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"Electron Spin Polarization Effects in Low-Energy
Electron Diffraction, Ion Neutralization, and Metastable-
Atom Deexcitation at Solid Surfaces"

(Contract Period: 1 January 1983 through 31 December 1983)

G. K. Walters

F. B. Dunning
Principal Investigators

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ELECTRON SPIN POLARIZATION EFFECTS IN LOW ENERGY
ELECTRON DIFFRACTION, ION NEUTRALIZATION AND METASTABLE
ATOM DEEXCITATION AT SOLID SURFACES

I. INTRODUCTION

The importance of electron spin polarization (ESP) effects in the various spectroscopies used to study solid surfaces has become increasingly apparent in recent years. Recent low energy electron diffraction (LEED) investigations in this laboratory,¹⁻⁶ and elsewhere,⁷⁻¹³ have shown that a great deal of new information contributing to the understanding of the geometrical arrangements of atoms at a surface can be obtained if the polarization of the various LEED beams is measured, or if the incident electron beam is polarized. Polarized LEED studies have shown large polarization features that are very sensitive to the presence of adsorbed layers, surface reconstruction, etc. In addition, theory suggests that polarization measurements can provide a more sensitive test of many of the parameters used in a surface model than can conventional LEED intensity measurements alone.¹⁴ Polarized LEED has also been applied to the study of surface magnetism.^{15,16}

In the present contract year, polarized LEED has been used, together with Auger analysis and LEED intensity measurements, as a diagnostic to characterize Ni(001) surfaces produced by laser annealing. The successes achieved with laser annealing point to its future application in the preparation of other metal surfaces. In addition, a GaAs polarized electron source has been developed that will provide greatly increased data acquisition rates. This source is being used in a polarized LEED study of order-disorder transformations at Cu₃Au surfaces.

A detailed polarized LEED study of Ni(001) and Ni(001)c(2x2)Te surfaces was completed last year. The data are in good accord with preliminary results of relativistic dynamical calculations, indicating that substrate-adsorbate systems can be successfully treated theoretically. Further detailed investigations of the sensitivity of the calculated polarizations to variations in the surface parameters are now being undertaken, in conjunction with Prof. Dr. R. Feder of the Universität Duisburg, to determine, through comparisons with the experimental data, the power of polarization analyses, as opposed to intensity analyses, in determining surface parameters.

In recent years there has been increasing interest in the use of Ion Neutralization Spectroscopy (INS)^{17,18} and Metastable Deexcitation Spectroscopy (MDS)¹⁹⁻²⁷ to probe surface electronic structure in metals and semiconductors. These spectroscopies are particularly surface sensitive in that incident ions or metastable atoms only interact with the outermost surface layer. However, much new surface information can be obtained using these techniques if the electron spins in the incident ion or metastable atom are polarized and if the ESP of the ejected electrons is measured. Such measurements will answer questions relating to the dynamics of ion neutralization and metastable deexcitation, and electron correlation effects, thereby increasing the utility of INS and MDS as surface spectroscopies. Indeed, with the added refinement of polarization measurements, we believe INS and MDS will provide powerful probes of surface electronic structure and surface magnetism.

Thus a program was initiated under the present contract to utilize ESP measurements in conjunction with INS and MDS to study surface electronic structure. An initial study of Ni(110) surface magnetism is underway using a Ni crystal magnetized along the easy $[1\bar{1}1]$ direction. Spin dependencies in the Auger electron yield have been observed that provide a measure of the surface magnetism and are being used to probe the dependence of the surface magnetism on temperature, adsorbate coverage, etc. A Mott polarization analyzer has also been constructed to measure the ESP of the ejected electrons and is being installed on the apparatus. As discussed in the initial proposal, such measurements will provide direct information concerning the dynamics of secondary electron ejection and the details of adsorbate-substrate bonding.

II. PROGRESS--POLARIZED LOW ENERGY ELECTRON DIFFRACTION

A. Laser Cleaning and Annealing

In recent years there has been increasing interest in the use of laser beams to process materials. However, no comprehensive studies of laser cleaning or annealing of metal surfaces has been reported and we therefore decided to evaluate this technique in detail using a Ni(001) surface and a high-power, Q-switched Ruby laser. Ni(001) was selected because it is difficult to clean using conventional sputtering/thermal annealing techniques. The laser treated surface was characterized by Auger analysis and by both conventional and spin-polarized LEED techniques.

The results of this research are described in the attached preprint (Appendix I). Briefly, irradiation of an argon-ion sputtered surface at energy densities of 0.8 J cm^{-2} leads to complete removal of residual argon, without segregation of carbon or other contaminants at the surface. However, it is observed that irradiation at room temperature, even at power densities approaching the damage threshold, does not result in a well ordered surface, indicating that annealing is not complete. On the other hand, irradiation at an elevated crystal temperature (200°C) results in a surface whose cleanness and order is comparable to that obtained using conventional sputtering/thermal annealing techniques. The inherent speed and simplicity of laser cleaning and annealing make it particularly attractive and the successes achieved with Ni(001) point to its future application in the preparation and modification of other metal surfaces.

B. Spin-polarized Electron Source

A GaAs polarized electron source similar to that developed at the National Bureau of Standards²⁸ has been constructed and tested. This source provides electron beam currents of $\sim 10^{-6}$ - 10^{-7} A with a polarization, measured directly by a Mott polarization analyzer, of $\sim 30\%$. This source is now being used to study order-disorder transformations at Cu_3Au surfaces and preliminary data are expected before the end of this contract year.

III. PROGRESS--POLARIZED ION NEUTRALIZATION AND METASTABLE ATOM DEEXCITATION SPECTROSCOPIES

A. Studies of Surface Magnetism

A MDS study of surface magnetism at a Ni(110) surface magnetized along the easy $[1\bar{1}1]$ direction is underway. A difference in the total secondary electron yield is observed between the situations where the incident metastable atoms are polarized parallel and anti-parallel to the bulk magnetization. This spin dependence, which for the highest ejected electron energies amounts to $\sim 5-10\%$ of the total ejected current, provides a measure of surface magnetism and results because (as discussed in the initial proposal) the incident metastable atom beam probes either majority- or minority-spin bands depending as to its polarization. The dependence of surface magnetism on crystal temperature is being investigated together with the extent to which surface magnetism is modified by the presence of controlled adsorbates. It is expected that studies of Ni(110) will be completed before the end of this contract year, and we plan to extend this work to iron, where the exchange splitting is much greater, and to selected magnetic glasses which have a number of interesting spin-dependent properties.

B. Studies of Ejection Dynamics

A UHV compatible, medium-energy Mott polarization analyzer has been constructed to analyze the ESP of the ejected electrons. This analyzer has been tested and calibrated and will be installed on the INS/MDS apparatus in the near future. The design and performance of the Mott analyzer is described in the attached preprint (Appendix II).

As discussed in the initial proposal, analysis of the ESP of the ejected electrons provides direct information concerning the dynamics of secondary electron ejection, i.e., whether it occurs through a single- or multi-step process. The polarimeter will also enable further investigation of magnetic surfaces since it permits measurement of the ESP of the electrons ejected from a magnetized sample by unpolarized UV photons or particle beams. Further, polarization analysis is expected to provide an important new diagnostic with which to probe chemisorption.

As a first experiment the dependence of the secondary electron ejection processes on the work function of the surface will be investigated and it is hoped that this experiment will be underway before the end of the present contract year.

C. 1.08 μ m Color-Center Laser

As demonstrated previously in this laboratory^{29,30}, NaF(F₂⁺)* color-center lasers provide an ideal source of 1.08 μ m radiation to optically pump He(2³S) atoms. We have therefore continued to develop and refine a color-center laser system for use in this application. A number of improvements in both the HITC dye laser used to pump the color-center laser (described in the attached preprint, Appendix III) and in the mechanical construction of the laser have resulted not only in sizable increases in output powers but also in more stable operation. Further work aimed at active frequency stabilization of the laser is being undertaken.

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VI. PERSONNEL

A. List of Personnel Working on Project During Year to 15 August 1983

G. K. Walters,	Co-Principal Investigator
F. B. Dunning,	Co-Principal Investigator
K. Giberson,	Graduate Student
M. Hart,	" "
K. Jamison,	" "
D. Lind,	" "
P. McConnell,	" "
M. Onellion,	" "

(Dr. E. Rille will join the project as a Research Associate in September 1983.)

B. Time Devoted by Faculty Investigators

Professor G. K. Walters devoted 2 months of full-time effort to the contract during the summer of 1983, and 30% time during the academic year.

Professor F. B. Dunning devoted 1 month of full-time effort during the summer of 1983, and 15% time during the academic year.

C. Other Support

A Robert A. Welch Foundation Grant (\$21,000/year) to G. K. Walters, and a Petroleum Research Fund Grant (\$15,000/year) to F. B. Dunning provide support for graduate students. Mr. Onellion is a Hertz Foundation Predoctoral Fellow. In addition to academic salaries for Professors Walters and Dunning, Rice University has provided this year \$6,533 for supplies and expenses needed on the project.

VII. PUBLICATIONS ARISING FROM CONTRACT

Several papers resulting from research carried out under this contract have either been published or submitted for publication in the past year; these papers are listed below.

"Optical pumping of He(2^3S) atoms by a color-center laser," K. W. Giberson, Chu Cheng, M. Onellion, F. B. Dunning and G. K. Walters, Rev. Sci. Instr. 53, 1789 (1982).

"Spin polarization in low energy electron diffraction from Ni(001) and Ni(001)c(2x2)Te," J. K. Lang, K. D. Jamison, F. B. Dunning, G. K. Walters, M. A. Passler, A. Ignatiev, E. Tamura and R. Feder, Surf. Sci. 123, 247 (1982).

* "Laser annealing of Ni(001)," R. P. McConnell, K. D. Jamison, F. B. Dunning and G. K. Walters, J. Vac. Sci. Tech. (in press).

* "Generation of tunable cw radiation near 875 nm," K. W. Giberson, F. B. Dunning and T. H. Jeys, Appl. Optics (in press).

* "A simple, compact, medium-energy Mott polarization analyzer," L. G. Gray, M. W. Hart, F. B. Dunning and G. K. Walters, Rev. Sci. Instr. (submitted).

* Preprints of these three papers are attached as Appendices.

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