**APPLICATION OF SPIN-SENSITIVE ELECTRON SPECTROSCOPIES TO
INVESTIGATIONS OF ELECTRONIC AND MAGNETIC PROPERTIES OF
SOLID SURFACES AND EPITAXIAL SYSTEMS**

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G. K. Walters and F. B. Dunning

Rice University, Houston, TX 77251

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APPLICATION OF SPIN-SENSITIVE ELECTRON SPECTROSCOPIES TO INVESTIGATIONS OF ELECTRONIC AND MAGNETIC PROPERTIES OF SOLID SURFACES AND EPITAXIAL SYSTEMS

Research during the current grant year has focused on:

- (1) Investigation of angular dependence of polarizations of electrons backscattered from metallic surfaces, as a function of energy loss, using Spin-Polarized Electron Energy Loss Spectroscopy (SPEELS).
- (2) Studies of the dynamics of metastable $\text{He}(2^3\text{S})$ deexcitation at xenon covered metallic surfaces utilizing Spin-Polarized Metastable Deexcitation Spectroscopy (SPMDS).

I. SPEELS

In these experiments, a beam of spin-polarized electrons is directed at the target surface and the energy- (and angle-) dependence of the spin polarization of electrons leaving the surface is measured for primary beam energies of ~15 to 150 eV. A major overhaul of the apparatus, to enable accurate measurements of angular dependences with reasonable data acquisition rates, was completed several months ago. Other modifications completed at that time permit cooling of substrates to ~40 K and saturation magnetization of epitaxially deposited ferromagnetic films.

Efforts in recent months have focussed on the angular dependence of SPEELS spectra from bare substrates (Cu, Ag) and epitaxially deposited thin films (Mo, Fe). SPEELS is a principal spectroscopy for studies of Stoner excitations and spin-split band structure of ferromagnetic

surfaces.^{1,2} The interpretation of SPEELS spectra is based on the assumption that inelastic losses at low (~ 15 -50 eV) electron energies result exclusively from electron-hole pair excitation by electrons penetrating the target surface, with contributions from both direct (non-spin-flip) and exchange (spin-flit) scattering. However, theory predicts that inelastic scattering events should also occur in the near-surface vacuum outside the target surface as a result of interactions of the incident electron with electric field fluctuations.³ Such processes, termed dipole scattering, do not permit exchange (spin-flip) contributions, hence would produce a background of fully polarized electrons backscattered predominantly in the specular direction.

Studies of SPEELS angular dependences offer the first possibility of determining the relative contributions of electrons inelastically scattered inside (Stoner) and outside (dipole) the target surface. Our measurements suggest that there is indeed a background of dipole-scattered polarized electrons upon which the Stoner-like spectrum is superimposed. The contributions to the spectra from inelastic scattering events inside and outside the target are comparable in magnitude, and also have comparable angular distributions. The extensive data we have obtained from Au, Ag, Mo and Fe surfaces suggests that all inelastically scattered electrons have undergone small-angle inelastic scattering events either preceded or followed by large angle elastic scattering that redirects the incident electron away from the target. Contributions due to dipole scattered electrons must be taken into account for proper interpretation of SPEELS data to yield Stoner excitation spectra from ferromagnets.

II. SPMDS

In these studies, a beam of spin-polarized $\text{He}(2^3\text{S})$ metastable atoms is incident on the target surface, and we measure both the energy distribution and the energy dependence of the spin polarization of electrons ejected from the surface as a result of metastable deexcitation there. Energy distributions of the ejected electrons can also be measured for incident helium atoms excited to the 2^1S and 2^3P states.⁴

During the present grant year we have extended our investigation of dynamics of metastable atom deexcitation to include rare-gas adsorbates on Cu(100) and Au(100) surfaces. Our previous studies of CO₂, H₂O, Cl₂ and O₂ films on Cu(100) showed that in each case metastable deexcitation is closely analogous to gas-phase Penning ionization, i.e., the condensed molecules can be approximated as a "solid gas."⁵ The simpler physisorbed rare gas systems might be expected to behave even more gas-like; indeed we find argon and krypton to exhibit gas-like spectra exclusively. In the case of xenon, however, in addition to the expected gas-like features, a prominent new peak appears near threshold in the metastable deexcitation spectrum. The new feature has no counterpart in gas-phase He(2³S)+Xe Penning ionization spectra, and appears only upon completion of a full monolayer of adsorbed xenon. The position of the new feature does not shift when more energetic He(2¹S) or He(2³P) atoms are incident on the surface, suggesting that a fraction of the incident excited helium atoms undergo resonance ionization (RI) followed by Auger deexcitation (AN) in which the resulting He⁺ ion captures a valence electron from one adsorbed xenon atom while a second (Auger) electron is ejected from a neighboring xenon atom. In other experiments we have found that the new feature is absent when the surface work function is lowered by depositing a layer of cesium in the substrate prior to its exposure to xenon.

The spectra obtained from these xenon-metal systems are qualitatively unlike those from any other system previously investigated by metastable deexcitation spectroscopy, and offer promise of providing important new insights into the dynamics of metastable-surface interactions. The experiments are nearly completed and we are presently attempting to interpret our extensive data collection in terms of a model in which RI+AN competes with direct Auger deexcitation (AD) of the incident excited helium atom, taking into account the Coulomb energy associated with the two xenon ions left on the surface following the AN event proposed above as the origin of the new spectral feature.

III. PUBLICATIONS

- D. M. Oró, Q. Lin, P. A. Soletsky, X. Zhang, F. B. Dunning and G. K. Walters, "Spin correlation in Auger neutralization of He^+ ions at a Cu(100) surface," *Phys. Rev. B*, **46**, 9893 (1992).
- D. M. Oró, Q. Lin, X. Zhang, F. B. Dunning and G. K. Walters, "Use of spin-labelling techniques to study the dynamics of surface Penning ionization," *J. Chem. Phys.*, **9**, 7743 (1992).
- G. K. Walters and C. Rau, "Probing the surface-vacuum interface with spin-sensitive metastable atom deexcitation, electron capture and electron emission spectroscopies," *1993 Spring Meeting Symposium Proceedings*, accepted for publication. (Invited paper)

IV. PERSONNEL

D. M. Oró will complete the requirements for his Ph.D. degree within a few weeks. Postdoctoral Research Associate X. Zhang accepted a position as Research Scientist with Ford Microelectronics, Inc. in February 1993.

V. REFERENCES

1. D. Venus and J. Kirschner, *Phys. Rev. B* **37**, 2199 (1988).
2. K.-P. Kämper, D. L. Abraham and H. Hopster, *Phys. Rev. B* **45**, 14335 (1992).
3. D. L. Mills, *Surface Science* **48**, 59 (1975).
4. D. M. Oró, Q. Lin, P. A. Soletsky, X. Zhang, F. B. Dunning and G. K. Walters, *Phys. Rev.* **46**, 9893 (1992).
5. D. M. Oró, Q. Lin, X. Zhang, F. B. Dunning and G. K. Walters, *J. Chem. Phys.* **97**, 7743 (1992).

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