversed the electron beam polarization) is shown in Fig. 3. The measured polarization value is comparable to that measured by Pierce and Meier /2/ at the same light energy. Extrapolating to band gap energy using Pierce and Meier's data indicates that the expected polarization at 1.52 eV should be 53%. This is somewhat larger than that expected on simplified theoretical grounds and a discussion of this point may be found in their paper.

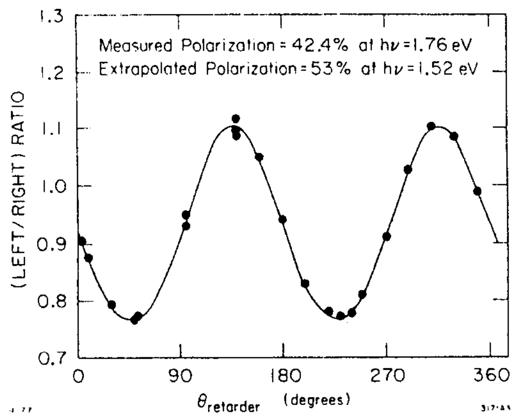

Fig. 3--Measured polarization data using Mott analyzer. Details are in text.

DISCUSSION

What can polarized LEED tell us about the spin structure of a solid? Like ordinary LEED, its value lies in surface sensitivity. Spin-polarized-neutron studies of solids have been a powerful technique for elucidating spin structure of bulk materials, but, unlike electron scattering, neutron scattering cross sections are very small. The inclusion of spin as one of the labeled properties of the incident electron beam provides additional information pertinent to structure determination. For instance, current spin-dependent LEED theories /7/ indicate that accurate analysis is sensitive to the shape of the surface potential barrier. Polarization measurements can provide the necessary information for a proper barrier construction. Applications of PLEED to this problem and others involving spin-orbit interactions are relatively simple experimentally. Not so trivial are applications to exchange scattering. The only studies done thus far are on antiferromagnets where the chemical and magnetic unit cells are different. Again, more information could be gained using polarized electrons; for instance, magnetic scattering form factors or magnetic moment directions are obtainable /8/. Measurements suggested on ferromagnets /9/, however, will be difficult due to net surface fields. Clever design in terminating the fringe fields may make such measurements possible.

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