

NBSIR 88-3699

A11102 753201

Technical Activities 1987 Surface Science Division

C. J. Powell, Chief

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Chemical Physics
Surface Science Division
Gaithersburg, MD

January 1988

Prepared for:

U.S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
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ABSTRACT

This report gives a brief summary of the technical activities conducted in the NBS Surface Science Division during Fiscal Year 1987. These activities include surface-standards work, experimental and theoretical research in surface science, the development of improved measurement methods, and applications to important scientific and national problems. Listings are given of publications, talks, Division staff, and guest scientists.

key words: surface chemistry; surface physics; surface science; surface standards

FOREWORD

This report is a brief summary of the technical activities of the NBS Surface Science Division for the period October 1, 1986 to September 30, 1987. The report was prepared as part of the Annual Report of the Center for Chemical Physics within the National Measurement Laboratory of NBS.

Section 1 of the report contains narrative descriptions of technical projects within three program areas: surface standards, surface measurements, and surface competence. Sections 2 and 3 contain listings of papers published and talks presented during the year. The Division staff are listed in section 4 and guest scientists who have worked in the Division in section 5.

Further information on the activities of the Division can be obtained by contacting Dr. C. J. Powell, Chemistry B-248, National Bureau of Standards, Gaithersburg, MD 20899 (telephone, 301-975-2534).

NOTE: Certain commercial equipment, instruments, or materials are identified in this report in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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1. SUMMARY OF TECHNICAL WORK

(a) Introduction

Over the last ten years, there has been a dramatic growth in surface science and its applications. A large number of techniques are utilized for surface characterization. A choice of one or more techniques is made typically on the basis of the property to be measured, the specimen material, and the specific needs (e.g., spatial resolution, chemical information, sensitivity, degree of difficulty, and cost). Most surface analyses, for example, are now qualitative since there are very few standard procedures and limited reference data and reference materials.

The goal of the Surface Science Division is to improve the quality of existing surface-characterization measurements and to extend the present capability. Specific objectives of the Division are to: perform research so as to develop improved methodologies; provide data for surface properties and processes; develop standards in cooperation with relevant organizations; and develop expertise to provide new measurement services. These objectives are met organizationally through three formal NBS programs: surface standards, surface measurements, and surface competence. This report contains brief descriptions of work conducted during 1987 in these three programmatic areas; further information on these activities is contained in a more detailed Division report prepared in 1986 (Technical Activities 1986 - Surface Science Division, C. J. Powell, editor, NBSIR 86-3491, December, 1986).

(b) Surface Standards Program

The Division improves the quality of surface measurements through the development of reference data, reference materials, and reference procedures. New calculations have been made of inelastic electron mean free paths in thirty-one materials in the energy range important for quantitative surface analyses by Auger-electron spectroscopy and x-ray photoelectron spectroscopy (XPS). From these calculations, a general formula has been developed to predict inelastic mean free paths in other materials. New measurements of electron attenuation lengths are being made in a number of molecular solids using an improved measurement method developed at NBS. High-accuracy measurements have been made of core-electron binding energies for copper, silver, and gold and found to correspond, within the combined uncertainties, with independent measurements at the UK National Physical Laboratory. These data will be useful for the calibration of XPS energy scales. Work is nearing completion on a compilation and evaluation of elemental sputtering yields, data important for the calibration of the depth scales when ion bombardment is used with surface analysis to obtain depth profiles.

A new batch of the Ni/Cr multi-layer thin-film SRM 2135 has been characterized and will be issued shortly. A new "marker" type of multilayer material consisting of about 3 ML of Cr_2O_3 between much thicker Cr layers is under development. Sputter-depth profiles of Ni/Ag multi-layered thin-film structures have broad interfaces when measured at room temperature on account of radiation-enhanced diffusion. When measured above 130°C , however, the

profiles are much sharper due apparently to the annealing of bombardment-produced defects.

The Division provides leadership to standards committees, particularly to ASTM Committees E-42 on Surface Analysis and D-32 on Catalysts and to the Surface Chemical Analysis Working Party of the Versailles Project on Advanced Materials and Standards (VAMAS). The latter group is an international cooperation involving the USA, Canada, UK, FRG, France, Italy, Japan, and the European Economic Community; at present, 12 projects are underway and others are expected to be initiated. Liaison is made between this VAMAS group, the ASTM E-42 Committee, and an active IUPAC Working Group on Surface Analysis. Finally, workshops and conferences have been organized to promote the development of needed reference procedures in surface analysis.

(c) Surface Measurements Program

The Division undertakes a number of projects directed to improved determinations of surface properties and processes. New techniques are developed along with theories of the measurement processes. Applications to important scientific and national problems are pursued. One area of importance concerns the "high-temperature" superconductivity materials which have caused great excitement in the scientific community as well as interest by the administration during the past year. In collaboration with scientists at NRL, Division staff made the first measurements of the photoelectron spectra of $\text{YBa}_2\text{Cu}_3\text{O}_7$ to compare with electronic structure calculations. The measurements showed two unexpected results: the density of states at the Fermi level was small and the Cu was in the +2 oxidation state with no evidence for the +3 state.

In another area, measurements are made of the reaction kinetics and the structures of molecules on single-crystal surfaces to understand heterogeneous catalytic chemistry. In preliminary experiments, monolayer films of platinum have been deposited on a W(110) surface and shown to have chemisorption properties quite different from those of clean tungsten or platinum surfaces alone. This work will be extended to search for unusual catalytic activity of the Pt/W system. Division staff have constructed a novel digital-imaging instrument to give direct information on the structure of adsorbed molecules using the NBS-developed Electron Stimulated Desorption Ion Angular Distribution method. This instrument has been used to investigate the interactions of the first-row protic hydrides (H_2O , NH_3 , and HF) with both stepped and planar Si(100) surfaces. All molecules adsorb dissociatively between 125 and 300 K and structures of the adspecies on both types of silicon surfaces have been determined. Similar measurements have been made to investigate the orientation of H_2O on a Cu(110) surface; at 90 K, H_2O adsorbs molecularly with tendency to cluster into hydrogen-bonded dimers. In related work, inelastic incoherent neutron scattering has been employed to characterize the adsorption and absorption of hydrogen by palladium black, a high-surface-area Pd powder. These experiments at the NBS reactor have shown the presence of subsurface hydrogenic species in addition to the expected bulk and surface phases.

Synchrotron radiation is used in a number of Division projects (at both the NBS SURF facility and the Brookhaven National Synchrotron Light Source). In addition to the experiments on the superconducting materials mentioned earlier, investigations have been made of the interaction of H₂O with TiO₂(110) surfaces, in one case with a near-perfect surface and in another case with a surface having numerous defects. The reactivity of H₂O was greater on the "defective" TiO₂ surface which was shown to have traces of Ti³⁺, Ti²⁺, and metallic Ti whereas the more perfect surface was almost completely Ti⁴⁺. Molecular dynamics calculations have been made to give a better understanding of the effects of defect structures on particular surface properties. In other experiments, a new mechanism was found for the photon-stimulated desorption of ions from an MgO surface: core-exciton-induced desorption. This and other mechanisms of surface decomposition are important in establishing rates of beam damage in other surface spectroscopies. Recent collaborative work at the Cornell synchrotron has shown that chemisorbed monolayers can be detected using glancing-incidence x-ray diffraction to excite transverse x-ray standing waves. Finally, improved devices have been developed in which a photovoltaic x-ray detector has been fabricated on a silicon monochromator crystal; such devices are efficient and useful for instrumental alignment.

The pathways and rates of energy transfer at surfaces remain key unresolved issues for understanding chemical reactions at interfaces. In cooperation with the Laser Spectroscopy Group, the Division utilizes both the temporal and spectral characteristics available in state-of-the-art lasers to address the issues of energy transfer on surfaces. Laser-excited fluorescence along with multi-photon ionization are used as state-specific probes of laser-induced desorption processes. Investigations of the desorption of NO from Pt surfaces have shown that there is non-equilibrium partitioning of kinetic and internal energy at all laser wavelengths studied. This result indicates that the desorption does not occur through a NO resonance but through a coupling with the substrate, perhaps involving electron-hole pair excitations. In other experiments, vibrational lifetimes have been measured on a series of metal-cluster carbonyls in solution and for metal particles on SiO₂. Complementary theoretical studies are being made to elucidate the roles of quasi-periodic versus chaotic intramolecular dynamics as applicable in molecule-surface collisions and in surface vibrational spectroscopies. Another theoretical study has demonstrated that chemical selectivity can be obtained in the scattering of polyatomic molecules by surfaces.

(d) Surface Competence Program

The Surface Competence Program (initiated in 1984) has two components: "Novel Two-Dimensional Materials" and "State Characterization of Energetic Species Ejected from Surfaces". The objective of the first component is to synthesize and determine the fundamental chemical properties of ultrathin layered materials with layers so thin (a few atoms thickness) that they exhibit two-dimensional behavior. The objective of the second component is to understand the excitation dynamics by which atoms and molecules are desorbed from surfaces in ion-sputtering processes as well as in electron- and photon-stimulated processes. Each program component consists of several technical projects.

Within the first program component, the x-ray photoelectron spectroscopy (XPS) searchlight effect has been applied to the characterization of the growth modes of ultra-thin metal films. Superlattice structures consisting of Cu and Fe layers on Cu(100) have been successfully prepared with film thicknesses of 1, 2, and 3 monolayers and atomically sharp interfaces. These structures have been found to have novel magnetic properties: the Fe layers are ferromagnetic and the magnetic moment is perpendicular to the film plane with a large anisotropy. In other experiments, the XPS searchlight effect has been used to study the initial stages of Schottky barrier formation when Ni is deposited on GaAs(110); it was found that Ni replaced both Ga and As in the second and third atomic layers beneath the surface. A second-generation design has been developed for the ovens that generate ultra-thin metal films by molecular beam epitaxy. The new ovens are both simple, compact, and effective. Four such ovens are being mounted on a single flange and will be used to fabricate non-equilibrium ordered alloys, a new class of materials, by alternating monolayer deposition. An auxiliary vacuum chamber has also been constructed to perform Mossbauer spectroscopy on superlattice structures containing iron films using an electron multiplier to detect the conversion electrons.

In a separate project, the microstructure of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ ($0 < x < 0.5$) has been examined by field-ion microscopy (FIM). Specimens from nominally superconducting and nonsuperconducting samples (determined by magnetic susceptibility measurements) were studied by FIM and significant differences were found. Preferential imaging of atomic or molecular layers, due to preferential field evaporation, field ionization, or both, was found in the superconducting phase below the transition temperature, and is interpreted as possible evidence for the occurrence of relatively highly conducting layers in the $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ unit cell perpendicular to the orthorhombic c-axis.

The nucleation and growth of crystalline layers of Cr on W and of Cr on Re has been studied using field-electron emission microscopy. Two different modes of nucleation on W(100) were found to occur at room temperature, depending only on the angle of incidence of the Cr flux. In separate work, it has been demonstrated that the field-ion microscope atom probe can measure compositional changes and impurity distributions at metal-metal interfaces with monolayer resolution.

Theoretical contributions have been made to the understanding of the fractional quantum Hall effect. A particular type of off-diagonal long-range order has been shown to lead to the fractional quantum Hall effect. This result extends the analogies previously found between superconductivity and superfluidity; both types of systems have dissipationless transport because of a remarkably low density of excited states at low energies.

Within the second program component, new instrumentation has been designed and built to determine the energy states of sputtered neutral particles by resonant multiphoton ionization and time-of-flight mass spectrometry. Following tests, improvements have been made to reduce the neutral and doubly-ionized components in the ion beam to insignificant levels. The incident Ar^+ beam is rapidly switched and a 38 ns plus width has been obtained. The instrument has been interfaced to a computer that also displays time-of-flight spectra and kinetic-energy distributions. This instrumentation will be used to determine

the energy states of neutral species sputtered from Al and Mg surfaces by resonance-ionization mass spectrometry.

In another project, a special angle-resolving, display-type ion and electron energy analyzer has been constructed and is undergoing testing. This analyzer will be installed at the NBS synchrotron radiation facility SURF-II to measure simultaneously the angular, energy, and mass distributions of ions desorbed from surfaces by photon or electron excitation. Special video-processing software for manipulating and displaying the data is being developed as is software for controlling voltages applied to the instrument. The instrument will be employed to examine the desorption dynamics of adsorbed molecules.

2. PUBLICATIONS

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3. TALKS

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- Cavanagh, R. R., "Vibrational Relaxation of Adsorbed Molecules," American Vacuum Society Meeting, Baltimore, MD, October 27, 1986.
- Cavanagh, R. R., "Energy Transfer and Chemical Bonds: Laser Probes of Molecular Dynamics," Air Force Office of Scientific Research, Bolling Air Force Base, Washington, DC, March 11, 1987.
- Cavanagh, R. R., "Dynamics of Laser Driven Thermal Desorption: Internal States Distributions Induced by Laser Heating Pulses," American Chemical Society Meeting, Denver, CO, April 6, 1987.
- Cavanagh, R. R., "Energy Transfer and Chemical Bonds: Laser Probes of Molecular Dynamics," E. I. duPont deMours & Company, Inc., Wilmington, DE, April 21, 1987.
- Cavanagh, R. R., "Vibrational Relaxation Rates and Mechanisms: Surfaces and Model Compounds," IBM, San Jose, CA, June 26, 1987.
- Cavanagh, R. R., "Laser Induced Desorption: LEF Evidence for Non-Thermal Channels," Physical Electronics Conference, Monterey, CA, June 29, 1987.
- Cavanagh, R. R., "Time-Domain Measurements of Vibrational Relaxation at Surfaces," Chemistry Department, University of East Anglia, Norwich, England, August 31, 1987.
- Cavanagh, R. R., "Time-Domain Measurements of Vibrational Relaxation at Surfaces, Fifth International Conference on Vibrations at Surfaces, Garmisch, W. Germany, September 8, 1987.
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- Egelhoff, Jr., W. F., "Angle-Resolved XPS and AES Studies of the Structure of Crystal Surfaces," Chemistry Department, University of Wisconsin, Madison, WI, October 9, 1986.
- Egelhoff, Jr., W. F., "Angle-Resolved XPS and AES Studies of the Structure of Crystal Surfaces," Chemistry Department, Northwestern University, Evanston, IL, October 10, 1986.
- Egelhoff, Jr., W. F., "The Relative Importance of the Major Factors Contributing to the Angular Variation of Intensities in XPS and AES of Crystals," American Vacuum Society Meeting, Baltimore, MD, October 27, 1986.
- Egelhoff, Jr., W. F., "A Born-Haber Cycle, Core-Level Shift Analysis of Atomic C, N, and O on Ni(100)," American Vacuum Society Meeting, Baltimore, MD, October 31, 1986.
- Egelhoff, Jr., W. F., "Core-Level Binding-Energy Shifts: Introduction and Basics," Simon Fraser University, Vancouver, Canada, November 12, 1986.
- Egelhoff, Jr., W. F., "Core-Level Binding-Energy Shifts: Theoretical Background and Experimental Case Studies," Physics Department, Simon Fraser University, Vancouver, Canada, November 12, 1986.
- Egelhoff, Jr., W. F., "Core-Level Binding-Energy Shifts: Selected Advanced Topics," Physics Department, Simon Fraser University, Vancouver, Canada, November 12, 1986.
- Egelhoff, Jr., W. F., "Core-Level Binding-Energy Shifts: Selected Advanced Topics," Physics Department, Simon Fraser University, Vancouver, Canada, November 12, 1986.
- Egelhoff, Jr., W. F., "XPS Forward Scattering Studies of Epitaxial Structures," Simon Fraser University, Vancouver, Canada, November 13, 1986.
- Egelhoff, Jr., W. F., "Structural Characterization of Thin Overlayers by XPS and AES Forward Scattering," Materials Research Society Meeting, Boston, MA, December 4, 1986.
- Egelhoff, Jr., W. F., "The Importance of Multiple Scattering in XPS and Auger Diffraction in Crystals," American Physical Society Meeting, New York, NY, March 17, 1987.
- Egelhoff, Jr., W. F., "A (Z+1) Core-Level Shift Analysis of the Adsorption of Atomic C, N, and O on Ni(100) and Cu(100)," American Physical Society Meeting, New York, NY, March 18, 1987.
- Egelhoff, Jr., W. F., "XPS Forward Scattering Studies of Ultrathin Film Growth," American Vacuum Society Meeting, Detroit, MI, May 28, 1987.

- Fine, J., "Computer Analysis of Auger-Depth Profiles," Workshop on Quantitative Surface Analysis, National Bureau of Standards, Gaithersburg, MD, October 24, 1986.
- Fine, J., "Collisionally Excited Auger Electron Emission from Al(100): Dependence on Azimuthal Orientation," American Vacuum Society Meeting, Baltimore, MD, October 27, 1986.
- Fine, J., "Reference Materials for Surface Analysis," University of Dayton, Dayton, OH, June 3, 1987.
- Gadzuk, J. W., "Dynamics of Dissociative Adsorption and Associative Desorption," American Vacuum Society Meeting, Baltimore, MD, October 28, 1986.
- Gadzuk, J. W., "Charge Transfer in Molecular Scattering from Studies," Montana State University, Bozeman, MT, November 17, 1986.
- Gadzuk, J. W., "Exciting Vibrations at Surfaces," University of Washington, Seattle, WA, November 19, 1986.
- Gadzuk, J. W., "Selectivity of Elementary Molecular Processes: Coherent 2-photon Processes Vs. Surface Scattering," IMB Almaden Research Laboratory, San Jose, CA, November 21, 1986.
- Gadzuk, J. W., "Intra-Molecular Dynamics in Molecule Surface Collisions," Max-Planck-Institut, Gottingen, W. Germany, January 23, 1987.
- Gadzuk, J. W., "Fundamentals of Surfaces," Tata Institute of Fundamental Research, Lonayla, India, January 27, 1987.
- Gadzuk, J. W., "Easy Modeling in Time-Dependent Quantum Mechanics," Tata Institute of Fundamental Research, Lonayla, India, January 28, 1987.
- Gadzuk, J. W., "Exciting Vibrations at Surfaces: Spectroscopy," Tata Institute of Fundamental Research, Lonayla, India, January 29, 1987.
- Gadzuk, J. W., "Exciting Vibrations at Surfaces: Molecular Scattering," Tata Institute of Fundamental Research, Lonayla, India, January 30, 1987.
- Gadzuk, J. W., "Dynamics of Dissociative Adsorption and Scattering," American Physical Society Meeting, New York, NY, March 19, 1987.
- Gadzuk, J. W., "Selectivity of Elementary Processes in Molecular Surface Collisions," Dynamics of Molecular Collisions Conference, Wheeling, WV, July 14, 1987.
- Gadzuk, J. W., "Molecular Scattering and Vibrational Spectroscopy at Surfaces: A Dynamic Symbiosis," Fifth International Conference on Vibrations at Surfaces, Garmisch, W. Germany, September 10, 1987.

- Girvin, S., "Off-Diagonal Long Range Order, Oblique Confinement and the Fractional Quantum Hall Effect," Physics Department, University of Minnesota, Minneapolis, MN, November 13, 1986.
- Girvin, S., "The Quantum Hall Effect," Physics Department, Virginia Commonwealth University, Richmond, VA, November 18, 1986.
- Girvin, S., "The Fractional Quantum Hall Effect: Fractionally Charged Vortices, Electrons and Bosons and Other Mysteries," Physics Department, Colloquium, Indiana University, Bloomington, IN, January 21, 1987.
- Girvin, S., "Introduction to Replica Field Theory Methods for Random Systems," National Research Council of Canada, Ottawa, Canada, February 9, 1987.
- Girvin, S., "Off-Diagonal Long Range Order in the Fractional Quantum Hall Effect," American Physical Society Meeting, New York, NY, March 20, 1987.
- Girvin, S., "Theoretical Aspects of the Quantum Hall Effect," National Academy of Sciences, Washington, DC, March 24, 1987.
- Girvin, S., "The Fractional Quantum Hall Effect: Fractionally Charged Vortices, Electrons as Bosons and Other Mysteries," Yale University, New Haven, CT, April 6, 1987.
- Jach, T., "Observation of Whisker Growth on Gold Thin Films using Reflection Electron Microscopy," American Physical Society Meeting, New York, NY, March 19, 1987.
- Jach, T., "Dynamical Diffraction of X-Rays from Crystal Surfaces at Glancing Incidence--A New Surface Science Technique," Physics Division Seminar, Naval Research Laboratory, Washington, DC, April 2, 1987.
- Jach, T., "PIN Diodes as X-Ray Detectors for Synchrotron Radiation," Cornell High Energy Synchrotron Source Seminar, Ithaca, NY, May 1, 1987.
- Jach, T., "Using Silicon Diodes to Instrument Synchrotron Radiation Experiments," Ecole Polytechnique, Palaiseau, France, September 11, 1987.
- Jach, T., "Energy Dependence of the $K\beta$ Fluorescent Line and its Satellites in Ar Gas," International Conference on X-Ray and Inner-Shell Processes (X-87), Paris, France, September 15, 1987.
- Jach, T., "Using Silicon Diodes to Instrument Synchrotron Radiation Experiments," Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, Orsay, France, September 21, 1987.
- Johnson, A., "Recent Work on the Chemisorption of First Row Protic Hydrides on Si(100) Using ESDIAD," Lawrence Berkeley Laboratory, Berkeley, CA, March 9, 1987.

- Johnson, A. L., "First Row Protic Hydrides Adsorbed on Si(100): Structure and Reactivity," American Chemical Society Meeting, Denver, CO, April 8, 1987.
- Johnson, A. L., "Chemistry in One and Two Dimensions: Structural Studies of Chemisorption on Platinum and Silicon Using Near Edge X-ray Absorption Fine Structure (NEXAFS) and Electron Stimulated Desorption Ion Angular Distributions (ESDIAD)," Department of Chemistry/Chemical Engineering, University of Washington, Seattle, WA, April 30, 1987.
- Johnson, A. L., "Structural Studies of Chemisorption on Platinum and Silicon Using Near Edge X-ray Adsorption Fine Structure (NEXAFS) and Electron Stimulated Desorption Ion Angular Distributions," Department of Chemistry/Chemical Engineering, California Institute of Technology, Pasadena, CA, May 1, 1987.
- Johnson, A. L., "Digital Video Data Acquisition/Analysis for Existing ESDIAD Apparatus," Desorption Induced by Electronic Transitions (DIET-III), Shelter Island, NY, May 21, 1987.
- Johnson, A. J., "H₂O, NH₃, and HF on Si(100) by ESDIAD," Department of Chemical Engineering, Stanford University, Stanford, CA, August 6, 1987.
- Johnson, A. L., "ESDIAD of First Row Protic Hydrides (H₂O, NH₃, and HF Adsorbed on Si(100): Structure and Reactivity," Department of Chemistry, Oak Ridge National Laboratory, Oak Ridge, TN, August 17, 1987.
- Kurtz, R. L., "Photon-Stimulated Desorption via Core Exciton Production in MgO," American Physical Society Meeting, New York, NY, March 19, 1987.
- Kurtz, R. L., "Ion Desorption Induced by Core Exciton States in MgO," Desorption Induced by Electronic Transitions (DIET III), Shelter Island, NY, May 20, 1987.
- Kurtz, R. L., "The Influence of Surface Structure on Mechanisms of Stimulated Desorption," Desorption Induced by Electronic Transitions (DIET III), Shelter Island, NY, May 21, 1987.
- Kurtz, R. L., "The Dynamics of O⁺ Desorption from TiO₂," Desorption Induced by Electronic Transitions (DIET III), Shelter Island, NY, May 21, 1987.
- Kurtz, R. L., "Performance of the SURF-II High-Throughput Toroidal Grating Monochromator," Synchrotron Radiation Instrumentation Conference, Madison, WI, June 22, 1987.
- Kurtz, R. L., "Resonant Photoemission Measurements of Superconducting Y-Ba-Cu-O," Forty-Seventh Annual Conference on Physical Electronics, Pacific Grove, CA, June 29, 1987.
- Madey, T. E., "The Structure of Molecules on Surface - Application of Electron Stimulated Desorption," Department of Materials Science Seminar, University of Illinois, Urbana, IL, February 11, 1987.

- Madey, T. E., "The Interaction of Water with Solid Surfaces: Fundamental Aspects," Chemistry Department Seminar, Howard University, Washington, DC, February 13, 1987.
- Madey, T. E., "Direct Determination of the Structure of Surface Molecules," Spanish Vacuum Society Meeting, Madrid, Spain, March 1, 1987.
- Madey, T. E., "The Interaction H₂O with Surfaces: Basic Aspects," National Council for Scientific Investigation (CSIC), Madrid, Spain, March 10, 1987.
- Madey, T. E., "Electron and Photon Stimulated Desorption as Probes of Structure and Bonding at Surfaces," Department of Materials Science Seminar, Princeton University, Princeton, NJ, March 30, 1987.
- Madey, T. E., "Structure of Molecules on Surfaces," American Chemical Society Meeting, Denver, CO, April 7, 1987.
- Madey, T. E., "Direct Determination of Molecular Structure and Surfaces," Department of Material Sciences Seminar, Pennsylvania State University, Philadelphia, PA, April 14, 1987.
- Madey, T. E., "Direct Determination of Molecular Bonds at Surfaces," Department of Chemistry Seminar, Ohio State University, Columbus, OH, April 27, 1987.
- Madey, T. E., "Direct Determination of Molecular Bonds at Surfaces," Chemistry Department Seminar, University of Minnesota, Minneapolis, MN, May 15, 1987.
- Madey, T. E., "ESDIAD of Small Molecules on Surfaces: A Few Caveats," Desorption Induced by Electronic Transitions (DIET III), Shelter Island, NY, May 20, 1987.
- Madey, T. E., "Electron and Photon Beam Damage in Surface Analysis: Fundamental Aspects," Microbeam Analysis Society Meeting, Kona, Hawaii, July 13, 1987.
- Madey, T. E., "The Interaction of Water with Solid Surfaces: Fundamental Aspects," American Chemical Society Meeting, New Orleans, LA, August 31, 1987.
- Madey, T. E., "The Local Orientation of Molecular and Dissociated H₂O on FCC (110) Surfaces: Ag, Ni, Cu," American Chemical Society Meeting, New Orleans, LA, September 2, 1987.
- Madey, T. E., "Determination of Molecular Structure at Surfaces Using Electron Stimulated Desorption," Joint Symposium of American Vacuum Society and Chinese Vacuum Society VASA-87, Beijing, China, September 8, 1987.

- Melmed, A., "Field Ion Microscopy and the Icosahedral Problem," University of California, Berkeley, CA, November 6, 1986.
- Melmed, A., "Atomic Dissection of Icosahedral-AlMn: The FIM View," American Physical Society Meeting, New York, NY, March 16, 1987.
- Melmed, A., "Nucleation and Growth of Cr on Stepped Surfaces with Facets - An FEEM Study," Thirty-Fourth International Field Emission Symposium, Osaka, Japan, July 17, 1987.
- Powell, C. J., "Recent Developments in Surface Analysis by X-Ray Photoelectron Spectroscopy (XPS or ESCA)," Eastern Analytical Symposium, New York, NY, October 22, 1986.
- Powell, C. J., "High Accuracy Measurements of XPS Binding Energies and AES Kinetic Energies for Copper, Silver, and Gold," American Vacuum Society Meeting, Baltimore, MD, October 29, 1986.
- Powell, C. J., "Recent Developments in Surface Analysis by X-Ray Photoelectron Spectroscopy," Chemistry Department Seminar, University of Maryland, College Park, MD, November 7, 1986.
- Powell, C. J., "Reference Materials for Surface Analysis," NPL-VAMAS Workshop, National Physical Laboratory, London, UK, November 17, 1986.
- Powell, C. J., "High-Accuracy Measurements of XPS Binding Energies and AES Kinetic Energies for Copper, Silver, and Gold," Fourth International Conference on Quantitative Surface Analysis, National Physical Laboratory, London, UK, November 18, 1986.
- Powell, C. J., "The Development of Standards for Surface Analysis," Fourth International Conference on Quantitative Surface Analysis," National Physical Laboratory, London, UK, November 19, 1986.
- Powell, C. J., "The Energy Dependence of Electron Inelastic Mean Free Paths," Fourth International Conference on Quantitative Surface Analysis," National Physical Laboratory, London, UK, November 20, 1986.
- Powell, C. J., "Comparison of L_3 -Shell Binding Energies of 3d Metals by XPS, APS, and EELS," Deutsches Elektronen Synchrotronen Laboratory, DESY, Hamburg, Germany, November 21, 1986.
- Powell, C. J., "Dependence of Inelastic Electron Mean Free Paths on Electron Energy and Material," Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlantic City, NJ, March 10, 1987.
- Powell, C. J., "Recent Developments and Trends in Surface Characterization," Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlantic City, NJ, March 13, 1987.

- Powell, C. J., "Dependence of Inelastic Electron Mean Free Paths on Electron Energy and Material," American Physical Society Meeting, New York, NY, March 20, 1987.
- Powell, C. J., "Reference Materials, Reference Data, and Reference Procedures for Surface Analysis: National and International Standards Activities," Electronic Materials and Processes Conference, Society for the Advancement of Material and Process Engineering, Santa Clara, CA, June 24, 1987.
- Powell, C. J., "The Quest for Universal Curves to Describe the Surface Sensitivity of Electron Spectroscopies," Stanford University, Stanford, CA, June 24, 1987.
- Powell, C. J., "Recent Developments in Surface Analysis by X-Ray Photoelectron Spectroscopy," Applied Physics Division Seminar, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia, July 20, 1987.
- Powell, C. J., "Comparison of L_3 -Shell Binding Energies in Six 3d Metals by X-Ray Photoelectron Spectroscopy, Appearance-Potential Spectroscopy, and Electron Energy-Loss Spectroscopy," Physics Department Seminar, University of Western Australia, Perth, Australia, July 30, 1987.
- Powell, C. J., "The Quest for Universal Curves to Describe the Surface Sensitivity of Electron Spectroscopies," Physics Department Seminar, LaTrobe University, Melbourne, Australia, August 6, 1987.
- Powell, C. J., "The Accuracy of Surface Analyses," Symposium on Accuracy in Trace Analysis-Accomplishments, Goals, Challenges, National Bureau of Standards, Gaithersburg, MD, September 30, 1987.
- Steigerwald, D. A., "Anisotropy of Equilibrium Surface Composition," American Vacuum Society Meeting, Baltimore, MD, October 29, 1986.
- Steigerwald, D. A., "Structural Studies of Ultrathin Sandwiches of Cu/Fe," American Physical Society Meeting, New York, NY, March 18, 1987.
- Steigerwald, D. A., "Structural Studies of Ultrathin Sandwiches of FCC Fe/Cu(100)," Texas Instruments Central Research Laboratory, Dallas, TX, April 13, 1987.
- Steigerwald, D. A., "Growth and Magnetic Properties of Ultrathin FCC Fe Films on Cu(100)," Hewlett Packard Laboratories, San Jose, CA, July 28, 1987.
- Stockbauer, R., "Ion Desorption from Surfaces," 28th Okazaki Conference, Okazaki, Japan, February 6, 1987.
- Stockbauer, R., "Ion Desorption from Surfaces," Electrotechnical Laboratory, Ibaraki, Japan, February 10, 1987.

Stockbauer, R., "Ion Desorption Induced by Core Exciton States in MgO,"
Desorption Induced by Electronic Transitions (DIET-III), Shelter Island,
NY, May 20, 1987.

Stockbauer, R., "An Ellipsoidal Mirror Analyzer for the Study of Photon
Stimulated Desorption," Desorption Induced by Electronic Transitions
(DIET-III), Shelter Island, NY, May 20, 1987.

Stockbauer, R., "Construction and Performance of an Ellipsoidal Mirror
Analyzer," Synchrotron Radiation Instrumentation Conference, University
of Wisconsin, Madison, WI, June 22, 1987.

Stockbauer, R., "Resonant Photoemission Study of the Electronic Structure
of High Temperature Superconductors," Boulder Superconductivity
Meeting, National Bureau of Standards, Boulder, Co, July 16, 1987.

4. SURFACE SCIENCE DIVISION STAFF

As of September 30, 1987, the Surface Science Division was staffed as follows:

C. J. Powell, Chief
L. M. Johnson, Secretary
R. R. Cavanagh
W. F. Egelhoff, Jr.
N. E. Erickson
J. Fine
J. W. Gadzuk
T. J. Jach
A. J. Melmed
D. A. Steigerwald*

Surface Structure and Kinetics Group

T. E. Madey, Group Leader
B. E. Stewart, Secretary
P. M. Connelly#
R. A. Demmin*
R. L. King+
R. L. Kurtz
E. O. Neitzel#
D. E. Ramaker@
R. L. Stockbauer

- * NBS-NRC Postdoctoral Research Associate
- @ Faculty Appointment, Part Time
- # Engineering Technician
- + Electronics Technician

5. GUEST SCIENTISTS

The Surface Science Division has been host during the past year to the following guest scientists who have worked in the Division staff on problems on mutual interest.

- G. P. Chambers (University of Maryland)
- C. K. Chen (Precision Instrument Development Center, Taiwan)
- H. H. Chen (Precision Instrument Development Center, Taiwan)
- T. L. Einstein (University of Maryland)
- I. Jacob (Ben Gurion University of the Negev, Israel)
- R. D. Kelley (Department of Energy)
- R. Klein (Retired)
- C. U. S. Larsson (Royal Institute of Technology, Sweden)
- D. Marton (Technical University of Budapest, Hungary)
- D. R. Mueller (Naval Research Laboratory)
- J. M. Nicol (University of Maryland)
- J. L. Pena (National Polytechnic Institute, Mexico)
- M. Polak (Ben Gurion University of the Negev, Israel)
- E. L. Roman (Institute for the Physics of Materials, Spain)
- P. Roncin (University of Paris-South, France)
- M. H. Shapiro (California State University, Fullerton)
- A. Shih (Naval Research Laboratory)
- S. M. Shivaprasad (National Physical Laboratory, India)
- S. Tanuma (Nippon Mining Company, Japan)
- M. W. Walczak (Iowa State University)
- Q. Wang (Fudan University, Peoples Republic of China)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET <i>(See instructions)</i>	1. PUBLICATION OR REPORT NO. NBSIR 88-3699	2. Performing Organ. Report No.	3. Publication Date JANUARY 1988
4. TITLE AND SUBTITLE Technical Activities 1987 Surface Science Division			
5. AUTHOR(S) C.J. Powell, editor			
6. PERFORMING ORGANIZATION <i>(If joint or other than NBS, see instructions)</i> NATIONAL BUREAU OF STANDARDS U.S. DEPARTMENT OF COMMERCE GAITHERSBURG, MD 20899			7. Contract/Grant No. 8. Type of Report & Period Covered
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS <i>(Street, City, State, ZIP)</i>			
10. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
11. ABSTRACT <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> <p>This report gives a brief summary of the technical activities conducted in the NBS Surface Science Division during Fiscal Year 1987. These activities include surface-standards work, experimental and theoretical research in surface science, the development of improved measurement methods, and applications to important scientific and national problems. Listings are given of publications, talks, Division staff, and guest scientists.</p>			
12. KEY WORDS <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> surface chemistry; surface physics; surface science; surface standards			
13. AVAILABILITY <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. <input checked="" type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161			14. NO. OF PRINTED PAGES 27 15. Price \$11.95

