Surface Characterization

G. E. McGuire,* Max L. Swanson, Nalin R. Parikh, Steve Simko, P. S. Weiss, J. H. Ferris, R. J. Nemanich, D. R. Chopra, and A. R. Chourasia

Electronic Technologies Division, MCNC, 3021 Cornwallis Road, P.O. Box 12889, Research Triangle Park, North Carolina 27709

Review Contents	
Ion Beam Analysis	199R
Rutherford Backscattering Spectrometry	199R
Elastic Recoil Detection	200R
Particle-Induced X-ray Emission	200R
Nuclear Reaction Analysis	200R
Accelerator Mass Spectrometry	201R
Channeling Applications	201R
Nontraditional Applications Of Ion Beams	201R
Electron Spectroscopy	202R
X-ray Photoelectron Spectroscopy	202R
Auger Electron Spectroscopy	203R
Proximal Probes	203R
Scanning Tunneling Microscopy	203R
Atomic Force Microscopy	206R
Other Proximal Probes	208R
Optical Characterization of Surfaces	208R
X-ray Techniques	211R
Appearance Potential Spectroscopy	211R
Glancing-Angle X-ray Diffraction	212R
Extended X-ray Absorption Fine Structure	212R

Reviews of surface characterization have appeared in Analytical Chemistry every two years since 1977 (1-9). During this time, the field has grown significantly in the volume of papers published as well as the number of applications and diversity of surface characterization tools. This review is similar to the last one in this series, being written by multiple authors with specialties in one or more of the broad categories of surface analysis in an attempt to highlight advances in each of these areas. This review begins with literature from January 1993 and ends with literature from October 1994.

ION BEAM ANALYSIS

The main areas of ion beam analysis (IBA) can be divided into Rutherford backscattering spectrometry (RBS), elastic recoil detection (ERD), particle-induced X-ray emission (PIXE), nuclear reaction analysis (NRA), accelerator mass spectrometry (AMS), and channeling applications of these various methods. Whereas the first four of these methods are generally restricted to determinations of elemental composition-depth profiles of nearsurface regions of materials, channeling applications of these methods are often included for determinations of structures, lattice imperfections, and lattice sites. For example, the quality of epitaxial layers; the structure of surfaces; the nature, depth, and annealing of radiation or implantation damage; and the lattice position of impurity atoms or impurity-defect complexes have been studied. Low-energy elastic scattering of ions from surfaces has also been used extensively for surface structure studies. In the following review, these studies will be grouped with the RBS or channeling data.

The various IBA topics form the basis of a long-standing series of international conferences and also are often included within more topical conferences. In the years 1993-1994, proceedings of the following conferences were published: Sixth International Conference on Accelerator Mass Spectrometry, September 27-October 1, 1993, Canberra/Sydney, Australia (A1); Seventh International Conference on Radiation Effects in Insulators, September 6-10, 1993, Nagoya, Japan (A2); Fifteenth International Conference on Atomic Collisions in Solids, July 26-30, 1993, London, Canada (A3); 16th International Conference on X-Ray and Inner-shell Processes, July 12–16, 1993, Debrecen, Hungary (A4); Elon Ion Beam Analysis, July 5-9, 1993, Balatonfured, Hungary (A5); E-MRS 1993 Spring Meeting: Material Aspects of Ion Beam Synthesis: Phase Formation and Modification, May 4-7, 1993, Strasbourg, France (A6); Eighth International Conference on Ion Beam Modification of Materials (IBMM), September 7-11, 1992, Heidelberg, Germany (A7): Twelfth International Conference on the Application of Accelerators in Research and Industry, November 2-5, 1992, Denton, TX (A8).

Two additional conferences were held in 1994 and will be published shortly: Thirteenth International Conference on the Application of Accelerators in Research and Industry, November 7–10, 1994, Denton, TX; MRS 1994 Fall Meeting Symposium A, Beam–Solid Interactions for Materials Synthesis, November 28– December 2, 1994, Boston, MA.

In 1992 a valuable reference book was published, the *Ency*clopedia of Materials Characterization (A9), which describes ion beam spectroscopies, as well as optical, electron beam, X-ray emission, nuclear, and mass spectroscopies.

A major new publication in the field of IBA will appear in 1995, the *Handbook of Modern Ion Beam Materials Analysis*, edited by J. R. Tesmer, M. Nastasi, C. J. Maggiore, J. C. Barbour, and J. W. Mayer, and published by the Materials Research Society (MRS). This book is a greatly expanded version of the *Catania Handbook*, which has been the standard reference in IBA for many years.

Rutherford Backscattering Spectrometry. In the last two years, further developments in the areas of microbeam analysis, high detection sensitivity, and microelectronics materials have been made.

Microbeam Analysis. Ding et al. (A10) used a rastered microbeam to study lateral diffusion near the edge of a Ni film deposited on Si. A series of nickel silicide regions were formed by heating the sample. Secondary electrons emitted from the microbeam gave an SEM-like image of the sample, while other detectors used PIXE and RBS for elemental analysis. Takai (A11) described nuclear microprobe applications to microelectronics materials and, in particular, to semiconductor process development. Churms and Pretorius (A12) reported on a Van de Graaff data acquisition system for three-dimensional RBS, using the Faure nuclear microprobe system. Sayama et al. (A13) used a 400 keV proton microprobe to study charge collection and soft errors (a change of a bit state caused by collection of charges created by an energetic particle) in p-n junction diodes. It was observed that the proton-induced current could be reduced by the use of a retrograde well structure.

High Sensitivity. Knapp et al. (A14) utilized time-of-flight heavyion RBS to improve the sensitivity for measuring low-level contamination on Si wafers to 10⁹ atoms/cm² and to give a mass resolution that could separate Fe from Cu. A 150 keV N⁺ beam was used. Beams of Li ions (A15) were used to improve RBS and ERD analysis of high-temperature superconductors and to analyze H in CVD samples. In the MRS Fall 1994 meeting, Ishibashi et al. (A16) demonstrated a novel method to improve near-surface heavy impurity detection by a charged particle energy filter (CPEF) technique. In this technique, an electric field is applied across a pair of plates placed before the detector (in the conventional RBS setup) so that backscattered particles of only a selected energy range go through slits to strike the detector. This can be used to filter out particles scattered from the lighter substrate atoms and thus reduce pulse pileup in the region of the impurity signal. The feasibility of this scheme was studied for silicon wafers implanted with 1×10^{14} and 1×10^{13} ${}^{54}\text{Fe}/\text{cm}^2$ at an energy of 35 keV, using a 0.5 MeV He⁺ analysis beam. It was found that the backscattered ion signals from the Si atoms can be reduced by more than 3 orders of magnitude. This suggests the detection limit for contaminants can be improved by at least 2 orders of magnitude compared to the conventional Rutherford backscattering method. This technique can be incorporated in 200-300 kV ion implanters for monitoring of surface contaminants in samples prior to implantation. The use of CPEF with both electric and magnetic deflection fields is also being studied. Kimura et al. (A17) used a 90° sector magnetic spectrometer with DE/E = 0.1% to resolve RBS signals from successive atomic layers near the (001) surface of SnTe.

Microelectronics Materials. (See also Microbeam Analysis entries.) Reeson et al. (A18) implanted Sb into ion beam synthesized $CoSi_2$ layers in Si and measured the diffusion of Sb and the perfection of the adjacent Si lattice during subsequent annealing. The Sb diffused toward the silicate interfaces. The adjacent Si lattice was more perfect in Sb-implanted samples than in samples that were not implanted with Sb, as determined by electron microscopy measurements. Frey et al. (A19) measured the segregation of Ge at or near the interface between an advancing oxide film and the Si–Ge substrate, under high-pressure oxidation conditions. They found that there was a transition from segregation at the interface to trapping of the Ge in the oxide, when the oxidation rate was faster than the diffusive flux of Si atoms across the Ge-rich interface layer.

Elastic Recoil Detection. A combination of ERD, RBS, and NRA was used to analyze diamond-like carbon films, especially in regard to the N composition (*A20*). N is an important deep donor in diamond. It was found that N reduced the internal stress without substantially affecting the film hardness. Skorodumov et al. (*A21*) used a 14 MeV beam of neutrons to measure H isotope concentration-depth profiles at much greater depths than can be done by standard charged-particle methods. The neutrons were produced in a 150 keV deuterion accelerator, using the ³H(d,n)⁴He and ²H(d,n)³He reactions. ERD analysis with heavy ions was reported by Assmann et al. (*A22*). They used 170 MeV iodine or 200 MeV gold ions, in conjunction with large-area

ionization detectors having both particle and position resolution, to obtain a sensitivity below 10^{14} atoms/cm³ for O, N, and C and a depth resolution below 10 nm. They also were able to obtain blocking patterns with their setup. Similar experiments by Siegele et al. (*A23*) with 136 MeV ¹²⁷I allowed the mass separation of elements up to Si.

Martinsson and Kristiansson used coincidence ERD to enhance the sensitivity of H analysis for application to atmospheric aerosol samples (A24), in conjunction with PIXE and ion beam thermography. Coincidences between scattered 3.6 MeV protons and recoiled H atoms were detected with 6 cm diameter plastic scintillation detectors, giving a detection limit of a few picograms per square centimeter.

Particle-Induced X-ray Emission. Koltay described the use of PIXE as well as particle-induced γ -ray emission (PIGE) to analyze atmospheric aerosols (A25). The PIGE method enhances the sensitivity for low-mass elements. This is a review article, comparing the results for Hungary with those from other European countries. A simple method of analyzing aerosols, used in conjunction with scanning electron microscopy (SEM), was described by Romo-Kroger (A26). He collected microparticles using a Nucleopore membrane filter and analyzed them via SEM and an electron microprobe. Antolak and Bench (A27) reported on the Livermore PIXE spectrum analysis package. A new data base was created, which calculated self-absorption, secondary fluorescence, and γ -ray background. Examples were given for an air filter sample, a HgI_2 sample, and a mollusk shell. Weber et al. (A28) studied the kinetics of biomaterials ossification, specifically the changes in the elemental composition of coral and apatite implanted into sheep femur bone. A LiGe detector instead of the usual Si(Li) detector was used to avoid the Si escape peak associated with the Ka X-ray of Ca, the major constituent of bone.

Nuclear Reaction Analysis. Sellschop and Connell reviewed the use of IBA in both structural and isotopic analyses (*A29*), with emphasis on the use of innovative nuclear reaction analysis. The use of ¹⁹F and ¹⁵N beams to study both the depth profile and the chemical state of surface hydrogen was described. A change in the bond strength of H on the surface of diamond by only 0.1 eV can change the resonance width for the nuclear reactions with ¹⁵N beams from 1.8 to 35 keV, an enormous effect. A unique method to study the lattice sites of F in materials, in particular diamond, was also discussed. It consists of using a proton beam to inject ¹⁹F from a surface layer into the diamond, and then via the nuclear decay of the ¹⁹F, the time differential perturbed angular distribution (TDPAD) method was used to show that a significant fraction of the F atoms were in bond-centered interstitial positions.

The ¹⁶O(d,p)¹⁷O reaction was used to measure the O concentration of high-temperature superconductors (*A30*), with an accuracy of 1%; i.e., for YBa₂Cu₃O_{7-d}, the error in *d* was about 0.12. In these experiments, the prompt 871 keV γ -rays from ¹⁷O were detected, so that self-absorption could be neglected. The (α, α) elastic scattering resonances have proven to be useful for analysis of light elements like *C* and *O*, in conjunction with standard RBS analysis. The resonance cross sections are over 100 times greater than the Rutherford cross sections of standard RBS. Davies et al. (*A31*) have calibrated the cross sections with ¹⁶O for 7.3–7.65 MeV α -rays, and with ¹²C for 5.5–5.8 MeV α -rays. Turos et al. (*A32*) used this O resonance together with standard RBS channeling to study oxide superconductors. The anomalous increase in channeling width at temperatures below T_c was

attributed to a decreased displacement of the oxygen atoms.

The sharp resonance at 620 keV in the reaction ${}^{9}Be(a,n){}^{12}C$ was studied, for profiling Be, especially for application to Tokamak materials (*A33*). The peak in the cross section was 0.21 mb and the width was less than 6 keV. The first accurate measurements of H in thin films of Nb were reported, using the ${}^{1}H({}^{15}N,\alpha\gamma){}^{12}C$ nuclear reaction (*A34*). In contrast to earlier indirect methods, it was observed that the H solubility was lower in thin films than in bulk Nb.

Ion sources for radioactive ion beams were described by Latuszynski and Maczka (A35). Such beams have application for marker experiments, especially for ion implantation processes.

Accelerator Mass Spectrometry. Recent advances in AMS were reported in ref A1. The emphasis in that conference was on the biomedical sciences, although continued strong efforts were reported in the fields of archaeology, geophysics, and materials science. Super-SIMS systems and AMS microprobes were considered to have considerable potential. There was a preconference workshop in the environmental sciences. A keynote address on "AMS beyond 2000" was made by Davis (A36), in which the present and future use of 10Be, 14C, 26Al, 36Cl, and 129I were described. Vogel and Turtletaub (A37) described the use of ¹⁴C analysis for measuring protein turnover rates, dermal chemistry, and carcinogens. They noted that drugs and toxins are effective at levels of 10^{-19} - 10^{-9} mol/mg of C, which are easily measured by ¹⁴C dating methods. Paul et al. (A38) measured the isotope abundance of the radionuclide ⁵⁹Ni in meteorites by AMS, using a Pelletron tandem accelerator. The interference from the stable isobaric ⁵⁹Co (100% natural abundance) was overcome by using a multianode ionization chamber, yielding a sensitivity of 5×10^{-13} in the ⁵⁹Ni isotopic abundance.

A computer-controlled AMS facility for measuring the concentration of stable isotopes in electronic materials has been developed (A39), using an ultraclean Cs ion source. It has mass resolution and sensitivity similar to SIMS and removes molecular interferences that reduce SIMS sensitivity for some elements. The sensitivity is 10^{10} atoms/cm³ for many elements. An AMS scan for a contaminated Si sample showed Fe (250 ppb), Co (50 ppb), Ni (6 ppb), and Cu (300 ppb). The isotopic ratios of ⁶³Cu (69.2%) and ⁶⁵Cu (30.8%) were found to be correct, which showed that the calibration was accurate. No V or Cr was present. Neither Zn nor Mn could be detected because neither forms a negative ion. A similar "accelerator SIMS" facility was described by Dobeli et al. (A40). It was used to detect Fe in Si, which is difficult for SIMS because of interference from the molecular Si₂.

Channeling Applications. Turos et al. (A32) did a detailed channeling analysis of the lattice location of O in high- T_c superconductors (Y(Eu)-Ba-Cu-O) and in UO₂, using the broad resonance of the ¹⁶O(α,α)¹⁶O scattering near 7.6 MeV for UO₂ and the resonance at 3.05 MeV for the superconductors. The anomalous increase in the channeling width below T_c for both Cu and O was attributed to a decrease in the vibrational amplitude of the O by 0.0035 nm. This analysis required the use of Monte Carlo simulations.

Parikh et al. (A41) gave a short summary of ion implantation effects in diamond, including ion damage, doping, and liftoff. They showed by channeling measurements that C implantation damage could be almost completely annealed out if the calculated (by TRIM) defect density was below 7 atom %. At a defect density of 7-10 atom %, a stable damaged form of diamond ("green"

diamond) was formed by annealing at 950 °C. Yu et al. (A42) showed for the first time that a spinel, in this case MgAl₂O₄, could be amorphized by irradiation. Channeling results for 400 keV Xe ion irradiation to a dose of 10^{16} /cm² at 100 K indicted the amorphization.

Transmission ion channeling with a rastered 2 MeV proton beam was used to image dislocations (A43) in a $Si_{0.85}Ge_{0.15}/Si$ sample. A 100 pA beam was focused to 0.5 mm diameter with a convergence angle of 0.2°. This was a preliminary experiment, and the resolution of individual dislocations was not good.

A unique experiment to measure the effect of an electric field on channeling in LiNbO₃ was reported (A44). The (0001) channel width for 2 MeV He ions was asymmetrically narrowed by the application of a field of 10^6 V/m. Ion beam deflection and piezoelectric strain cannot explain the magnitude of the observed narrowing.

Impact-collision ion scattering spectrometry (ICISS) was used to analyze the structure of the Si(100) – (4×3) In surface (A45). The deposition of In onto the Si(100) – (2×1) surface followed by annealing at 200–500 °C creates a (4 × 3) reconstructed surface. Bergmans et al. (A46) used low-energy ion scattering, with both energy- and angular-resolved spectrometry, to study the Cu₈₅Pd₁₅(110) – (2×1) surface. This is an important alloy for catalytic cracking of hydrocarbons. It was found that the surface was not reconstructed and that the first surface layer was possibly depleted in Pd, while the second layer was enriched.

Nontraditional Applications Of Ion Beams. In materials science and semiconductor research, ion beam techniques have become a major tool for research and manufacturing. Now these techniques are expanding steadily into diverse fields such as biomaterials, environment, archaeology, geoscience etc. (See the PIXE and AMS sections.) In addition, novel IBA methods are being applied to these new studies.

A review of innovative IBA methods for studying the environment was published recently by Malmqvist (A47). (See also Maenhaut (A48) for a general survey of nuclear methods for environmental studies.) In it, he describes "ion beam thermography", in which the temperature-dependent decomposition of chemical compounds present in aerosols is combined with PIXE or NRA to identify the compounds (A49). Coincidence methods, by which an emitted charged particle from a nuclear reaction is detected in coincidence with an emitted photon (giving a "photontagged" nuclear reaction), can reduce background radiation by orders of magnitude (A50). The lack of chemical information via traditional IBA can also be overcome by combining IBA with ioninduced luminescence (A51). The use of bolometers, or calorimetric radiation detectors, was reviewed by (A52). They have potential application to high depth resolution studies.

IBA has been used in plant studies; for example, the effect of acidification of trees on Mn/Ca contents was determined by PIXE (A53). A nuclear microprobe was used to measure metal uptake in sphagnum leaves (A54). The chemical composition of human kidney stones excreted over a period of years by a single patient was studied by a combination of PIXE and PIGE (A55). A constant ratio of Zn/Sr contents was obtained, which relates to the correlation between Zn in the stones and in urine. The use of IBA methods for detection of contraband, for example, narcotics and explosives, was discussed by Vourvopoulos (A56).

ELECTRON SPECTROSCOPY

X-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES) are established techniques that are used in a wide variety of applications. Almost 4000 English language papers related to X-ray photoelectron spectroscopy and Auger electron spectroscopy have been published since the last review. This report concentrates on recent trends in use of these techniques to solve materials problems. A review of the basic fundamentals of XPS and AES has been published recently by Turner and Schreifels (B1).

In recent years, the surface science community has been working to produce standard reference materials and collections of reference data. Reference materials and reference data sets are both useful for calibrating instruments and for standardizing data acquisition, which aids in comparing results between laboratories. Seah et al. proposed a copper and gold reference material to be used for calibrating the intensity scale of Auger spectrometers (B2). Interlaboratory tests show that intensity variations can be reduced to about 5% when asystematic calibration method is used (B3). Gallium arsenide/aluminum arsenide superlattices were proposed as a reference material for sputter depth profiling experiments (B4). Little sputter-induced roughness was noted during argon ion sputtering. A standard nickel/chromium multilayer specimen was used in an interlaboratory comparison of depth resolution in sputter depth profiling experiments (B5). Collections of reference spectra can be found in volumes 1 and 2 of Surface Science Spectra, a journal devoted solely to the publication of reference data (B6). In recent issues, called focused topic issues, spectra from similar materials are grouped together, for example, the XPS Spectra of Semiconductors IV, III-V, II-VI (B7).

X-ray Photoelectron Spectroscopy. As a mature analytical technique, XPS has applications in a wide variety of technical areas. Review articles of many applications of XPS have recently been published. Mathieu has reviewed several application areas of XPS in materials science including biomaterials, ceramic films on polymers, and metal corrosion (B8). The use of XPS to study metal corrosion has also been reviewed by Sherwood (B9). XPS has been crucial to the development of high- $T_{\rm c}$ superconducting oxides. Progress in this area has been reviewed by Brundle and Fowler (B10) and Klissureski and Rives (B11). Catalysis is another technical area where XPS has made significant contributions (B12). XPS analysis of heterogeneous catalysts (B13) and organoactinide catalysts (B14) and quantitation of catalyst species (B15) have been reviewed. The microelectronics industry continues to rely on surface analytical techniques, including XPS, to solve current problems and aid in the development of future technologies. Hattori has reviewed recent studies of the siliconsilica interface by XPS (B16). XPS studies of dry etching of III-IV semiconductors (B17) and of the electrochemical growth of oxide films (B18) have also been reviewed. Because it is relatively unaffected by surface charging, XPS is usually the method of choice for studying the surface of insulating materials such as polymers (B19). XPS has contributed greatly to the understanding of polymer adhesion by providing information on the surface functional groups that influence bonding (B20, B21). XPS has also aided the development of electroactive polymers (B22). Adhesion between the polymer matrix and the reinforcing fibers is critical to achieving the desired properties of fiber-matrix composites. XPS analysis of the surface functional groups on carbon fibers has been reviewed by Wightman (B23). XPS studies of glass and modified glass surfaces have been reviewed by Pantano (B24).

Improvements in spatial resolution of XPS are expanding the applications of this technique to small-area analysis, elemental mapping, and chemical-state imaging. Pulm and Herberg state that a key advantage of XPS imaging over other surface analysis techniques is the ease with which insulators can be imaged (B25). They give several examples of imaging experiments on insulators including surfactants on ceramics and oxidation of hair. Another key advantage of XPS imaging is the ability to image different chemical states of an element. Forsyth and Coxon describe an instrument with spatial resolution of $<5 \,\mu m$ and show examples of chemical-state images of polymer surfaces using different bonding states of C1s spectra (B26). The valence band can also be used to form images as described by Zupp et al. during their study of heterogeneous polymer surfaces (B27). XPS imaging was used to show phase separation at the surface of a poly(vinyl chloride)-poly(methyl methacrylate) blend (B28). Haak et al. studied the adhesion failure of epoxy-galvanized steel bonds using XPS mapping (B29). They determined the mechanisms of bond failure using these results. Nucleation sites for diamond film growth were imaged by Ajji et al. (B30). Different elemental distributions were noted between untreated areas of the silicon substrate and scratches where diamond crystals nucleated. The distributions of diacetylenic phosphorylcholine on metal and polymer substrates were determined using imaging XPS (B31). In an effort to further improve the spatial resolution of XPS, Jenkins and Castle explored the use of XPS in the transmission mode (B32). This is a revival of an old idea where an anode material is placed on the back of a thin section and illuminated by a focused electron beam. Photoelectrons are collected and measured from the front with high spatial resolution.

Development of biomaterials is an active research area that is being aided by XPS. Progress in this field was reviewed by Ratner (B33, B34). Many of the studies in this field involve measuring the surface chemistry of a material to explain its biocompatibility and/or modification of the materials surface to improve its biocompatibility. Lin and Cooper modified the surface of polyethylene to improve its blood compatibility (B35). XPS was used to determine the surface chemistry of titanium implants before and after exposure to various proteins (B36). Differences in surface chemistry were found to affect the enzyme-catalyzed degradation of two different lots of Biomer, a poly(ether urethane urea) (B37). The ultrahigh-vacuum environment required for XPS is a disadvantage when studying biomaterials since most of these materials are used in a hydrated state. Lin et al. used a coldstage and XPS to study PTMO-polyurethane copolymers in dry and hydrated states (B38). Hydration caused an enrichment of nitrogen-containing urethane segments to the surface. In addition to studies of biomaterials, XPS is also employed to study the surfaces of cells. Rouxhet et al. discuss the special techniques required to analyze microbial cell surfaces by XPS (B39). They relate surface composition results to bulk properties of the cells such as flotation, aggregation, and adhesion. Differences in surface composition were observed on wild-type and plasmid-cured microbial cells (B40). Dodge et al. found that the surfaces of certain microbial cells caused the chemical reduction of uranium-(VI) to uranium(IV) when radioactive waste was subjected to microbial action (B41).

Increasingly, XPS is being used to study more complex systems. XPS was employed to determine the fat coverage on spray-dried food powder (B42). Cocke et al. reviewed the analysis of soils and minerals by XPS (B43). Lead compounds were found on the surface of mine tailings from a precious metal mine (B44). XPS was used to show that silicates bind to the surface of hematite minerals (B45). Addition of silicates allowed the separation of hematite and apatite minerals using flotation techniques. Sulfur (B46) and nitrogen (B47) functional groups on the surfaces of coal specimens were characterized by XPS. Watts determined the acid-base properties of polymer and metal oxide surfaces using XPS (B48, B49). Results are used to explain adhesion properties of the materials. Segregation of species to the surfaces of liquids has been studied by XPS (B50) and angle-resolved XPS (B51). Janssen and Goldmann developed an instrument to measure the XPS spectra of aerosol particles in flight (B52).

Auger Electron Spectroscopy. The history of AES was reviewed by Gergely to commemorate the 25th anniversary of its discovery (*B53*). The early history of AES is discussed as well as major developments in analyzer technology. Major milestones in the development of AES are also described. The contributions of AES to the study of electrochemical corrosion (*B54*), catalysts (*B55*), electronic structure of crystals (*B56*), sputter-induced alloy segregation (*B57*), and electrode surfaces (*B58*) were reviewed.

Work is continuing on efforts to improve the analytical utility of scanning Auger imaging. Browning reviewed the use of multispectral imaging techniques to aide image interpretation (*B59*). Boehmig and Reichl describe the use of segmentation and scatter diagram analysis to facilitate interpretation of multispectral images (*B60*). Barkshire et al. describe methods for correcting Auger images using signals from absorbed sample current, backscattered electrons, and secondary electrons (*B61*, *B62*).

AES continues to be an important technique for characterizing semiconductor materials and devices. Analysis of grain boundaries in semiconductors using AES was reviewed by Kazmerski (B63). Derrien et al. reviewed the growth and characterization of semiconducting silicides (B64). Manabe et al. discussed methods of characterizing $0.5 \,\mu$ m wide resist lines formed by use of a silylation reagent (B65). Methods to eliminate charging artifacts during analysis of these insulating layers are also described. Palmer and Mathuni describe a method for measuring the oxide film thickness at the bottom of a contact hole (B66). Results are used to optimize the reactive ion etching process used to form the contact hole.

AES continues to be used in tribology and wear studies to characterize the surfaces of wear-tested specimens. AES studies of the wear process was reviewed by Glaeser (*B67*). Implantation of carbon, nitrogen, and oxygen into iron to improve its tribological properties was reviewed by Williamson (*B68*). Ion implantation was also used to grow zirconia films on metal substrates (*B69*). AES was used to characterize the film after growth and wear testing. Surface segregation of zinc was observed in worn areas after wear testing of copper-nickel-zinc alloys (*B70*). The friction coefficient and wear rate of a chromium oxide coating were both lowered when calcium and barium fluoride solid lubricants were employed (*B71*). AES showed that the friction coefficient was directly related to the amount of lubricant in the contact region. Films that form during interactions between extremepressure additives in lubricants and steel surfaces were characterized by AES (*B72*, *B73*). Formation of iron sulfide was found to improve scoring resistance of SAE 52100 steel (*B74*). Glaeser et al. describe the use of a pin-on-disk wear tester that is mounted inside an Auger spectrometer (*B75*). Results of sliding experiments using the oil additive zinc dialkyldithiophosphate are presented.

PROXIMAL PROBES

A critical report on surface chemistry applications of scanning tunneling microscopy, atomic force microscopy, and related techniques is presented. This review is taken from papers predominantly published in 1993 and 1994, the years since the previous Analytical Chemistry review (C1). This review is not meant to be a complete bibliography for research using proximal probes. The discussion is limited to applications beyond topographic and morphological characterization or to new proximal probe techniques and methods. There are two main meetings of the scanning probe microscopy community: the International Conference on Scanning Tunneling Microscopy and the Annual National Symposium of the American Vacuum Society. Both produce proceedings volumes (C2, C3) that contain a plethora of references on proximal probe techniques. Due to the wide accessibility of the proceedings, no further references from these two sources are included.

Scanning Tunneling Microscopy. Over the last two years several books and reviews have been published on scanning tunneling microscopy, applications, and related techniques, including the following: Wiesendanger and Güntherodt's Scanning Tunneling Microscopy I-III (C4); Chen's Introduction to Scanning Tunneling Microscopy (C5); Stroscio and Kaiser's Scanning Tunneling Microscopy (C6); Bonnell's Scanning Tunneling Microscopy: Theory, Techniques, and Applications (C7); Horton and Amrein's STM and SFM in Biology (C8); DiNardo's Nanoscale Characterization of Surfaces and Interfaces (C9); and Wiesendanger's Scanning Probe Microscopy and Spectroscopy, Methods and Applications (C10). Lagally reviewed applications of the scanning tunneling microscope (STM) to atomic-level studies of kinetic and thermodynamic influences on thin-film growth (84 references) (C11). Weiss discussed progress toward analytical applications of the STM (51 references) (C12). Wiesendanger discussed the use of scanning probe microscopes (SPMs) in the study and creation of nanometer-scale structures on surfaces (172 references) (C13). Molotkov discussed the theory of new modes of STM operation (10 references) (C14). Molotkov covered spin fluctuations in STM, spin-dependent tunneling in STM, spindependent tunneling in the case of the optical orientation of spins, resonant spectroscopy of the adsorbates by a STM, and related topics. The fundamental review issue of Analytical Chemistry published in 1994 included a review of SPMs by Louder and Parkinson (835 references) (C15). A short section on the use of proximal probes was also included in Perry and Somorjai's excellent general review of the characterization of organic surfaces (C16).

Of the proximal probe techniques available today, the STM is uniquely suited to the study of the local electronic properties of metal and semiconductor surfaces. Recently, the STM has been used as a direct probe of the dispersion of surface-state electrons on the close-packed surfaces of noble metals (C17-C20). These electrons form a two-dimensional (2D) nearly free electron gas. Eigler and co-workers observed standing-wave patterns in the local density of states (LDOS) on Cu{111} at low temperature (4 K) (C17). These spatial oscillations of the LDOS are quantummechanical interference patterns caused by scattering of the 2D electron gas off step edges and point defects. Hasegawa and Avouris have used a special spectroscopic imaging mode to observe these oscillations at room temperature due to scattering off steps on Au{111} and Ag{111} (C18). In the work of both Avouris and Eigler and their co-workers, the dispersion relations of the surface states were determined from spatial scanning tunneling spectroscopy (STS) studies of standing waves (C19). STS experiments agreed with previous data from photoemission, but more information about the spatial variations in surface standing waves could be determined by performing STS experiments. Along similar lines, Eigler and co-workers used the tip of a low-temperature STM to assemble artificial structures of Fe atoms on the surface of Cu{111} (C20). STM images showed that these "quantum corrals" produced spatial oscillations in surface electronic states at the nanometer scale whose structure was dominated by the eigenstates expected for a particle trapped in a 2D box (C20). Heller et al. presented a more realistic, mathematical description of the interaction between surface electrons and the Fe adatoms (C21). Unlike the particle-in-a-box treatment given in ref C20, this computational technique can be applied to scattering from single surface impurities and surface structures of arbitrary geometry. These nanometer-scale LDOS modulations observed in STM images serve as a warning that images cannot be readily interpreted in terms of surface atomic positions.

Even though the electronic structures of chemically different species are theoretically distinguishable, it is not yet possible to identify adsorbates solely from their characteristic STM images. Progress toward analytical application of the STM has been slow. The ability to correlate the electronic structure of the adsorbatesurface system with its STM image was demonstrated by Eigler and co-workers (C22). Using a low-temperature ultrahigh-vacuum (UHV) STM, they performed spectroscopic measurements on isolated Fe atoms adsorbed on the Pt{111} surface. When the STM tip was positioned over a single Fe atom a peak was found in the differential conductance (dI/dV) spectra. These dI/dVspectra were compared to theoretical calculations suggesting that this Fe peak is due to the Fe 4s/5s resonance. On GaAs $\{110\}$, the Ga and As atoms can be differentiated by switching the polarity of the tunneling bias voltage (C23). That is, by having electrons tunnel from tip to sample (negative tip bias), images show empty surface states, predominantly on Ga atoms on GaAs{110}. Electrons tunneling from substrate to tip (positive tip bias) show filled states, predominantly on As atoms for GaAs{110}. Salmeron and co-workers observed that when Zn atoms replace Ga atoms in GaAs{110}, the ZnGa atoms can be imaged in both filled-state and empty-state STM images (C24). Further, they demonstrated the ability to image ZnGa atoms in the first through sixth layers below the surface of GaAs{110}. In empty-state images ZnGa appeared as a delocalized triangle, but in filled-state images ZnGa was spherically symmetric. The origin of the triangular shape in the empty-state images is unknown. This study demonstrates chemical differentiation of surface and subsurface impurities using the STM. In other cases, "special" STM tips have been used for chemical differentiation. Ruan et al. reported atom-resolved discrimination of chemically different oxygen and metal atoms on both $Cu\{110\}$ and $Ni\{110\}$ (C25). By reversibly manipulating the apex of the STM tip between nominally clean W and a single O atom, Ruan et al. were able to image selectively either O adatoms or Cu (Ni) adatoms, respectively. Schmidt et al. observed that under "special" STM tip conditions there were apparent differences in corrugations for Pt and Ni atoms on the surfaces of single crystal alloys (C26). Schmidt et al. attributed the ability to observe large differences in atomic corrugation to unidentified single atoms adsorbed at the apex of the STM tip. The ability to discriminate between surface Pt and Ni atoms allowed Schmidt et al. to study chemical ordering in the alloy crystal with the STM. Michel and co-workers characterized dopants in Si with scanning surface harmonic spectroscopy (SSHS) (C27). Although SSHS does not chemically differentiate species, it is sensitive to capacitance/voltage characteristics of the tip-sample junction, dopant profiles, surface pinning, and insulator quality with nanometer lateral resolution.

There remain few instances where chemical differentiation is possible using the STM. In surface chemistry, the STM is better suited to investigations of surface chemical bonds. In certain cases, binding sites of atoms and molecules can be determined by their coordination and the electronic structures of the surface and adsorbate species. In addition to high-symmetry sites, adsorbates can bind at any number of defect sites. The nature of these interactions influences the LDOS at the surface and, therefore, the STM image characteristics. Weiss and Eigler have directly observed apparent differences in shapes of molecules in STM images (C28). Using a low-temperature STM, they observed three different characteristic images of isolated benzene molecules on Pt{111} (C28). These were assigned to molecules bound at different adsorption sites. They also determined the relative binding energies of the three sites. Theoretical calculations by Sautet and Bocquet also showed the site dependence of the apparent shape of the benzene molecules in STM images (C29). Further, Sautet and Bocquet's calculations confirmed Weiss and Eigler's binding site assignments for the three characteristic benzene images. Hallmark and Chiang used the STM to study the structural details of the mixed adsorbate systems of azulene, naphthalene, and methylazulene (C30). These experiments further demonstrated the ability of the STM to detect subtle differences in adsorbate structure, binding, and orientation.

The STM has recently been used to induce chemical reactions. McIntyre et al. used a STM inside a reaction cell to catalyze a chemical reaction (C31). A Pt-Rh STM tip was used to rehydrogenate carbonaceous fragments locally on the Pt{111} surface (C31). The Pt-Rh tip acted as a catalyst only after activation by short voltage pulses. This activated state was found to be reversible. This experiment also demonstrated that the STM can be used to drive chemical reactions with spatial resolution on the order of 10-100 nm. Sugimura et al. used a STM tip to induce anodization of Ti films (C32). They were able to fabricate nanometer- and micrometer-scale structures of arbitrary shapes, further demonstrating the capability of the STM to direct chemical processes with high spatial resolution.

In many systems, adsorbates are in motion and surface bonds are thus dynamic in nature. When it is possible to observe or even to control the bonding of an adsorbate species between two or more surface states, one can qualitatively measure binding energies and the relative stabilities of different surface states. Mo observed that Sb₄ has four different adsorption configurations on Si{100} (*C33*). Further, Mo demonstrated that by scanning at high bias voltages it is possible to convert all the Sb₄ to its most stable bonding geometry. The transition between the two most stable states, requiring only a rotation, could be induced in either direction using the STM. Mo discussed the nature of the forces between the STM tip and the Sb dimers and quantified the relative binding energies of and activation barriers between the four surface states.

Hamers and co-workers investigated the adsorption and dissociation of disilane (Si_2H_6) on $Si\{100\}$ with particular emphasis on identifying the surface molecular fragments and their bonding geometries (C34, C35). The dominant surface species observed were H and SiH₂, both of which were identified on the basis of the symmetry of their binding sites with respect to the $Si\{100\}$ - (2×1) surface. Annealing the disilane-covered surface produced pure Si in the form of one-dimensional "dimer strings" (C34). They showed that disilane dissociatively adsorbs forming SiH₃ and observed the initial stages of the growth of the Si{100} – (2×1) monohydride structure from the dimer precursor (C35). The SiH₃ groups spontaneously dissociate into SiH₂ and H within several minutes of adsorption, and individual disassociation events were observed in STM images (C35). From STM images at successive stages in the thermal decomposition reaction, Hamers and coworkers identified the initial adsorbates and the key intermediates in the dissociation of disilane on Si{100} and in the epitaxial growth of silicon islands on this surface.

At room temperature benzene adsorbs strongly to Ni $\{110\}$. Stensgaard et al. investigated the interaction of benzene with an oxygen-precovered Ni $\{110\}$ surface (C36). From atomic resolution STM images they determined the structure, reordering, and thermally induced chemistry between benzene and oxygen for this mixed adsorbate system.

Diffusion is usually difficult to observe with the STM. The time required to obtain high-resolution images is often much longer than the time for adsorbate motions. Currently there are two main strategies employed in STM studies of motion on surfaces. Conceptually simplest, but experimentally challenging, is to slow down or quench surface motion by reducing the temperature at which experiments are conducted. Alternatively, systems with sufficiently strong adsorbate-surface interactions can be studied at room temperature and above.

Self-assembled monolayers (SAMs) are of current interest for a wide variety of applications. The most studied of these systems are fabricated by the spontaneous adsorption of alkanethiol chains from solution onto Au{111}. The S-Au bond is very stable. At room temperature, motion in these systems is on a measurable time scale for scanning tunneling microscopy studies of surface dynamics. STM observations by Stranick et al. showed that mixed composition SAMs of alkanethiols phase segregate into lateral domains of like molecules (C37). Further, observations showed that, over time, lateral domains of like molecules coalesce into larger domains (C37). Stranick et al. demonstrated that one can estimate activation energies for this motion and diffusion parameters based on the time necessary to observe motion in these systems with a STM. In additional studies by Stranick et al., a new mechanism of surface diffusion was discovered (C38). Changes in STM images of Au-thiolate SAMs were interpreted as being due to diffusion of alkanethiolate-tethered Au along step edges of the substrate. Poirier et al. also observed motion of molecules in SAMs of alkanethiols on Au{111} (C39). Short-chain (four carbon) SAMs were initially found as 2D liquids at room temperature. Time-lapse studies showed that crystalline domains nucleated and propagated across the surface (C39). The dynamics found by Poirier et al. (C39) were consistent with the alkanethiolate-tethered Au model for surface diffusion in ref C38.

Another application of STM in surface dynamics is adatom diffusion. Dunphy et al. have observed S atom diffusion on Re (0001) at low coverages (*C40*) and found that at coverages below a complete monolayer STM images between ordered islands appeared "noisy". Using correlation techniques, they were able to show that this noise was due to S atoms diffusing on the same time scale as the STM imaging. Dunphy et al. were also able to estimate the barrier to diffusion and the strength of interaction energies between S adatoms. Similarly, defect motion on surfaces can be measured with the STM. Lagally and co-workers observed vacancy diffusion on Si{100}-(2 × 1) with the STM (*C41*). To follow this rapid motion, the STM tip was repeatedly scanned along a single line while the frequency and number of individual vacancy jumps were measured. From these observations, the activation barrier to single vacancy jumps was calculated.

Many electrical and chemical phenomena occur on short time scales, making real-time measurements difficult with an imaging technique as inherently slow as a STM. Weiss et al. demonstrated the ability to detect dynamic phenomena using an instrument called an ultrafast scanning probe microscope (USPM) (*C42*). By combining ultrafast optics with a STM, Weiss et al. were able to measure the response of the tunneling gap with picosecond time resolution and simultaneous 50 Å spatial resolution. Further picosecond resolution studies of dynamic phenomena using the USPM have been reported by Nunes and Freeman (*C43*). The ability to combine the spatial resolution of the STM with the time resolution of ultrafast optical techniques yields a powerful tool for the investigation of dynamic phenomena at the atomic scale, an area that remains largely unexplored.

The STM has also been used to study overlayer growth. Sakurai and co-workers extensively studied the adsorption and overlayer growth of C_{60} and C_{84} films on Si{100} (*C44*). In these studies STM "snap shots" were recorded at different stages of overlayer development from low coverage, to island nucleation, to the formation of well-ordered thin films. They reported observing the internal structure in STM images of single C_{60} and C_{84} molecules (*C44*). The also reported STS measurements of C_{60} and K-doped C_{60} films. They found that mild heating removed multilayers of both molecules, but that the first layer was never removed (*C44*). STM images of the surface after annealing to 1000 °C showed a change in morphology believed to be indicative of thermal degradation of the film into SiC islands (*C44*).

The above examples illustrate the potential for applications of the STM to studies of surface dynamics. Observing motion with the STM for many systems necessitates working at low temperatures. The interest in such experiments is evidenced by the numerous publications on the technical challenges of building lowtemperature STM apparatus (C45). Stranick et al. studied the atomic-scale dynamics of benzene molecules on the Cu{111} surface at low coverage and at 77 K (C46). Benzene molecules were mobile on terraces and pinned at step edges at 77 K. This is direct evidence that overlayer growth begins at substrate defect sites. Stranick et al. observed that benzene molecules move along the step edge and diffuse in and out of step edge sites. They also observed that at 4 K all diffusion was quenched and benzene molecules were found pinned at defect sites on the Cu{111} terraces (C46). Zeppenfeld and co-workers studied Xe overlayer growth on Pt{111} using a low-temperature STM. They observed the evolution of the monolayer from isolated Xe atoms on Pt{111} up to one monolayer coverage (C47). In other experiments, they investigated the temperature dependence of the Xe-layer morphology on Pt{111} and compared the differences in structures found for Xe overlayers with different thermal histories (C48).

Several research groups have reported techniques enabling application of the STM to the study of insulators. Stranick and Weiss reported successful imaging of insulating lead silicate glass using an alternating current STM (ACSTM) (C49). In the ACSTM, a microwave frequency (GHz) modulation is applied to the STM tip. This high-frequency switching of the bias induces electrons to tunnel back and forth between the ACSTM tip and the substrate surface. Mercer et al. imaged insulating diamond films with a conventional (dc) STM by utilizing photoinduced bulk carrier transport to establish tunneling currents (C50). The mechanism of photoinduced tunneling is not clear, but they suggested that N introduced into the diamond films during chemical vapor deposition (CVD) may play a role. Experiments by Guckenberger et al. determined that a thin layer of water molecules on an insulating surface could allow measurable tunneling currents (on the order of 0.01-10 pA at 1 V applied bias) (C51). In addition, Guckenberger et al. also demonstrated the ability to image biomolecules on mica with nanometer resolution using ultrathin water films.

Shortly after the invention of the STM, research in creating atomic-scale structures began. One way of modifying a surface with the STM is to apply voltage pulses to the tip. Hsiao et al. used such pulses to transfer metal atoms from a STM tip to a surface (C52). Using voltage pulses of 6-20 V for durations of $2-2000 \ \mu$ s, Hsiao et al. created metallic mounds on Si{111} as small as 200 Å in diameter and 10 Å in height. The chemical composition of these deposits was verified by Auger spectroscopy. Kobayashi et al. used the tip of a STM to carve grooves in Si-{111} by using high bias voltages $(2 V \pounds | V \text{ bias} | \pounds 10 V)$ (C53). They found that there was a critical voltage at which Si atoms were removed from the surface. Variation of the voltage threshold with current was explained quantitatively on the basis of variations in electric field strength (C53). Salling and Lagally demonstrated the ability to use the STM to fabricate structures on Si{100} with atomic-scale lateral control (C54). They removed atoms from the Si{100} surface using moderate-voltage pulses. STM images of the trenches and floors of trenches showed crystalline order. Kent et al. used a combination of CVD and STM to produce high aspect ratio nanometer-scale magnets (C55). These magnetic dots were grown by introducing a precursor into a CVD chamber while the STM tip was tunneling. The voltage was gradually raised while a constant current was maintained until deposits formed on the surface. By continuing to deposit until the feedback loop was fully retracted, Kent et al. were able to form deposits of reproducible size.

Atomic Force Microscopy. In addition to the books listed under Scanning Tunneling Microscopy, one volume is entirely devoted to the atomic force microscope (AFM)—the revised edition of Sarid's Scanning Force Microscopy with Applications to Electric, Magnetic, and Atomic Forces (C56). Hartman reviewed the application of SPMs to the study of superconductors (37 references) (C57). Giessibl reported on the advances of AFM in UHV (39 references) (C58). Lal and John evaluated the biological applications of AFM in an extensive review (136 references) (C59).

Better understanding of the forces in AFM will lead to improved imaging capabilities and provide methods for relating AFM force profiles to mechanical, magnetic, and/or chemical properties of systems. AFM images of flat surfaces often do not possess the same lateral resolution as seen in STM images. Ohnesorge and Binnig reported true atomic resolution on calcite (*C60*). They reduced the attractive forces between the AFM tip and surface by imaging under ultrapure water. This enabled them to image using attractive forces on the order of only 10^{-11} N. They attributed the enhanced resolution to limiting the dominant interaction forces only to those between single atomic sites and a few atoms at the apex of the AFM tip.

As with the STM, our understanding of AFM images remains incomplete. Calculations by Tang et al. simulated AFM images of highly ordered pyrolitic graphite (HOPG) using a diamond tip (C61). AFM images of HOPG have two characteristic structures: one is trigonal, in which only every other C atom is visible (as in STM), and the other is a honeycomb structure in which all C atoms are observed (C62). The forces that determine this change in apparent resolution were previously undetermined. This theoretical study showed that the orientation of the tip apex and the applied force determine which AFM image is found and that the AFM images do not rely on asymmetric tips or on graphite flakes on the AFM tip for atomic resolution (C61).

Optical methods are often used in AFMs to measure cantilever deflection. This makes AFM experiments in UHV or at low temperatures difficult. Takata described a method for contact-mode AFM with a piezoelectric cantilever which eliminates the need for optical methods (*C63*). The impedance of a piezoelectric crystal is sensitively dependent on its oscillation frequency near mechanical resonance. Directly monitoring the impedance of the cantilever thus eliminates the need for optical methods.

The AFM is sensitive enough to enable the measurement of the intermolecular forces between complementary pairs of biomolecules. Lee et al. demonstrated this by measuring molecular recognition interactions—the force profiles between biotinylated surfaces and a biotinylated AFM tip (C64). They quantified the force required to break the chemical bond between streptavidin and biotin (C64). In closely related work, Florin et al. measured adhesion forces between individual ligand—receptor pairs with a functionalized AFM tip (C65). Florin et al. demonstrated the specificity of different biological interactions for biotin, desthiobiotin, and iminobiotin in AFM force profiles. Lee et al. went on to measure the forces between complementary oligonucleotides and the thermal stability of these bonds as function of the number of bound pairs (C66).

AFM measurements of frictional force have been used by Overney et al. to differentiate molecular orientations within organic bilayers (*C67*). The anisotropy in frictional force exerted on the AFM tip could be explained by different alignments of the molecular structure with respect to the scanning direction (*C67*).

The major limitation of the AFM remains its general inability to provide chemical information. Overney et al. simultaneously measured applied force, frictional force, and elasticity of mixed composition monolayers of behenic acid and partially fluorinated carboxylic acid ether (*C68*). They determined the film formation mechanism and cohesive energy by correlating force measurements of the different functionalities and the Young's moduli with the film preparation conditions (*C68*). Frisbie et al. also reported chemical differentiation using the AFM (C69). This technique makes use of a chemically functionalized AFM tip and is called chemical force microscopy. Using AFM tips functionalized with either hydrophilic groups or hydrophobic groups, Frisbie et al. imaged self-assembled microstructures made up of well-differentiated areas of hydrophilic- vs hydrophobic-terminated alkane chains. They demonstrated micrometer-scale resolution with the chemical force microscope. Contrast in these images was determined by the chemical interactions between the functionalized AFM tip and the sample. They also qualitatively measured the hydrophilic-hydrophilic, hydrophobic-hydrophobic, and hydrophilic-hydrophobic interactions. They observed, as expected, that the interactions between two polar molecules were stronger than the interactions between a polar and a nonpolar molecule, which were in turn stronger than the interactions between two nonpolar molecules.

Biggs and Mulvaney attached a Au-coated colloid particle to the cantilever tip to measure van der Waals forces between two Au surfaces (7C0). Biggs and Mulvaney also determined that the size of the AFM tip had a large effect on the measured force curves. In a related study, Biggs et al. investigated the effects of anion adsorption at the gold-water interface on the forces measured using the AFM (C71). The variations in the forcedistance profiles observed between the colloidal Au particle and a Au surface demonstrated the complexity of the forces involved (C71). In addition to the expected electrostatic forces, other unexplained short-range repulsions were observed at the Auwater interface in the presence of adsorbed anions (C71). Tsao et al. reported local measurements of long-range attractive forces between hydrophobic surfaces using the AFM (C72). They proposed a model based on correlated motion within and between domains, caused by the interaction between the two surfaces as they move together (C72). Larson et al. measured the forcedistance profiles between macroscopic TiO₂ surfaces as functions of pH and electrolyte concentration (C73). Larson et al. also determined that cluster size and shape influence the clustersubstrate interactions. Mahoney et al. combined AFM measurements and transmission electron microscopy to correlate cluster shape with cluster-substrate interactions (C74).

Another interesting application of the AFM has been the study of molecular ordering at the solid-liquid interface. O'Shea et al. showed that the AFM can be used for direct observations of the local compliance at the solid-liquid interface and measured solvation forces to several molecular diameters (*C75*).

The STM has dominated applications in semiconductors, primarily because of its high lateral resolution and ability to probe electronic properties. However, atomic resolution has recently been demonstrated in UHV with the AFM as well. Sugawara et al. reported atomic resolution images of GaAs{110} in UHV (*C76*). However, they did observe the degradation of the lattice, presumably due to the loading force during repeated imaging (*C76*). Giessibl achieved high-resolution noncontact AFM images of Si{111}-(7 × 7) in UHV (*C77*). Giessibl outlined several of the difficulties in achieving atomic resolution with the AFM and analyzed the sensitivity of the imaging forces to tip-sample separation.

Surface morphology has important effects on the optical, magnetic, and chemical properties of materials. For some applications such as surface-enhanced Raman spectroscopy (SERS), rough surfaces are desirable. In order to make microscopically rough surfaces, Ag films have been grown over polymer nanospheres. These surfaces exhibit SERS activity comparable to electrochemically etched surfaces (C78). However, Van Duyne et al. used the AFM to demonstrate that these Ag films grown on nanospheres did not have the roughness previously thought to be necessary for SERS (C78). They suggested that SERS enhancement may be due to random structures on individual particles rather than on overall surface roughness. In another study designed to relate the optical properties of Ag thin films to surface structure, Roark and Rowlen measured Ag island height, radius, and aspect ratio (C79). Experimental data showed that increased aspect ratio for Ag island growth shifted the optical spectrum (C79).

The AFM is also useful in studies of overlayers and multilayers. Chua et al. used the AFM to demonstrate that layers of InGaAs could be grown in excess of the critical thickness without strain relaxation (C80). In a study of epitaxial growth of Ag on mica, Baski and Fuchs used the AFM to image films grown at different temperatures and to different thicknesses in order to determine the appropriate conditions for growing a large variety of surface morphologies (C81). Shen et al. determined the effect of rapid thermal annealing on the surface morphology of garnet/Fe multilayers using AFM (C82).

Lui et al. elucidated a previously unidentified surface structure in SAMs of fluorinated alkanethiols on Au{111} by AFM imaging of both the overlayer and the underlying substrate (C83). The lattice spacings measured by AFM were very close to the expected value for a $p(2 \times 2)$ structure. However, when Lui et al. pushed aside the monolayer with the AFM tip and the underlying Au surface was imaged, it was found that the fluorinated alkanethiolate monolayer was rotated 30° with respect to the underlying Au lattice. They concluded that the molecules formed an incommensurate structure or one nearly commensurate to a $c(7 \times 7)$ structure.

Bourdieu et al. studied the effect of annealing on molecular positions in Langmuir-Blodgett (LB) films of barium arachidate (C84). They studied the surface morphology on two length scales (1.7 μ m and 20 nm) before and after annealing the films (C84). Before annealing, films were disordered, with hexagonal symmetry on the atomic scale. After annealing, films formed ordered multilayers. Films prepared with higher Ba concentrations were destroyed by the force of AFM imaging, indicating that higher concentrations of counterions weaken the cohesive interactions in LB films. In an extensive study, Schwartz et al. used the AFM to investigate the roles of cations, alkyl chain length, and substrate on molecular ordering of LB films (C85). Schwartz et al. also reported AFM observations of a new structure in LB multilayers (C86). Molecular resolution images showed previously unobserved structures for multilayers of barium arachidate and cadmium arachidate.

In an AFM investigation of the structure of model liquid crystal molecules, Maliszewskyj et al. imaged bilayer LB films of monomeric triphenylene mesogens (*C87*). Maliszewskyj et al. used the AFM to differentiate between the two molecular orientations in the liquid crystal. Chi et al. investigated small grains found in the liquid expanded phase of phase-separated LB films (*C88*). These fine structures within the liquid expanded phase were too small for conventional optical techniques to resolve. The AFM was used to compare the elastic properties of the liquid expanded phase. Differences in elasticity revealed the small grains to be of the same composition as the liquid condensed phase. Zhu et al. studied alignment of liquid crystals on rubbed polyimide films with the AFM (C89). The rubbed polyimide had scratches on its surface that oriented along the rubbing direction. Although the scratches were far too large to orient single molecules, aggregates of polymer molecules nonetheless align along the rubbing direction (C89).

Using the AFM, Porter examined the relationship between grain size and ordering of grains in evaporated films of polyaniline in order to understand the mechanism of electrical conductivity in these films (C90). The poor conductivity in polyaniline films may be linked to formation of small conducting polymer bundles separated by a poorly conducting matrix (C90). Yang et al. studied the evolution of films of ethylene-polyethylene copolymer on mica under propanol using AFM (C91). By imaging films at different stages of the concentration-dependent aggregation, Yang et al. analyzed the size distributions and morphology of copolymer aggregates as a function of surface coverage.

AFM has a clear advantage over the STM in the study of biological samples. Biological samples are generally insulating and are thus inaccessible to the STM. Lyubchenko et al. demonstrated a method for imaging DNA strands with the AFM after binding the DNA strands to mica (C92). Once the DNA was bound to the mica it could be imaged with nanometer-scale resolution by an AFM without being disturbed, even by repeated imaging. In biological applications, it is important to develop methods for imaging samples under physiological conditions. Lyubchenko et al. also established that DNA remains strongly bound in an aqueous environment. In order to demonstrate the suitability and resolution of the AFM for imaging biomolecules and their related proteins, Lal et al. imaged reconstituted biological channels in artificial bilayer films (C93). They found molecular resolution of polar head groups, and long-range order similar to that observed in LB films (C93). Many biochemical and biological processes involve changes in chemical conformation. Radmacher et al. reported observing enzyme activity with the AFM (C94). Radmacher et al. first imaged lysozyme molecules under a physiological buffer. After introducing the enzyme's substrate protein, oligoglycoside, the apparent size of the enzyme in AFM images changed by 1 nm. The change in apparent size was not observed in the presence of the enzyme inhibitor chitobiose (C94). This apparent change in size was attributed to enzymatic binding of an enzyme to its substrate protein.

Other Proximal Probes. STM and AFM are not the only proximal probe methods for surface analysis. In addition to tunneling current and force other control interactions can be used to generate contrast on the atomic or nanometer scale. In particular, many new methods combining optics with SPMs are currently under development.

The photon scanning tunneling microscope (PSTM) combines optical techniques with a conventional STM. In a typical PSTM experiment, the sample is illuminated from the back while the STM is used to observe optically excited changes in the sample. Sharp et al. have written an introduction to the basic concepts and capabilities of the PSTM (*C95*). Adam et al. have observed photoinduced surface plasmons with the PSTM, demonstrating that surface excitations can be studied with PSTM (*C96*).

Berndt et al. reported experiments that use the tip of a lowtemperature STM to induce photoemission from single molecules (C97). Using a tunneling bias voltage of -2.8 V, Berndt et al. were able to induce photoemission from individual C₆₀ molecules. The emission spot size was about 4 Å and corresponded to the positions of individual C₆₀ molecules. These results suggest that an optical spectroscopic analysis of individual molecules excited by the STM tip may be feasible.

Due to the long-range nature of magnetic forces, the magnetic force microscope (MFM) does not have the resolution required for atomic resolution imaging. In an experimental and mathematical investigation of the imaging process in MFM, Müller-Pfeiffer et al. outlined the resolution problems inherent in MFM (C98). Despite limitations in resolution, MFM remains useful in the study of surface magnetism. Barnes et al. reported experiments in which a MFM was used as a local probe of magnetic properties rather than as an imaging tool (C99). Barnes et al. observed a sudden increase in the magnetic force at a distance of 28 nm from the surface of Co-Pd multilayers which they attributed to domain wall motion (C99) as has previously been observed in MFM (C100).

Despite the promise of providing spectroscopic information with high spatial resolution, applications of near-field scanning optical microscopy (NSOM) remain limited. NSOM experiments by Trautman et al. showed differences in spectral shape and peak shifts for individual dve molecules which were attributed to variations in local chemical environment (C101). Hess et al. imaged luminescent centers from single quantum well structures at 2 K using a NSOM (C102). Temperature, magnetic field, and line widths established these photoluminescent centers as interface structures. Ambrose et al. also demonstrated the ability to detect fluorescence and photobleaching of single molecules using NSOM (C103). Ambrose et al. observed other reversible changes in fluorescence which were tentatively ascribed to reorientations of single molecules on the surface. In additional work, Ambrose et al. discussed the proximal effects of the NSOM probe tip on fluorescence lifetimes within one wavelength of the surface (C104). Due to constructive or destructive interference with reflections from the metallized probe tip, the fluorescence signal was enhanced or suppressed.

All current and a number of new proximal probe techniques are undergoing rapid development. As the capabilities of the many SPMs are expanded and better understood, the applications of these instruments in surface characterization will grow at an increasing rate.

OPTICAL CHARACTERIZATION OF SURFACES

Optical measurements have proved to be a valuable method of surface characterization. Raman scattering and infrared (IR) spectroscopy measurements of the vibrational modes have become the most used optical methods of characterizing surface properties. The application of these techniques to thin film and surface structures is often difficult because of sensitivity limitations of the techniques. Other techniques such as ellipsometry, reflectance difference spectroscopy, and nonlinear laser techniques are also finding application in the characterization of surfaces. Continued advancement of the optical measurements has been stimulated by the advantage of nondestructive and noncontact measurements, which are often relatively straightforward to interpret. This review will highlight some of the applications of these techniques. While disordered and microstructured surfaces are important for many applications, the fundamental processes are most often demonstrated at ordered surfaces; and as such, the structures at ordered surfaces will be emphasized.

In prior reviews, the application of Raman and IR spectroscopy to the characterization of diamond films, fullerene materials, and high-temperature superconducting materials has been noted, and these techniques continue to be critical in the evaluation of the materials and the growth processes. This review will highlight new developments of optical characterization methods in semiconductors, insulators, and molecular adsorbates. In some instances thin multilayered structures will be considered, and the optical characterization techniques can be used to measure the properties of near-surface interfaces.

Optical characterization of compound semiconductors continues as a critical area, particularly with the continued development of CVD-type deposition processes. Surface treatments have also been developed to passivate the surfaces. One approach to the surface passivation of InP and GaAs is to employ a chemical treatment with sulfur-containing solutions. The chemistry of the (NH₄)₂S-treated GaAs (100) surfaces was explored with reflectance anisotropy spectroscopy, and the results determined the orientation of the surface dimers (D1). IR measurements indicated that the treatments removed the native oxide, and different passivations were obtained from wet chemical exposure and anodic sulfidation in an electrochemical treatment (D2). The defect passivation of n-type (100) InP and GaAs was obtained from Raman scattering measurements that displayed the band-bending changes for the sulfide treatments (D3). The etching on GaAs with SiCL₄ was explored with Raman spectroscopy (D4). The results indicate that the surface damage ranges from 3-9 nm.

New developments of optical techniques have also affected the measurements of compound semiconductor surfaces. Sum frequency generation has been accomplished with the combination of a widely tunable IR free electron laser that is synchronized with a frequency-doubled mode-locked YAG laser (D5). The system was demonstrated for vibrational modes of adsorbates on GaAs. Reflectance-difference spectra was applied as an in situ probe of the (100) GaAs surface (D6). The surface exhibits a series of reconstructions related to growth conditions and surface stoichiometry, and the RDS technique has indicated the presence and orientation of dimer structures on the various surfaces. The RDS technique holds substantial promise as an in situ real-time control technique for CVD techniques. The reflectance anisotropy spectroscopy technique has demonstrated monolayer sensitivity as an in situ growth monitor in MBE of GaAs and several other compound semiconductors (D7). Photoreflectance techniques have been used to examine the properties of GaAs surfaces. The results have been applied to plasma-exposed surfaces (D8), and a two-laser technique has been developed to separate the bulk and surface contributions (D9).

To analyze the initial stages of epitaxial growth, it is necessary to examine aspects such as interface bonding, strain, and defect formation. Raman spectroscopy of InSe homo- and heteroepitaxy was used to determine the polytype of the grown layer (D10). Raman spectroscopy indicated intermixing for MOVPE growth of InP on GaAs (D11), and for InAs on AlSb, the intermixing depended on the interface structure (D12). For an AlAs interface, As interdiffusion and atomic relaxation was observed, while for the InSb interface, pseudomorphic growth was observed. For InAs on GaSb using migration-enhanced epitaxy techniques, it was possible to obtain interfaces with nearly pure In-Sb or GaAs bonding (D13). Electric field-induced Raman scattering is sensitive to the formation of defects at the surface (D14). The technique was employed to measure the defects on InSb, and it was found that the Fermi level was pinned for n-type material but not in p-type surfaces. The strain in the initial stages of growth of InAs quantum wells was studied by far-IR absorption (D15). The MOCVD growth of AlN films on GaAs was also probed with IR reflectance (D16), and Raman spectroscopy was employed to examine the growth of BaTiO₃ in (111) InSb substrates (D17).

The properties of thin superlattices can in essence be considered as surface properties. Optical probes are particularly suited to examining these artificially structured materials. For Raman scattering from superlattices, sharp features are observed in the low-frequency region that are attributed to zone folded superlattice phonons. In addition, it has recently been shown that the continuous emission background in the same spectral region is attributed to disorder-induced scattering (D18). Analysis of the spectral shape of the disorder-induced background can lead to a characterization of the interface roughness and the dimension of growth islands. Other investigators have examined the intensity of the folded peaks to relate to the interface roughness of the AlInP/GaAs superlattice (D19). The folded phonons for GaAs/ AlAs superlattices on (111), (211), and (311) directions have been examined, and the results are consistent with selection rules based on the respective lattice symmetries (D20). The superlattices will exhibit vibrational modes with eigenvectors localized at the planes of the interface atoms (D21). Raman scattering can be used to measure the planar vibrational modes, which can then be related to the interface structure. In some instances, the Raman active modes of the superlattice materials occur at the same frequency. It has been demonstrated that resonance Raman scattering can be used to emphasize the LO modes of the different constituents in InAs/AlSb quantum wells (D22). Resonance effects can be used in the measurement of both interface and confined optic modes in strained InAs/InP single quantum wells (D23). Raman spectroscopy can also be used to examine the intra-subband plasmons in two-dimensional systems. The technique has been employed to measure the dispersion relation of the twodimensional electron gas formed at a GaAs-AlGaAs interface (D24).

In the recent past, the characterization of Si was viewed as largely understood. With the advancement of MOS technology, the properties of Si surfaces have become a subject of intense research, and optical characterization will play an increasingly important role as wafer sizes (and costs) increase, and singlewafer processing equipment is developed and moved into manufacturing. Few optical techniques have demonstrated sensitivity to the clean surface, but spectroscopic ellipsometry and optical anisotropy measurements can be used in UHV to examine reconstructed Si and Ge surfaces (D25, D26). In addition, both Raman scattering and IR spectroscopy have been used to examine the vibrations of adsorbates on Si surfaces. The dipole interactions between the adsorbates can affect the spectroscopic character of the vibrational resonances. These aspects have been explored with ultrafast pump-probe laser measurements of the Si-H vibration of H/Si (111) (D27). IR spectroscopy has proved particularly useful for determination of the bonding arrangements for adsorbed H on Si. While the terrace structure is well established, new results indicate the presence of defects in the 1 \times 1 ideally terminated (111) surfaces (D28). The bonding of hydrogen on steps has been studied, and IR results indicate long regions of straight step edges (D29, D30). The IR results can also be used to identify the terrace sizes on the Si(111) surface (D31). Raman scattering has also now been employed to determine the Si-H stretching vibrations on stepped (111) surfaces. The results indicate a large relaxation of the step atoms (D32).

The surface structure after various processing and cleaning procedures can likewise be explored with optical characterization. We note that H bonding is difficult to observe with most electron spectroscopies, and the prevalence of this structure emphasizes the importance of the optical techniques. As such, attenuated total reflection (ATR) FT-IR was used to examine the Si(111) surface after NaOH etching. The results indicate that the surfaces remain largely covered with Si-H bonds (D33). In situ IR reflectivity measurements also indicated a sharpening of the Si-H adsorption peak when the surface is exposed to boiling H_2O (D34). The oxidation of Si(111) in water was explored with multiple internal reflection IR spectroscopy. The results indicate that the oxidation of Si-H bonding and the formation of silicon oxide are coupled processes (D35). A systematic study of the oxidation of hydrogenterminated Si(100) indicated that the Si-Si backbonding of the surface Si-H atoms is attacked by the exposure to oxygen (D36). An internal reflection cell with a thin crystalline Si layer was combined with a Ge crystal to allow observation of the Si-O vibrational frequencies that occur at less than 1500 cm⁻¹. The technique was applied to study the HF etching and UV-ozone processes used for cleaning Si surfaces (D37). The UV-ozone process proceeds at the expense of Si-H surface states. Similar IR studies have indicated that the oxidation is enhanced by deionized water rinsing and that the interstitial oxygen content in the near-surface region increases (D38). Two studies have noted that the Si-O related frequency of the initial oxidation of Si surfaces is affected by the presence of H on the surface (D39, D40). For annealing in a H environment, it was suggested that the observed frequency shift was due to the presence of H at and near the interface. Multiple internal reflection (MIR) IR spectroscopy has indicated the chemical path of the oxidation of H-terminated Si under UV exposure (D41). The strain of the surface Si layers during the oxidation process has been examined with optical second harmonic and sum frequency spectra. A resonance is observed at 3.3 eV that is related to the strain of a few monolayers of the Si surface (D42).

The IR techniques also hold the potential of in situ monitoring of the processes. Attenuated total reflection FT-IR has been to optimize room-temperature plasma cleaning of Si surfaces. The results demonstrate process conditions in which the native oxide is removed (D43). Raman scattering has also been used as on on-line probe of the subsurface hydrogen incorporation for plasma cleaning of Si. It was found that subsurface H incorporation was not detected for substrate temperatures greater than 450 °C, but significant H was found for Si surface temperatures at ~150 °C (D44). Chemomechanical polishing of Si is important for the preparation of the initial Si surface and for planarization steps. It was shown that planarization with a silica slurry results in a largely H-terminated surface (D45). Raman spectroscopy has been used to monitor the surface damage due to plasma etching with SF_6 . The results indicate that both kinetic (ion beam) and chemical effects contribute to the disordering mechanism (D46).

Optical characterization has proved useful in discerning growth processes for other systems. The CVD epitaxial growth of Si on doped Si substrates was monitored in situ with emission FT-IR (D47). The film thickness was determined at the growth temperature in real time. Differential reflectivity measurements were combined with angle-resolved UV photoemission spectroscopy to characterize the role of surface states in the initial stages of antimony on Si (100) surfaces (D48). In another study, the surface properties of the same materials were explored with spectroscopic ellipsometry and Raman scattering, and the results indicated that the system did not form an ordered monolayer on the Si surfaces (D49). Optical probes were used to examine the growth of silver or gold on Si surfaces (D50, D51), and the transition to metallic surfaces was observed. The initial stages of Mo deposition from the photodecomposition of Mo (CO)6 were studied with single external reflection IR spectroscopy, and the technique showed sensitivity to submonolayer coverages (D52). Raman spectroscopy has also been used to characterize the formation of tungsten silicide from the reaction of tungsten deposited on Si (D53). Films of (CaSr) F_2 were grown on Si and examined with transmission IR spectroscopy. The measurements were used to determine the composition of the very thin films (D54).

The growth of epitaxial Si and Ge by CVD involves the interaction of germanium-containing species with the substrate. Multiple internal reflection IR spectroscopy was used to examine the adsorption and decomposition of digermane on Ge substrates (D55) and hydrogen and silane on Si, Ge, and SiGe surfaces (D56). Raman scattering has proved very useful for the characterization of SiGe layers on Si. The typical backscatter geometry will only allow measurement of LO modes, but the development of micro-Raman spectroscopy from the edge has allowed measurement of transverse modes (D57). An alternative approach to characterizing the interface is by micro-Raman spectroscopy combined with an angle-lapped surface. The technique has been used to measure the stress at the interface of Ge grown on Si (D58). The relaxation of strain was observed for SiGe epitaxial layers grown on micrometer-sized mesa structures etched in Si (D59).

A critical aspect in the plasma CVD growth of diamond films is the role of O and H on the surface. With use of a natural diamond crystal internal reflection element, MIR IR spectroscopy was used to examine the surface bonding. The results explored the monohydride surface and the OH bonding (D60, D61).

Insulating materials have long proven difficult for surface characterization because electron probes are not routinely applicable. With continued advances in optical methods, there are now increasing studies of these surfaces. FT-IR spectroscopy has been used to examine the bonding of CO and CO₂ on NaCl surfaces (D62-D65). Similar measurements have been used for hydrogen adsorption (D66). Polarized IR spectra have been used to examine CO_2 adsorbed on MgO (D67), and IR reflection absorption spectroscopy was used to examine the surface interactions of metal-organics on magnesia surfaces (D68, D69). The adsorption and decomposition of formic acid on MgO was studied with IR-visible sum frequency generation. It was found that the formate species (HCOO) was adsorbed at room temperature (D70). Coherent anti-Stokes Raman spectroscopy was employed to study the vibrations of molecules adsorbed on the (0001) surface of ZnO (D71, D72). FT-IR spectroscopy revealed the

vibrational modes of *n*-pentane on alumina (0001) (*D73*), and the same technique was used to examine water adsorbed to Cr_2O_3 (*D74*). Micro-Raman spectroscopy was employed for depth profile measurements of proton exchange in LiNbO₃ (*D75*).

Self-assembled molecular structures may prove exceedingly important for a wide range of chemical applications. IR spectroscopy was used to examine the adsorption of *n*-alkanethiols on (111) and (100) surfaces of Au. The samples were prepared by both solution and UHV exposure. The results indicated that the monolayers exhibit trans orientation, and differences are observed in the two surfaces (D76). Polarization modulation FT-IR reflection absorption spectroscopy was used for in situ studies of octodecanethiol adsorbed on Au. The results indicated that an applied potential has an organizing effect (D77). IR reflectance of TTF-TCNQ on Au indicates the molecular structure and charge transfer (D78). Surface-enhanced Raman spectroscopy has also proved useful for characterizing self-assembled monolayers (D79, D80), and the surface-enhanced mechanism may also play a role in the application of the Raman microscope to image monoand multilayer films (D81). Self-assembled monolayers have been formed on Si substrates and examined with attenuated total reflection IR spectroscopy and other optical techniques (D82, D83).

IR reflection-absorption spectroscopy continues to be an important probe of molecular bonding on metal surfaces, and many studies have explored new configurations. Studies have displayed dipole-forbidden adsorbate transitions, and these have been analyzed theoretically (*D84*, *D85*). The adsorbate can also affect the broad-band IR reflectance of the metal, and this effect has been explored for O on Cu (100). The results are described in terms of conduction band scattering from disordered adsorbates (*D86*). The adsorption of CO on processed surfaces can also be used to explore the surface structure. For Ni films on Mo (110), IR reflection-adsorption spectroscopy of adsorbed CO is used to explore the surface phase transitions (*D87*). Other studies have used the same techniques to explore sulfur modified Mo(110) and mixed Co- and S-modified Mo (110) (*D88*, *D89*).

X-RAY TECHNIQUES

Appearance Potential Spectroscopy. Appearance potential spectroscopy (APS) has assumed importance as one of the surface analysis techniques (*E1*). It probes the unoccupied density of states (DOS) in the vicinity of the Fermi level, $E_{\rm F}$, and thus provides information similar to that obtained from Bremsstrahlung isochromat spectroscopy, inverse photoemission spectroscopy, and X-ray absorption spectroscopy. An important feature of APS is that it reveals information regarding the total DOS because electronic excitation does not obey selection rules.

Appearance potential spectroscopy measures the probability of excitation of core electrons of the sample atoms as a function of incident electron energy. The experiment consists of measuring the changes in total X-ray fluorescence or secondary electron yield by a potential modulation technique. When the incident electron energy equals the threshold of the excitation of a core level, both the incident and core electrons are implanted at $E_{\rm F}$. The excitation process will be followed by the filling of the core state. This is signaled by the appearance of a bump in the total X-ray or secondary electron yield. Because the matrix element governing the core hole production at threshold energies involves the very short range wave function of the initial core electron state, APS reveals a localized DOS. If soft X-rays are measured as a signal of the process, the technique is characterized as soft X-ray appearance potential spectroscopy (SXAPS). In case the Auger electrons are monitored, the method is termed Auger electron appearance potential spectroscopy (AEAPS). SXAPS and AEAPS are therefore supplementary techniques for surface analysis. In another modification of the technique, the current of the elastically reflected electrons is measured. At the threshold energy of core level excitation, the number of electrons that undergo inelastic scattering disappears from the measured current. This method is therefore called disappearance APS (DAPS). In SXAPS and AEAPS the intensity depends upon the fluorescence and Auger yields, respectively, which in turn depend on the type of electron shell, on the binding energy, and on the atomic environment. These methods give results based on the details of the relaxation mechanism, whereas DAPS is free of these complications.

Since the DOS above $E_{\rm F}$ correlates with the number and not with the energy of characteristic X-rays resulting from the filling of the core holes, APS does not require energy analysis of the products of the experiment. It is, therefore, termed as a nondispersive spectroscopy. This accounts for the extreme simplicity of the APS spectrometer. The peaks in the spectrum are specific to a single element. Since the projectile electron beam is monochromatic, the APS spectrum consists of relatively sharp lines. An important aspect of APS is that it reveals a localized DOS. The intensity of the signal depends on the density of conduction band states. If the DOS is low, the signal obtained in the spectrum will be poor. Therefore, APS cannot be effectively employed as a universal technique for surface analysis. Nevertheless, APS has the potential for providing interesting results that cannot be obtained from other techniques. Mainly three groups of elements provide a strong signal: 3d transition metals, alkaline earths, and rare earths. APS gives information regarding the elemental identification, chemical bonding, density of unoccupied states, near-neighbor configuration in the surface layer, and mechanism of excitation and transport processes occurring in the surface region of the sample.

The usefulness of APS to the investigation of rare earths has been reviewed by Chopra (*E2*). The magnetic phase transitions of 3d transition metals and 4f rare earths have been studied by Nolting et al. (*E3*). They used a generalized multiband model to describe the physical properties of these systems. The twoparticle spectral density is expressed in terms of one-particle spectral density using a diagrammatic vertex-correction method. They observe the spectral line shape to be dependent on temperature. Scheipers and Merz (*E4*) studied the oxygen K threshold in UHV-cleaved single crystal NiO (100) surface by SXAPS. Nitric oxide was found to be an intermediate valence system in which the charge-transfer gap is smaller than the Hubbard correlation energy. The comparison of the SXAPS spectra with X-ray absorption spectra showed the dominance of optically allowed channels.

Potthoff et al. (E5) investigated the correlations between the valence band and core electrons. The spectrum exhibits three different spectral features which are ascribed to effects of final-state correlations: the bandlike part of the spectrum corresponds to final states in which both valence band electrons are moving independently through the lattice. Strong correlations lead to two additional satellites. The first one is narrow and corresponds to two-electron bound states that are localized at the site where the

transition takes place. The second one has a width equal to the width of the free Bloch band and belongs to the final states in which one electron is localized in the core-hole potential while the other one is moving through the lattice. Ertl et al. (E6) studied the spin-dependent densities of empty electronic states in iron and nickel by spin-resolved SXAPS. They found good agreement with the model calculations using spin and angular momentumresolved densities with experimental data. Pavluch and Siezak (E7) investigated the information depth in 3d transition metals obtained from AEAPS and DAPS. Vasiliev and Martynyuk (E8) studied the Ba 3d threshold of the metal and the superconductor YBa₂Cu₃O_{7-x}. The features observed in the spectra are due to the surface electronic structure and are different from those originating at deeper atomic layers. Perez et al. (E9) studied the electronic structure of chemical vapor deposited diamond films using scanning tunnel microscopy. The surface density of states obtained from the I-V curves are compared with those obtained from SXAPS. Shinde and Padalia (E10) measured the Bremsstrahlung background in an APS spectrum as a function of the spectrometer parameters. Chourasia et al. (E11) studied the electronic structure of GdMn₂ using SXAPS. They found that the magnetic property of the intermetallic is related to the hybridization between the 5d states of Gd and 3d states of Mn.

Glancing-Angle X-ray Diffraction. The near-surface crystal structure of materials can be characterized by employing X-rays at grazing angle geometries. This enhances the surface sensitivity of materials under investigation. Glancing-angle X-ray diffraction thus differs from the conventional X-ray diffraction in that it provides information about crystallinity for materials at surfaces. It allows one to investigate the atomic position of adatoms and thin-film characterization. Cui has reviewed (*E12*) the application of this technique to the structural studies of surfaces, interfaces, and thin films. Boer and Hoogenhof (*E13*) have described the technique and showed its usefulness for thin-film analysis related to structural and chemical depth profile, crystallinity, composition, and nature of interfaces.

Crabb et al. (*E14*) studied the initial stages of oxidation of Ni– 20Cr at 700 °C. Day et al. (*E15*) used pulsed laser deposition to grow thin films of niobium diselenide and studied the crystallinity and stoichiometry by changing the deposition parameters. The influence of nitrogen ion implantation on the surface characteristics of AISI 316 stainless steel has been examined by Aggarwal et al. (*E16*). The crystal structures of TiBN and HfBN films formed by cosputtering from Ti, Hf, and BN targets were investigated by Friesen et al. (*E17*). The phase formation as a result of reactions between nickel silicides and Si ion beam mixing was studied by Zhu et al. (*E18*). The initial oxidation behavior of a pure Si₃N₄ in the temperature range of 1000–1450 °C was studied by Chen et al. (*E19*). They observed that the initial oxidation of Si₃N₄ is a diffusion-controlled process and the oxide is easier to devitrify as compared to single crystal Si.

Makino et al. (*E20*) studied the microstructure of titanium oxide films synthesized by the ion beam dynamic mixing method. They found that the crystallite size of the rutile phase increased with increase in the oxygen ion energy per Ti atom. Martinez et al. (*E21*) performed a series of experiments to characterize the epitaxial YSi_{2-x} films grown on Si(111), with thicknesses of 85–510 Å. They determined the mean film lattice constants and observed the strain along the basal plane to increase as a function of film thickness. The behavior of rare-gas atoms implanted in

by Sakamoto et al. (E22). A nondestructive study of the ion implantation affected zone in titanium nitride performed by Perry et al. (E23) showed that the implantation did not change the residual stress in the film. Setsuhara et al. (E24) studied the titanium aluminide thin films synthesized by ion beam-enhanced deposition. The diffraction patterns showed that the phase structure of Ti-Al films was determined by both the Ar ion energy and the Ar/(Ti + Al) transport ratio. Zhang et al. (E25) deposited tantalum nitride films on steel and silicon substrates by a dc triodesputtering ion plate method. The films were implanted with N⁺ and Ar⁺ ions. The results show a preferred orientation along the fcc TaN(111) plane, and a hexagonal phase appeared in the film. The interfaces in NiAl/n-GaAs, NiAl/Al/Ni/n-GaAs, and Ni/Al/ Ni/n-GaAs studied by Chen et al. (E26) were found to be planar between the contacts and GaAs. The structure and crystallite size in cubic boron nitride and metal boron nitride have been studied by Gissler (E27). Kuech et al. (E28) reviewed the influence of oxygen doping on the electronic and structural properties of semiconductors grown by a metalloorganic vapor-phase epitaxy technique. They observed that the incorporation of oxygen at the GaAs to Al_xGa_{1-x}As interface led to a modest increase in the average roughness of the heterointerface with changes in the interfacial structure. The preparation of nanometer-sized crystallites of Si by pulsed laser ablation supersonic expansion technique was studied by Werwa et al. (E29). van Brussel and Hosson (E30) described a novel technique to study the depth profiles of stresses and transformed phases in structures consisting of implanted materials.

stainless steel after Ar, Kr, and Xe ion irradiation was investigated

The structure of fcc crystalline and amorphous phases coexisting in Al–Mn alloys was examined by Takayama et al. (*E31*). The amorphous and fcc phases were found to homogeneously distributed in the sample. However, the amorphous phase increased while the fcc phase decreased with increasing manganese concentration. Wang et al. (*E32*) characterized the sputter deposited a-Si_xC_{1-x} alloys and found that the films annealed at temperatures of <850 °C remained amorphous. The mixing process in UHV-evaporated Fe₆₅Ni₃₅ multilayers and irradiated with 200 keV Kr ions was studied by Tosello et al. (*E33*). The study shows a partial bcc to fcc phase transformation even at the lowest irradiation dose.

Extended X-ray Absorption Fine Structure. X-ray absorption spectroscopy has developed into a technique of choice for determining critically important atomic-scale structural information in a variety of materials systems. These systems include not only those of traditional interest to condensed matter physicists and materials scientists but also mineral, catalytic, wet chemical, and biological systems. Its widespread use has been due to the feasibility of determining the atom species and number of the near-neighbor atoms of each atom species of interest.

The X-ray absorption cross section above the threshold for exciting a deeply bound core electron exhibits oscillations that are caused by interference between the outgoing electron wave and that portion of it scattered back by atoms which are neighbors of the excited atom. The character of the oscillations depends simply on the type and distribution of neighbors and can readily be analyzed to yield detailed structural information about the environment of the excited atom. Different portions of an X-ray absorption spectrum can be analyzed to yield complementary information. The oscillations that occur more than 50 eV above

the absorption edge are known as the extended X-ray absorption fine structure (EXAFS). These oscillations are dominated by electrons that scatter only once from a near-neighbor atom. The analysis of these oscillations yields the distribution of interatomic distances. The oscillations that occur within the first 50 eV from the edge have substantial contributions from multiple-scattering electron trajectories involving two or more neighboring atoms. These are referred to as the X-ray absorption near-edge structure (XANES). EXAFS has now emerged as a widely used technique for the investigation of local structure in materials where the popular techniques of X-ray diffraction (XRD) and neutron diffraction have failed. The short range of EXAFS allows structural information to be obtained from amorphous and dispersed materials that lack sufficient long-range order. Materials studied by EXAFS include heterogeneous catalysts, glasses, intermetallic alloys, polymers, proteins, catalysis, and metal sites in bioinorganic materials. EXAFS experiments are conducted in laboratories using Bremsstrahlung radiation from conventional or rotating anode X-ray tubes. The access to the very high flux beams of hard X-rays available at synchrotrons has extended the application of EXAFS to metastable systems and systems having a very low concentration of elements of interest. Several review articles on the experimentation and applications of EXAFS have been reported (E34).

Rehr et al. (E35) developed standards for EXAFS from molecules and solids. The standards are obtained from ab initio calculations which includes multiple scattering. The theoretical results are compared with the experimental results and are found to yield distances better than 0.02 Å and coordination numbers better than 20%. Tyson (E36) developed a relativistic model by using a complex energy-dependent exchange-correlation potential to account for the energy loss of the emitted photoelectron. The single scattering signal has been computed for Th, Pt, Eu, and Sr. Comparison of the relativistic scattering amplitudes with the Schroedinger curved-wave model reveals some deviations. Bauchspiess (E37) developed a curve-fitting program to provide an efficient data analysis for EXAFS. In this the emphasis has been placed on ease of use of the program and high flexibility with parameter input and fitting model. It is possible to fit several spectra simultaneously. This reduces the correlation among the fit parameters in cases where several spectra have one or more parameters in common.

Houde-Walter et al. (E38) determined the local environment of sodium in sodium silicate and aluminosilicate glasses. The firstshell distances between Na and oxygen were found in the range 2.30-2.32 Å. The coordination number of oxygen was observed to be 5, which got reduced in the presence of Al₂O₃. A study of the amorphous Fe₄₀Ni₄₀P₁₄B₆ and Co₇₀(Si,B)₂₃Mn₅(Fe,Mo)₂ alloys by Kizler (E39) suggested the segregation into microphases with different stoichiometric compounds. The first alloy contains microphases mainly of Ni and P and others mainly of Fe and B. The second alloy contains mainly the Co-Si and a Mn-Fe-M-B mixture in the remaining part of the microstructure. The coloration of amorphous tungsten trioxide in an acid aqueous solution has been studied by Kuzmin and Purans (E40). They found that the formation of W5+ colored centers is accompanied by the appearance of local deformation around them. A study of the amorphous Ni_xTi_{1-x} alloys (E41) showed that the short-range chemical order in these alloys is intermediate between that of a random alloy and that of an ordered crystalline alloy. Yao et al.

(*E42*) studied the liquid–glass transition in CdRb(NO₃)₃ and found that the Rb–O distance increases with decreasing temperature in spite of the volume contraction. Amorphous alloys formed by mechanical alloying of elemental Cu and Ti as well as mechanical grounding of intermetallic compound CuTi were investigated by Nakamura and Nagumo (*E43*). The two processes showed two different arrangements for Cu–Ti bonds. The mechanical grinding process exhibited the existence of an additional Cu–Ti bond.

The Ba and La structural environments in two-component and multicomponent fluorozirconate glasses was studied by Almeida et al. (E44). The Ba-F distances and Ba coordination numbers were about 2.7 Å and 7.2-7.4 in all glasses, respectively, similar to those in crystalline BaF2. The La-F distances and coordination numbers were about 2.43 Å and 9.6 in all glasses, respectively, similar to those in LaF3. The anisotropic local structure in amorphous Tb₂₆Fe₇₄ films deposited at different temperatures \geq 300 K exhibited (*E*45) anisotropic pair correlations in which like atomic pairs are favored inplane and unlike pairs are favored out of plane. Saiter et al. (E46) studied the short-range order around Ge atoms in Ge_zSb_zTe_(100-x-z) glasses in which x = 15 and z = 0.5, 3, and 5. The structural results show that Ge atoms are 4-fold coordinated by uniquely Te atoms at the distance 2.6 Å and that no Ge-Ge homopolar bonds and no Ge-Sb bonds exist in these glasses. The coordination of Te in $PbO-TiO_2-TeO_2$ glasses has been studied by Yamamoto et al. (E47). The Te coordination changed from trigonal bipyramid to trigonal pyramid with the addition of PbO. On addition of PbO, the observed decrease rate in TeO₄ is smaller than that in the Li_2O-TeO_2 glasses with Li_2O addition.

The application of EXAFS to the characterization of catalysts was reviewed (E48). Berry et al. (E49) studied the changes induced in the local environments of Ce and Er in rare-earthexchanged Y-zeolites by dehydration and rehydration processes. The hydrated Ce ions were found to be located in the large spaces in the supercages of the zeolite framework. Treatment in vacuum at 300 °C induced limited dehydration. During the washing of the material in NH₄Cl, most of the Ce ions are removed from the zeolite supercages. The Er environment is also similarly affected in these processes. Caballero et al. (E50) studied the structural evolution of monometallic Pt/Al₂O₃ and bimetallic Pt-Re/Al₂O₃ catalysts. During the catalytic re-forming of n-heptane, the formation of Pt bonds to carbon species is observed. The bimetallic systems show significant differences with monometallic systems. In bimetallic systems, a reduction occurs in the temperature range over which Pt-C bonds are observed. The binary Cu/ZnO and ternary Cu/ZnO-Al₂O₃ catalysts of varying compositions on reduction with hydrogen at 523 K were investigated by Arunarkavalli et al. (E51). The presence of Cu microclusters and a species of Cu⁺ dissolved in ZnO is observed in addition to metallic Cu and Cu₂O. The proportions of different phases critically depend on the heating rate of the catalysts. Li et al. (E52) studied the zirconia polymorphs (monoclinic, orthorhombic, tetragonal, cubic) at 10 K. The tetragonal Zr cation network is nearly fcc and higher-order Zr-Zr coordinated shells up to 9 Å are observed. The Zr-O shell is bifurcated into two tetrahedra. In other structures, a similar Zr-O polyhedron with 7-fold coordination and a comparable bond length is observed. Capitan et al. (E53) investigated the oxidative dimerization of methane over samarium oxide supported on alumina as a function of the samarium loading and the calcination temperature. Sm ions

are found to be present at the catalyst surface. At higher loadings, crystalline phases containing Sm appear, their structure depending upon the calcination temperature. As the Sm loading is increased, two phases develop, depending on the calcination temperature. For the same Sm loading, the oxide-like structure shows better selectivity toward C₂ than the SmAlO₃ phase. Van Zon et al. (*E54*) characterized the metal-support interface in catalysts consisting of very small Ir clusters on the surface of MgO powder. The average Ir-Ir coordination in Ir₄/MgO is observed to be 2.6 neighbors at a distance of 2.72 Å. The average Ir-Ir coordination in Ir₆/MgO is 2.7 neighbors at a distance of 2.72 Å. The Ir-support interfaces in Ir₄/MgO and Ir₆/MgO were characterized by single Ir-Mg coordinations at 1.6 Å and 4-fold Ir-O coordinations at 2.6 Å.

Andrews et al. (E55) examined highly homogeneous nickel catalysts for an alkene dimerization catalyst prepared by the lowtemperature addition of AlEt₃ to Ni(h³-C₃H₅) (PPh₃)Br. The first coordination sphere around nickel comprised 3.9 carbon atoms at 1.93 Å and 1.0 phosphorus at 2.19 Å, with a more distant aluminum present at 3.21 Å. The results show that the Ni-Al interactions proceed via alkyl bridges in the predominant solution species during catalysis. The structure of Mo at the surface of a sulfated Fe₂O₃ and ferrihydrite catalysts was investigated by Zhao et al. (E56). The results show that Mo is surrounded by three to four oxygens at 1.73-1.75 Å with an extended coordination shell beyond the nearest oxygen shell. The changes in the structure of TiO2-supported molybdena induced by Na doping have been studied by Martin et al. (E57). Molybdenum is found in the octahedral coordination and the [MoO6] units join edges to form molybdenum rows that are similar to those found along the c-axis direction in bulk MoO3. The addition of Na changes the coordination of Mo⁶⁺ ions from octahedral to tetrahedral. The Mo-Mo bonds found in the Na-free sample are broken. At low Na content, isolated MoO42- units and poorly crystallined Mo2O72chains are formed. The fraction of Mo atoms in tetrahedral coordination increases with the increase in the amount of the Na dopant. Gloor and Prins (E58) determined the chemisorption of Cl on Rh/SiO₂ at temperatures 573 and 673 K. The Rh ion had slightly more than one Cl ligand. The Rh-O coordination number was higher after calcination at 673 K. Reduction at 673 K led to small Rh particles containing about 10 metal atoms. A Rh-Cl contribution at 2.25 Å showed that during the reduction at 673 K not all chlorine atoms had been removed and that the remaining Cl atoms were in contact with Rh atoms. The colloidal dispersions of polymer-protected Pt/Rh bimetallic cluster particles were studied by Harada et al. (E59). The colloidal particles were found to consist of an assembly of Pt/Rh bimetallic microclusters. These microclusters have a Pt core and modified Pt core structure of colloidal dispersions of 1:4 Pt/Rh, and 1:1 Pt/Rh bimetallic clusters, respectively.

The EXAFS technique provides advantages over traditional diffraction techniques in determination of the local structure of high-temperature superconductors (*E60*). Renevier et al. (*E61*) analyzed the local structure around the cobalt cations by substituting Co for Cu in YBa₂Cu₃O_{6+x}. The cobalt valence is 3+ in both oxidized and reduced forms. The cobalt cations are displaced from the (000) position and are surrounded by five oxygen atoms: four at 1.82 Å and one at 2.02 Å. The difference between these two sets of Co-O distances decreases for reduced compounds. The temperature dependence of the local structure in

superconducting and nonsuperconducting Ba₂CuTl₂O_y was investigated by Yamaguchi et al. (E62). The result indicates a splitting of Cu–O bond lengths in the CuO_2 plane. This splitting shows a strong temperature dependence over a wide temperature range well above $T_{\rm c}$. The magnitude of splitting abruptly decreases in the vicinity of $T_{\rm c}$. The nonsuperconductor samples did not show any such splitting. The local environment of different cations in the superconducting compounds $La_{2-x}(Ba,Sr)_xCuO_4$, with x = 0.15and 0.20 has been studied by Akhtar et al. (E63). The La-O bond length is found to be different from the Ba-O and Sr-O bond lengths. The bond lengths between the dopant and oxygen atoms vary with the concentration of the dopant. The Cu-O bond lengths depend upon doping La₂CuO₄ with Ba or Sr at La sites. Bridges et al. (E64) studied the zinc environment on copper sites in several samples of YBa₂Cu₃O₇. In many samples Zn resides in ZnO. One group of samples showed no evidence for ZnO-like precipitates indicating that, in this case, most of the Zn is in solution or in a YBCO-like environment. For this group, there are about five oxygen neighbors at 2.03 Å. Zn primarily occupies the Cu(2) plane sites.

The effects of oxygen partial pressure on the crystallization of amorphous Bi-Sr-Ca-Cu-O with and without the presence of Ag was studied by Kramer et al. (E65). In the as-quenched amorphous material, Cu is in a reduced state. Annealing the amorphous material in oxygen increases the oxidation state of Cu, leading to the formation of Bi₂Sr₂CaCu₂O₈ without additional oxygen diffusion. This relaxation of the glass is found to increase the crystallization temperature of the Bi-2201 to 500 °C. The crystallization sequence of Bi-2201 to Bi-2212 occurs at all partial pressures of ≥ 0.1 bar. The local disorder in the oxygen environment around praseodymium in $Y_{1-x}Pr_xBa_2Cu_3O_7$ with x = 0, 0.3,0.5, and 1 was investigated by Booth et al. (E66). Most of the Pr substitutes onto the Y site and is ordered with respect to the unit cell. The Y-O environment is little affected with Pr concentration. The Pr-O nearest-neighbor distance is 2.45 Å. A mixture of Pr³⁺ and Pr⁴⁺ bonds is observed.

The application of EXAFS in bioinorganic chemistry and metalloproteins was reviewed (E67, E68). The structure of the Fe sites of nitrogenase in dithionite-reduced and thionine-oxidized forms of the Mo-Fe and V-Fe proteins was investigated by Chen et al. (E69). The Fe-S and Fe-Fe bond lengths were determined to be 2.32 and 2.64 Å, respectively, in the diothionite-reduced Azotobacter vinelandii Mo-Fe protein. An additional Fe-Mo bond was found to be at 2.73 Å. The reduced A. vinelandii V-Fe protein showed a similar pattern of Fe interactions. In both Mo-Fe and V-Fe proteins, the first coordination sphere Fe-S distances contracted slightly upon thionine oxidation. True et al. (E70) studied the environment of iron in the purple acid phosphate from porcine uterus (uteroferrin). The study included the native reduced enzyme and the oxidized enzyme in its phosphate- and arsenate-bound forms. In all the three complexes, the first sphere consists of 1.5 N/O at 1.94 Å, 4 N/O at 2.1 Å, and 0.5-1 N/O at 2.4 Å. The second sphere in uteroferrin has an Fe-Fe bond length of 3.52 Å. Persson et al. (E71) investigated the solvates of copper(I) and copper(II) in acetonitrile, dimethyl sulfoxide (DMSO), pyridine, and tetrahydrothiophene solutions. The copper(I) solvates are in tetrahedral coordination with the bond distances Cu-N as 1.99 Å in acetonitrile, Cu-O as 2.09 Å in DMSO, Cu-N as 2.06 Å in pyridine, and Cu-S as 2.30 Å in tetrahydrothiophene. The copper(II) solvates are as Jahn-Teller

distorted octahedrons with the bond distances Cu–N as 1.99 Å in acetonitrile and Cu–O as 1.98 Å in DMSO. The local structure in nitrogenase Mo–Fe proteins was studied by Chen et al. (*E72*). The first shell distances were observed at 2.37, 2.70, 2.29, and 2.63 Å, respectively, for Mo–S, Mo–Fe, Fe–S, and Fe–Fe. In addition, the second shell was found to consist of Fe–Fe, Fe–S, and Mo–Fe neighbors at distances 3.8, 4.3, and 5.1 Å, respectively. In these proteins, Fe exists in both Fe²⁺ and Fe³⁺ states.

Teranishi et al. (E73) studied the chelate resin-Fe complex. The study indicated that the Fe(III) ion has the coordination number of six with one iminodiacetic acid moiety and three water molecules. In the case of the chelate resin-Fe(II) complex, the coordination number of Fe(II) ion is four. This suggested the coordination of Fe(II) to be four or five oxygen and/or nitrogen atoms including one or two iminodiacetic acid moieties and one water molecule. The chelate resin-Fe(II) complex was found to adsorb NO gas by coordination of NO to the vacant orbital of Fe(II) ions, resulting in the 5-coordinate structure. Bertini et al. (E74) studied the iron(II) catechol 2,3-dioxygenase in the native and the 2-chlorophenol forms. The Fe(II) environment consists of either six N/O atoms at an average distance of 2.05 Å or five N/O atoms at an average distance of 2.04 Å. The inhibited enzyme showed slight shortening of the average metal-donor bond distances. The structures of solvated complexes of Mn(II), Fe(II), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), and In(III) ions in 1,1,3,3-tetramethylurea were investigated by Inada et al. (E75). The solvation structures are square pyramidal for Mn(II) and Ni-(II) ions, distorted tetrahedral for the Co(II) and Cu(II) ions, tetrahedral for the Zn(II) ion, and octahedral for the Cd(II) and In(III) ions. The metal-oxygen bond lengths of the solvated metal ions are 2.09, 2.05, 2.00, 2.00, 1.92, 1.95, 2.28, and 2.13 for Mn(II), Fe(II), Co(II), Ni(II), Cu(II), Zn(II), Cd(II), and In(III) ions, respectively. These bond lengths are shorter than the corresponding metal(II) ions in water.

The applications of surface EXAFS (SEXAFS) for determining adatom-substrate distances, adsorption sites, and local structure at the interfaces were reviewed (E76, E77). Lederer et al. (E78) studied the chemisorption of oxygen on copper (100). Two different chemisorption sites are observed; one corresponds to a reconstructed surface and the other to an unreconstructed surface. The O-Cu bond length for the unreconstructed surface is 1.88 Å. Upon reconstruction, the O-Cu bond is shortened by 0.020 A. The bonding geometry of (1 monolayer Sb)/GaP(110) interface was investigated by Miyano et al. (E79). The results show that the Sb zigzag chains lie nearly parallel to the GaP surface. The Sb-P, Sb-Ga, and Sb-Sb bond lengths were 2.60, 2.79, and 2.88 Å, respectively. Kafader et al. (E80) investigated the epitaxial growth of a cubic Fe silicide phase on Si(111). The Fe atoms are coordinated with eight Si atoms with bond length of 2.38 Å and with six Fe atoms with bond length of 2.71 Å. The cubic iron silicide formed has a CsCl-type structure. Purdie et al. (E81) studied the structure of Si(100)2 \times 1–Cl by exposing the Si substrate to Cl₂ at 500 K to yield a coverage of 0.25 monolayer. The results indicate that Cl sits atop the upper Si atoms of a buckled dimer at a bond distance of 2.00 Å.

The atomic structure of ErSi_{2-x} (bulk and epitaxially grown on Si(111)) was studied by Tuilier et al. (*E82*). The shortest Er-Si bond length observed was 2.95 Å. The epitaxial film also yielded the same bond length, confirming the orthorhombichexagonal deformation of the AlB₂ structure. The effect of the strain due to the mismatch to the Si substrate was also observed. The two-dimensional Er silicide layer showed the strong anisotropy of Er environment for one monolayer Er coverage. The structure of Ge epitaxial overlayers on well-oriented Si (001) (Ge_n/ Si <001>, n < 7) was investigated by Oyanagi et al. (E83). For one monolayer (ML) Ge on Si, elongated Ge dimers with a local structure characteristic of s²p³ configuration were observed. For two ML Ge, half the atoms of Ge in the second layer are replaced with Si atoms in the third layer. This was observed to relieve elastic strain in the second layer caused by a large atomic size mismatch between the adatom and substrate atom. Heckmann et al. (E84) studied the Co/Cu(001) films and found that they have a face-centered tetragonal structure. The mean nearestneighbor distance parallel to the surface was observed to be 2.55 Å, and the interlayer bond length was 2.50 Å. The films formed a perfect epitaxy on Cu(001) with a contraction of the lattice parameter perpendicular to the surface of 4%. Yokoyama et al. (E85) analyzed the spectra of $c(2 \times 2)$ S/Ni(100) and $c(2 \times 2)$ S/ Ni(110) surfaces. From the S-Ni coordinations for the first and second layer Ni, they were able to observe noticeable thermal vibration and expansion of the surface S-Ni bonds. Significant differences between the two systems were also found in the vertical S-Ni bonds.

ACKNOWLEDGMENT

The authors thank D. L. Maggs for assistance in the preparation of the manuscript. J.H.F. and P.S.W. gratefully acknowledge the support of the National Science Foundation Chemistry and PYI Programs, and the Office of Naval Research. A.R.C. and D.R.C. acknowledge support from the Robert A. Welch Foundation, Grant T-0643.

Gary E. McGuire received his Ph.D. in inorganic chemistry from the University of Tennessee. He is presently the Director of the Materials Development and Device Technology Laboratory of MCNC in the Electronic Technologies Division. Active programs under his direction include field emitter devices, ferroelectric materials, materials characterization and display technologies. He is Editor of the Journal of Vacuum Science and Technology B and the Journal of Electron Spectroscopy and Related Phenomena, and Series Editor for Noyes Publication of the Materials Science and Process Technology Series.

Max L. Swanson was Research Professor (retired 1993) in the Department of Physics and Astronomy, University of North Carolina at Chapel Hill. He received his Ph.D. from the University of British Columbia in Vancouver, Canada, in 1958. He was employed by Carneig Institute of Technology, Pittsburgh, from 1958 to 1960, by Atomic Energy of Canada, Chalk River, from 1960 to 1986; and by UNC from 1986 to 1993. His research interests are defects and the physics of kinetic processes in metallic, semiconducting, and insulating materials. His research areas include doping, epitaxial regrowth, interface behavior, and point defects in Al, Cu, Zr, Ni, Si, Si/Ge, Hg-Cd-Te, silver halides, diamond, and SiO₂.

Nalin R. Parikh is Associate Research Professor of Physics and Astronomy and Adjunct Professor with the Applied Science Curriculum at the University of North Carolina at Chapel Hill. He received a Ph.D. in Metallurgy and Materials Science from McMaster University, Hamilton, Canada, in 1979. He joined UNC-CH August 1985 and since has expanded the ion beam characterization and modification of materials facilities. His research interests include implantation doping in semiconductors, and radiation damage and recovery of semiconductors; growing/etching of diamond films by the electron cyclotron resonance microwave chemical vapor deposition method; and developing microstructures from diamonds for microelectromechanical systems. He is currently President of the Materials Research Society—NC Section.

Steven J. Simko is a Staff Research Scientist at the General Motors, NAO Research and Development Center. He received a B.S. degree in chemistry from the University of Delaware in 1980 and his Ph.D. in analytical chemistry from the University of North Carolina—Chapel Hil in 1985 under the direction of Richard W. Linton. His research interests include characterization of insulating materials surfaces, ion—solid interactions, failure analysis, and characterization of electrical contacts. He serves as treasurer of the Michigan Chapter of the American Vacuum Society and is a member of the American Chemical Society and Sigma Xi. **Prof. Paul S. Weiss** is an Assistant Professor of Chemistry at The Pennsylvania State University, University Park, PA. He investigates the chemistry and physics of surfaces using scanning tunneling microscopy/ spectroscopy and other techniques.

James H. Ferris is finishing his doctoral degree in surface chemistry at The Pennsylvania State University, University Park, PA. He investi-gates adsorption and motion of atoms and molecules on metal surfaces using an ultrastable, low-temperature, UHV STM.

Robert J. Nemanich is Professor, Department of Physics and associate member of the Department of Materials Science and Engineering at North Carolina State University. He received a Ph.D. in physics from The University of Chicago in 1976. He joined the Xerox Palo Alto Research Center in 1986 and held positions of senior member of research staff and project leader. In 1986 he joined NCSU as an associate professor. His research interests include properties of thin films and thin-film interfaces of electronic materials. Particular emphasis has been on metal/ semiconductor interfaces (silicide/Si, M/SiGe, M/SiC and M/diamond). He is currently a member of the greating of the Division of He is currently a member of the executive committee of the Division of Materials Physics of the committee of the Materials Research Society.

D. R. Chopra received his M.S. in Physics from the University of Nebraska and Ph.D. in Physics from New Mexico State University. He is Professor of Physics at East Texas State University. His fields of research include surface physics, materials science, and chemical physics. He utilizes appearance potential, X-ray photoelectron, and soft X-ray spec-troscopies for the characterization of materials. He is a member of the American Physical Society, American Vacuum Society, and Society of Sigma Xi. He has received numerous professional citations including Distinguished Faculty Award (ETSU Faculty Senate), Distinguished Faculty Teaching Award (Texas Association of College Teachers) and Distinguished Scientist (Society of Sigma Xi).

A. R. Chourasia received his Ph.D. in Physics from Nagpur University, India, in 1986. At present, he is a Robert A. Welch Foundation Research Associate and Adjunct Assistant Professor at East Texas State University. Associate and Adjunct Assistant Professor at Last Texas State University. His fields of research are surface physics, materials science, and chemical physics. He utilizes appearance potential, X-ray photoelectron, and soft X-ray spectroscopies for the characterization of materials. He has utilized EXAFS for structural studies of intermetallics at Nagpur University. He is a member of the American Vacuum Society and Society of Sigma Xi. He has received a research award from the Society of Sigma Xi.

LITERATURE CITED

- Kane, P. F.; Larrabee, G. B. Anal. Chem. **1977**, 49, 221R-230R. Kane, P. F.; Larrabee, G. B. Anal. Chem. **1979**, 51, 308R-317R. Larrabee, G. B.; Shaffner, T. J. Anal. Chem. **1981**, 53, 163R- $\binom{2}{3}$
- 174R Bowling, R. A.; Larrabee, G. B. Anal. Chem. 1983, 55, 133R-(4)
- 156R. (5)

- 156R. Bowling, R. A.; Shaffner, T. J.; Larrabee, G. B. Anal. Chem. **1985**, 57, 130R-151R. McGuire, G. E. Anal. Chem. **1987**, 59, 294R-308R. Fulghum, J. E.; McGuire, G. E.; Musselman, I. H.; Nemanich, R J.; White, J. M.; Chopra, D. R.; Chourasia, A. R. Anal. Chem. **1989**, 61, 243R-269R. Ray, M. A.; McGuire, G. E.; Musselman, I. H.; Nemanich, R. J.; Chopra, D. R. Anal. Chem. **1991**, 63, 99R-118R. McGuire, G. E.; Ray, M. A.; Simko, S. J.; Perkins, F. K.; Brandow, S. L.; Dobisz, E. A.; Nemanich, R. J.; Chourasis, A. R.; Chopra, D. R. Anal. Chem. **1993**, 65, 311R-333R.
- (8)
- (9)

ION BEAM ANALYSIS

- (A4)
- (A5)
- (A6)
- (A7
- Nucl. Instrum. Methods Phys. Res. 1994, B92, 1-512.
 Nucl. Instrum. Methods Phys. Res. 1994, B91, 1-700.
 Nucl. Instrum. Methods Phys. Res. 1994, B90, 1-610.
 Nucl. Instrum. Methods Phys. Res. 1994, B87, 1-302.
 Nucl. Instrum. Methods Phys. Res. 1994, B85, 1-942.
 Nucl. Instrum. Methods Phys. Res. 1994, B85, 1-942.
 Nucl. Instrum. Methods Phys. Res. 1994, B85, 1-942.
 Nucl. Instrum. Methods Phys. Res. 1993, B80/B81, 3-1510.
 Nucl. Instrum. Methods Phys. Res. 1993, B79, 3-948.
 Brundle, C. R., Evans, C. A., Jr., Wilsons, S., Eds. Encyclopedia of Materials Characterization; Butterworth-Heinemann: Boston, 1992. (A9)
- (A10) Ding, P. J.; Talevi, R.; Lanford, W. A.; Hymes, S.; Muraka, S. P. Nucl. Instrum. Methods Phys. Res. 1994, B85, 167-170.
 (A11) Takai, M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 664-
- (A12)
- Churms, C. L.; Pretorius, R. Nucl. Instrum. Methods Phys. Res. 1994, B85, 699-702. Sayama, H.; Kimura, H.; Ohno, Y.; Sonoda, K.; Kotani, N.; Satoh, S.; Takai, M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 703-707. (A13)
- B85, 703-707.
 (A14) Knapp, J. A.; Banks, J. C.; Doyle, B. L. Nucl. Instrum. Methods Phys. Res. 1994, B85, 20-23.
 (A15) Liu, J. R.; Zheng, Z. S.; Zhang, Z. H.; Chu, W. K. Nucl. Instrum. Methods Phys. Res. 1994, B85, 51-54.
 (A16) Ishibashi, K.; Patnaik, B. K.; Parikh, N. R.; Tateno, H.; Hunn, J. D. MRS Fall 1994 Meeting, Symp. A, to be published.
 (A17) Kimura, K.; Ohtsuka, H.; Ohsihima, K.; Mannami, H.-h. Nucl. Instrum. Methods Phys. Res. 1994, B90, 227-230.

- (A18) Reeson, K. J.; Hunt, T. D.; Spraggs, R. S.; Gwilliam, R. M.; Sealy, B. J.; Meekison, C. D.; Booker, G. R. Nucl. Instrum. Methods Phys. Res. 1994, B84, 139-142.
 (A19) Frey, E. C.; Yu, N.; Patnaik, B.; Parikh, N. R.; Swanson, M. L.; Chu, W. K. J. Appl. Phys. 1993, 74, 4750-4755.
 (A20) Freire, F. L., Jr.; Franceschini, D. D.; Achete, C. A. Nucl. Instrum. Methods Phys. Res. 1994, B85, 268-271.
 (A21) Skorodumov, B. G.; Yatsevich, I. O.; Ulanov, V. G.; Zhukovska, E. V.; Zhukovsky, O. A. Nucl. Instrum. Methods Phys. Res. 1994, B85, 803-807.
 (A22) Assmann, W.; Huber, H.; Steinhausen, Ch.; Dobler, M.; Gluckeler, H.; Weidinger, A. Nucl. Instrum. Methods Phys. Res. 1994, B89, 131-139.
 (A23) Siegele, R.; Davies, J. A.; Forster, J. S.; Andrews, H. R. Nucl. Instrum. Methods Phys. Res. 1994, B82, 589-599.
 (A24) Martinsson, B. G.; Kristiansson, P. Nucl. Instrum. Methods Phys. Res. Res. 1993, B82, 589-599.
 (A25) Koltay, E. Nucl. Instrum. Methods Phys. Res. 1004

- Res. 1993. B82, 589-599.
 (A25) Koltay, E. Nucl. Instrum. Methods Phys. Res. 1994, B85, 75-848.
 (A26) Romo-Kroger, C. M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 845-848.
 (A27) Antolak, A. J.; Bench, G. S. Nucl. Instrum. Methods Phys. Res. 1994, B90, 596-601.
 (A28) Weber, G.; Robaye, G.; Braye, F.; Oudadesse, H.; Irigaray, J. L. Nucl. Instrum. Methods Phys. Res. 1994, B89, 200-203.
 (A29) Sellschop, J. P. F.; Connell, S. H. Nucl. Instrum. Methods Phys. Res. 1994, B85, 1019.
 (A30) Vickridge, I.; Tallon, J.; Presland, M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 28-99.
 (A31) Davies, J. A.; Almeida, F. J. D.; Haugen, H. K.; Siegele, R.; Forster, J. S.; Jackman, T. E. Nucl. Instrum. Methods Phys. Res. 1994, B85, 28-32.
 (A32) Turos, A.; Meyer, O.; Nowicki, L.; Remmel, J.; Wielunski, M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 28-32.
 (A34) Hartman, J. F.; Knox, J. M.; Vizkelethy, G. Nucl. Instrum. Methods Phys. Res. 1994, B85, 24-27.
 (A34) Blasser, S.; Steiger, J.; Weidinger, A. Nucl. Instrum. Methods Phys. Res. 1994, B85, 798-802.
 (A35) Latuszynski, A.; Maczka, D. Nucl. Instrum. Methods Phys. Res. 1994, B85, 78-832.
 (A36) Davis, J. C. Nucl. Instrum. Methods Phys. Res. 1994, B85, 770-774.
 (A39) McDaniel, F. D.; Anthony, J. M.; Kirchoff, J. F.; Marble, D. K.; Kim, Y. D.; Renfrow, S. N.; Grannan, E. C.; Reznik, E. R.; Vizkelethy, G.; Matteson, S. Nucl. Instrum. Methods Phys. Res. 1994, B89, 242-249.
 (A40) Dobeli, M.; Neiker, P. W.; Suter, M.; Synal, H. A.; Vetterli, D. Nucl. Instrum. Methods Phys. Res. 1994, B89, 242-249.
 (A41) Parikh, N. R.; Hunn, J. D.; McGucken, E.; Swanson, M. L.; Witke, C. W.; Zuhr, R. In Laser and Ion Beam Modification of Materials; Yamada, I., et al., Eds.; Elsevier Science B. V.: Amsterdam, 1994, pp 565-570.
 (A43) Breese, M. B. H.; King, P. J. C.; Whitehurst, J.; Booker, G. R.; Grime, G. W.; Watt, F.; Romano, L. T.; Parker, E. H. C. J.

- 70, 235-240.
 (A43) Breese, M. B. H.; King, P. J. C.; Whitehurst, J.; Booker, G. R.; Grime, G. W.; Watt, F.; Romano, L. T.; Parker, E. H. C. J. Appl. Phys. **1993**, 73, 2640-2653.
 (A44) Zimmerman, R. L.; Ila, D.; Kukhtarev, N.; Williams, E. K. Mater. Res. Soc. Symp. Proc. **1994**, 316, 667-671.
 (A45) Steele, B. E.; Cornelson, D. M.; Lian, Li.; Tsong, I. S. T. Nucl. Instrum. Methods Phys. Res. **1994**, B85, 414-419.
 (A46) Bergmans, R. H.; van de Grift, M.; van der Gon, A. W. D.; van Welzenis, R. G.; Brongersman, H. H.; Francis, S. M.; Bowker, M. Nucl. Instrum. Methods Phys. Res. **1994**, B85, 435-438.
 (A47) Malmqvist, K. G. Nucl. Instrum. Methods Phys. Res. **1994**, B85, 84-94.
- 34-94.

- 84-94.
 (A48) Maenhaut, W. Int. J. PIXE 1992, 2, 609.
 (A49) Martinsson, B. G.; Hansson, H.-C. Nucl. Instrum. Methods Phys. Res. 1988, B34, 203-208.
 (A50) Kristiansson, P.; Swietlicki, E. Nucl. Instrum. Methods Phys. Res. 1990, B49, 98-105.
 (A51) Yang, C.; Larsson, N. P.-O.; Swietlicki, E.; Malmqvist, K. G.; Jamieson, D. N.; Ryan, C. G. Nucl. Instrum. Methods Phys. Res. 1993, B77, 188-194.
 (A52) Broniatowski, A. Nucl. Instrum. Methods Phys. Res. 1994-400.
 (A53) Perrestal K.; Jonsson B.; Hallgren L.F. Nucl. Instrum. Methods
- (A53) Pernestal, K.; Jonsson, B.; Hallgren, J.-E. Nucl. Instrum. Methods Phys. Res. 1993, B75, 326-329.
 (A54) Watkinson, S. C.; Watt, F. Bryologist 1992, 95, 181.
 (A55) Pineda, C. A.; Peisach, M. Nucl. Instrum. Methods Phys. Res. 1994, B85, 896-900.
 (A56) Vourvopoulos, G. Nucl. Instrum. Methods Phys. Res. 1994, B89, 388-393.

ELECTRON SPECTROSCOPY

- (B1) Turner, N. H.; Schreifels, J. A. Anal. Chem. 1994, 66, 163R-185R.
- (B2) Seah, M. P.; Hunt, C. P.; Tosa, M. J. Electron Spectrosc. Relat. Phenom. 1993, 61, 149-171.
 (B3) Seah, M. P.; Hunt, C. P.; Sykes, D.; Valeri, S.; Muller, R.; Lamb, B. J. Electron Spectrosc. Relat. Phenom. 1993, 61, 173-182.

- (B4) Yoshihara, K.; Moon, D. W.; Fujita, D.; Kim, K. J.; Kajiwara, K. Surf. Interface Anal. 1993, 20, 1061-1066.
 (B5) Hofmann, S.; Zalar, A.; Cirlin, E. H.; Vajo, J. J.; Mathieu, H. J.; Panjan, P. Surf. Interface Anal. 1993, 20, 621-626.
 (B6) Surf. Sci. Spectra 1992-1994, 1, 2.
 (B7) Surf. Sci. Spectra 1994, 2(3).
 (B8) Mathieu, H. J. Analusis 1993, 21, M17-M19.
 (B9) Sherwood, P. M. A. Anal. Chim. Acta 1993, 283, 52-61.
 (B10) Brundle, C. R.; Fowler, D. E. Surf. Sci. Rep. 1993, 19, 143-168.

- (B10)

- (B11) Klissurski, D.; Rives, V. Appl. Catal., A 1994, 109, 1-44.
 (B12) Vedrine, J. C. In Catalyst Characterization; Imelik, B., Vedrine, J. C., Eds.; Plenum: New York, 1994; pp 467-496.
 (B13) Furlani, C. J. Electron Spectrosc. Relat. Phenom. 1994, 68, 569-
- (B14)
- 578.
 Eisen, M. S.; Marks, T. J. J. Mol. Catal. 1994, 86, 23-50.
 Hercules, D. M.; Houalla, M.; Proctor, A.; Fiedor, J. N. Anal. Chim. Acta 1993, 283, 42-51.
 Hattori, T. J. Vac. Sci. Technol. 1993, B11, 1528-1532.
 Cheung, R. Mater. Sci. Forum 1993, 140-142, 619-640.
 Schrott, A. G.; Frankel, G. S. IBM J. Res. Dev. 1993, 37, 191-206. (B15)
- (B17)
- (B18)
- Munro, H. S.; Singh, S. In *Polymer Characterisation*; Hunt, B. J., James, M. I., Eds.; Blackie: Glasgow, UK, 1993; pp 333-356. (B19)
- (B20) Comyn, J. Anal. Proc. 1993, 30, 27-28.
 (B21) Rouxhet, P. G.; Doren, A.; Dewez, J. L.; Heuschling, O. Prog. Org. Coat. 1993, 22, 327-344.
 (B22) Kang, E. T.; Neoh, K. G.; Tan, K. L. Adv. Polym. Sci. 1993, 106, 135-190.

- Wightman, J. P. NATO ASI Ser. E **1993**, 230, 259–285. Pantano, C. G. In *Experimental Techniques of Glass Science*; Simmons, C. J., El-Bayoumi, O. H., Eds.; American Ceramic Society: Westerville, OH, 1993; pp 129–160. Pulm, H.; Herberg, W. D. Fresenius J. Anal. Chem. **1993**, 346, (B24)
- (B25) 61 - 65
- (B26) Forsyth, N. M.; Coxon, P. Surf. Interface Anal. 1994, 21, 430-434.
- (B27)
- ⁴³⁴.
 ²Zupp, T. A.; Fulghum, J. E.; Surman, D. J. Surf. Interface Anal. **1994**, 21, 79-86.
 Jackson, S. T.; Short, R. D. Polym. Prepr. (Am. Chem. Soc., Div. Polym. Chem.) **1993**, 34, 813-814.
 Haak, L. P.; DeBolt, M. A.; Kaberline, S. L.; De Vries, J. E.; Dickie, R. A. Surf. Interface Anal. **1993**, 20, 115-120.
 Ajji, Z.; Buck, M.; Woell, C. Diamond Relat. Mater. **1993**, 2, 1525-1528. (B28)
- (B29)
- (B30) -152
- (B31) Robinson, K. S.; West, R. H.; Carrick, A. Polym. Prepr. (Am. Chem. Soc., Div. Polym. Chem.) 1993, 34, 82-83.
 (B32) Jenkins, S. N.; Castle, J. E. Surf. Interface Anal. 1993, 20, 935-
- 940
- (B33)
- Ratner, B. D. Cardiovasc. Pathol. 1993, 2, 875-100S. Ratner, B. D.; Tyler, B. J.; Chilkoti, A. Clin. Mater. 1993, 13, (B34) 71-84.
- (B35) Lin, J. C.
- Lin, J. C.; Cooper, S. L. Polymer Prepr. (Am. Chem. Soc., Div. Polym. Chem.) **1993**, 34, 659-660. Sutherland, D. S.; Forshaw, P. D.; Allen, G. C.; Brown, I. T.; Williams, K. R. Biomaterials **1993**, 14, 893-899. (B36) (B37) Tyler, B. J.; Ratner, B. D. J. Biomed. Mater. Res. 1993, 27,
- (B38) Lin, H. B.; Lewis, K. B.; Leach-Scampavia, D.; Ratner, B. D.; Cooper, S. L. J. Biomater. Sci., Polym. Ed. 1993, 4, 183–198.
 (B39) Rouxhet, P. G.; Mozes, N.; Dengis, P. B.; Dufrene, Y. F.; Gerin, P. A.; Genet, M. J. Colloids Surf., B 1994, 2, 347–369.
 (B40) Nordstroem, K. M.; Mozes, N. Colloids Surf., B 1994, 2, 67–

- 89-93
- 89-93.
 (B42) Faeldt, P.; Bergenstahl, B.; Carlsson, G. Food Struct. 1993, 12, 255-234.
 (B43) Cocke, D. L.; Vempati, R. K.; Loeppert, R. H. In Quantative Methods in Soil Mineralogy; Amonette, J. E., Zelazny, L. W., Eds.; Soil Sci. Soc. Am.: Madison, WI, 1994; pp 205-235.
 (B44) Tingle, T. N.; Borch, R. S.; Hochella, M. F., Jr.; Becker, C. H.; Walker, W. J. Appl. Surf. Sci. 1993, 72, 301-306.
 (B45) Qi, G. W.; Klauber, C.; Warren, L. J. Int. J. Miner. Process. 1993, 39, 251-273.
 (B46) Hitle L. R.; Sharkey A. G.; Houalla M.; Proctor, A.; Hercules.

- 1993, 39, 251-273.
 (B46) Hittle, L. R; Sharkey, A. G.; Houalla, M.; Proctor, A.; Hercules, D. M.; Morsi, B. I. Fuel 1993, 72, 771-773.
 (B47) Kelemen, S. R; Gorbaty, M. L.; Kwiatek, P. J. Energy Fuels 1994, 8, 896-906.
 (B48) Watts, J. F. Int. J. Adhes. Adhes. 1993, 13, 85-88.
 (B49) Chehimi, M. M.; Watts, J. F. J. Electron Spectrosc. Relat. Phenom. 1993, 63, 393-407.
 (B50) Morgner, H. J. Electron Spectrosc. Relat. Phenom. 1994, 68, 771-777.
- (B51) Baschenko, O. A.; Boekman, F.; Bohman, O.; Siegbahn, H. O. G. J. Electron Spectrosc. Relat. Phenom. 1993, 62, 317-334.
- (B52)
- (B53)
- G. J. Electron Spectrosc. Relat. Phenom. 1993, 62, 317–334. Janssen, E.; Goldmann, A. J. Electron Spectrosc. Relat. Phenom. 1993, 63, 327–340. Gergely, G. Vacuum 1994, 45, 311–313. Castle, J. E. Corrosion Control for Low-Cost Reliability, Proceedings—International Corrosion Congress, 12th; NACE: Houston, TX, 1993; Vol. 5B, pp 3982–3990. (B54)

- (B55) Bertolini, J. C.; Massardier, J. In Catalyst Characterization; Imelik, B., Vedrine, J. C., Eds.; Plenum: New York, 1994; pp 247-270.
- Weightman, P. J. Electron Spectrosc. Relat. Phenom. 1994, 68, (B56)
- (B57) Li, R. Nucl. Instrum. Methods Phys. Res., Sect. B 1993, 82, 283-290
- (B58) Hubbard, A. T.; Cao, E. Y.; Stern, D. A. Electrochim. Acta 1994, *39*, 1007–1014.
- (B59) Browning, R. Surf. Interface Anal. 1993, 20, 495-502.
 (B60) Boehmig, S. D.; Reichl, B. M. Fresenius J. Anal. Chem. 1993, 346, 223-226.

- 340, 223-226.
 (B61) Barkshire, I. R.; Prutton, M.; Greenwood, J. C.; El Gomati, M. M. Surf. Interface Anal. 1993, 20, 984-990.
 (B62) Barkshire, I. R.; Walton, J. M.; Prutton, M. Surf. Interface Anal. 1993, 20, 583-588.
 (B63) Kazmerski, L. L. Surf. Sci. Rep. 1993, 19, 169-189.
 (B64) Derrien, J.; Chevrier, J.; Le, T. V.; Berbezier, I.; Giannini, C.; Lagomarsino, S.; Grimaldi, M. G. Appl. Surf. Sci. 1993, 73, 90-101 -101.
- (B65) Manabe, Y.; Takahashi, R.; Shiibashi, T.; Yanagihara, K. Jpn. J. Appl. Phys., Part 1 1993, 32, 5765-5770.
 (B66) Palmer, W.; Mathuni, J. J. Vac. Sci. Technol., A 1994, 12, 12-
- Glaeser, W. A. In *Characterization of Tribological Material*; Glaeser, W. A., Ed.; Butterworth-Heinemann: Boston, MA, 1993; pp 65-79. (B67)
- Williamson, D. L. Nucl. Instrum. Methods Phys. Res., Sect. B 1993, B76, 262-267. (B68)
- (B69) Bunker, S. N.; Armini, A. J. J. Am. Ceram. Soc. 1993, 76, 347-349(B70) Honda, F.; Kometani, T.; Nakajima, K. Wear 1993, 161, 187-
- 191.
- (B71) Liu, G. H.; Robbevalloire, F.; Gras, R.; Blouet, J. Wear 1993, 160, 181-189.
 (B72) Singh, T.; Chandrasekharan, C. V. Tribol. Int. 1993, 26, 245-

- (B73) Han, X. A.; Qiong, L. Tribol. Trans. 1993, 36, 283-289.
 (B74) Jansson, C.; Nielsen, G. T.; Jakobsen, J.; Morgen, P. J. Vac. Sci. Technol., A 1993, 11, 183-194.
 (B75) Glaeser, W. A.; Baer, D.; Engelhardt, M. Wear 1993, 162-164, 132-138.

PROXIMAL PROBES

- (C1) McGuire, G. E.; Ray, M. A.; Simko, S. J.; Perkins, F. K.; Brandow, S. L.; Dobisz, E. A.; Nemanich, R. J.; Chourasia, A. R; Chopra, D. R. Anal. Chem. 1993, 65, 311R-333R.
 (C2) Proceedings of the 1993 International Conference on Scanning Tunneling Microscopy. J. Vac. Sci. Technol., A 1994, 12(3).
 (C3) Proceedings of the 1993 National Symposium of the American Vacuum Scienty. J. Vac. Sci. Technol., B 1994, 12(3).
 (C3) Proceedings of the 1993 National Symposium of the American Vacuum Scienty. J. Vac. Sci. Technol., B 1994, 12(3).
- Vacuum Society. J. Vac. Sci. Technol., B 1994, 12(3), (Parts 1 and 2)
- Vacuum Society. J. Vac. Sci. Technol., B 1994, 12(3), (Parts 1 and 2).
 (C4) Scanning Tunneling Microscopy I: General Principles and Applications to Clean and Adsorbate-Covered Surfaces; Wiesendanger, R., Güntherodt, H.-J., Eds.; Springer Series in Surface Sciences 21; Springer-Verlag: New York, 1992; Scanning Tunneling Microscopy II: Further Applications and Related Scanning Probe Techniques; Wiesendanger, R., Güntherodt, H.-J., Eds.; Springer Series in Surface Sciences 28; Springer-Verlag: New York, 1993; Scanning Tunneling Microscopy III: Theory of STM and Related Scanning Probe Techniques; Wiesendanger, R., Güntherodt, H.-J., Eds.; Springer Series in Surface Sciences 29; Springer-Verlag: New York, 1993; C50 Chen, C. J. Introduction to Scanning Tunneling Microscopy; Oxford Series in Optical and Imaging Sciences; Oxford University Press: New York, 1993.
 (C6) Scanning Tunneling Microscopy; Theory, Techniques, and Applications; Bonnell, D. A., Ed.; VCH: New York, 1993.
 (C7) Scanning Tunneling Microscopy: Theory, Techniques, and Applications; Bonnell, D. A., Ed.; VCH: New York, 1993.
 (C8) STM and SFM in Biology; Horton, O., Amrein, M., Eds.; Academic Press: San Diego, CA, 1993.
 (C9) DiNardo, N. J. Nanoscale Characterization of Surfaces and Interfaces; VCH: New York, 1993.
 (C10) Wiesendanger, R. Scanning Probe Microscopy and Spectroscopy, Methods and Applications; University Press: New York, 1994.
 (C10) Wiesendanger, R. Scanning Probe Microscopy and Spectroscopy, Methods and Applications; University Press: New York, 1994.
 (C11) Weiss, P. S. Trends Anal. Chem. 1994, 13, 61-67.

- (C12)
- (C13)
- C14)
- Weiss, P. S. Trends Anal. Chem. **1994**, 13, 61-67. Wiesendanger, R. J. Vac. Sci. Technol., B **1994**, 12, 515-529. Molotkov, S. N. Surf. Sci. **1993**, 287/288, 1098-1101. Louder, D. R.; Parkinson, B. A. Anal. Chem. **1994**, 66, 84R-(C15) 105**R**.
- (C16) Perry, S. S.; Somorjai, G. A. Anal. Chem. 1994, 66, 403A-415Á
- Crommie, M. F.; Lutz, C. P.; Eigler, D. M. Nature 1993, 363, 524-527. (C17)
- (C18) Hasegawa, Y.; Avouris, Ph. Phys. Rev. Lett. 1993, 71, 1071-1074
- (C19)
- Hasegawa, Y.; Avouris, Ph. Jpn. J. Appl. Phys., Part 1 1994, 33, 3675–3678. Crommie, M. F.; Lutz, C. P.; Eigler, D. M. Science 1993, 262, 218–220. (C20)

Analytical Chemistry, Vol. 67, No. 12, June 15, 1995 217R

- (C21) Heller, E. J.; Crommie, M. F.; Lutz, C. P.; Eigler, D. M. Nature 1994, 369, 464-466.
 (C22) Crommie, M. F.; Lutz, C. P.; Eigler, D. M. Phys. Rev. B 1993, 48, 2851-2854.
 (C23) Feenstra, R. M.; Stroscio, J. A.; Tersoff, J.; Fein, A. P. Phys. Rev. Lett. 1987, 58, 1192-1195.
 (C24) Zheng, Z. F.; Salmeron, M. B.; Weber, E. R. Appl. Phys. Lett. 1994, 64, 1836-1838.
 (C25) Ruan, L.; Besenbacher, F.; Stensgaard, I.; Lægsgaard, E. Phys. Rev. Lett. 1993, 70, 4079-4082.
 (C26) Schmidt, M.; Stadler, H.; Varga, P. Phys. Rev. Lett. 1993, 70, 1441-1444.
 (C27) Bourgoin, J.-P.; Johnson, M. B.; Michel, B. Appl. Phys. Lett.

- Bourgoin, J.-P.; Johnson, M. B.; Michel, B. Appl. Phys. Lett. 1994, 65, 2045–2047. Weiss, P. S.; Eigler, D. M. Phys. Rev. Lett. 1993, 71, 3139– (C27)
- (C28) 3142
- (C30) (C31)
- 3142.
 Sautet, P.; Bocquet, M.-L. Surf. Sci. 1994, 304, L445-L450.
 Hallmark, V. M.; Chiang, S. Surf. Sci. 1993, 286, 190-200.
 McIntyre, B. J.; Salmeron, M.; Somorjai, G. A. Science 1994, 265, 1415-1418.
 Sugimura, H.; Uchida, T.; Kitamura, N.; Masuhara, H. J. Vac. Sci. Technol., B 1994, 12, 2884-2888.
 Mo, Y. W. Science 1993, 261, 886-888.
 Bronikowski, M. J.; Wang, Y.; McEllistrem, M. T.; Chen, D.; Hamers, R. J. Surf. Sci. 1993, 298, 50-62.
 Wang, Y.; Bronikowski, M. J.; Hamers, R. J. Surf. Sci. 1994, 311, 64-100.
 Stensgaard, I.; Ruan, L.: Læegsaard, E.: Besenbacher, F. IFA (C32)
- (C33) (C34)
- (C35)

- (C35) Wang, Y.; Bronikowski, M. J.; Hamers, R. J. Surf. Sci. 1994, 311, 64-100.
 (C36) Stensgaard, I.; Ruan, L.; Læegsaard, E.; Besenbacher, F. IFA Prepr. 1994, 94/21.
 (C37) Stranick, S. J.; Parikh, A. N.; Tao, Y.-T.; Allara, D. L.; Weiss, P. S. J. Phys. Chem. 1994, 98, 7636-7646.
 (C38) Stranick, S. J.; Parikh, A. N.; Allara, D. L.; Weiss, P. S. J. Phys. Chem. 1994, 98, 11136-11142.
 (C39) Poirier, G. E.; Tarlov, M. J.; Rushmeier, H. E. Langmuir 1994, 10, 3383-3386.
 (C40) Dunphy, J. C.; Sautet, P.; Ogletree, D. F.; Salmeron, M. B. J. Vac. Sci. Technol., A 1993, 11, 2145-2152.
 (C41) Kitamura, N.; Lagally, M. G.; Webb, M. B. Phys. Rev. Lett. 1993, 71, 2082-2085.
 (C42) Weiss, S.; Ogletree, D. F.; Botkin, D.; Salmeron, M.; Chemla, D. S. Appl. Phys. Lett. 1993, 63, 2567-2569.
 (C43) Nunes, G. Jr; Freeman, M. R. Science 1993, 262, 1029-1032.
 (C44) Wang, X.-D.; Hashizume, T.; Shinohara, H.; Saito, Y.; Nishina, Y.; Sakurai, T. Phys. Rev. B 1993, 47, 15923-15930.
 (C54) Wolkow, R. A. Rev. Sci. Instrum. 1992, 63, 4049-4052. Bando, H.; Tokumoto, H.; Zettl, A.; Kajimura, K. Ultramicroscopy 1992, 42-44, 1627-1631. Wildöer, J. W. G.; van Roy, A. J. A.; van Kempen, H.; Harmans, C. J. P. M. Rev. Sci. Instrum. 1994, 65, 2849-2852. Horch, S.; Zeppenfeld, P.; David, R.; Comsa, G. Rev. Sci. Instrum. 1994, 65, 3204-3210. Stranick, S. J.; Kamna, M. M.; Weiss, P. S. Nev. Sci. Instrum. 1994, 65, 3211-3215.
 (C44) Stranick, S. L: Kamna, M. M.; Weiss, P. S. Science 1994, 266. 3211 - 3215
- Stranick, S. J.; Kamna, M. M.; Weiss, P. S. Science 1994, 266, 99-102. (C46)
- Zeppenfeld, P.; Horch, S.; Comsa, G. Phys. Rev. Lett. 1994, 73, 1259-1262. Horch, S.; Zeppenfeld, P.; Comsa, G. Appl. Phys. A 1995, 60, 147-153.
 Horch, S.; Zeppenfeld, P.; Comsa, G. Surf. Sci., in press. Stranick, S. J.; Weiss, P. S. J. Phys. Chem. 1994, 98, 1762-1264. (C47)
- (Č49)
- (C50) Mercer, T. W.; Carroll, D. L.; Liang, Y.; DiNardo, N. J.; Bonnell, D. A. J. Appl. Phys. 1994, 75, 8225-8227.
 (C51) Guckenberger, R.; Heim, M.; Cevc, G.; Knapp, H. F.; Wiegräbe, W.; Hillebrand, A. Science 1994, 266, 1538-1540.
 (C52) Hsiao, G. S.; Penner, R. M.; Kingsley, J. Appl. Phys. Lett. 1994, 64, 1350-1352.
 (C53) Kobarashi A. Corre, F. M.W.
- (C53)
- (C54) (C55)
- 64, 1350-1352.
 Kobayashi, A.; Grey, F.; Williams, R. S.; Aono, M. Science 1993, 259, 1724-1726.
 Salling, C. T.; Lagally, M. G. Science 1994, 265, 502-506.
 Kent, A. D.; Shaw, T. M.; von Molnár, S.; Awschalom, D. D. Science 1993, 262, 1249-1252.
 Sarid, D. Scanning Force Microscopy with Applications to Electric, Magnetic, and Atomic Forces; Oxford University: New York, 1994.
 Hartmann, U. Appl. Phys. A 1994, 59, 41-48.
 Giessibl, F. J. Jon. J. Appl. Phys., Part 1 1994, 33, 3726-3734.
 Lal, R.; John, S. A. Am. J. Physiol. 1994, 266, C1-C21 (Cell Physiol, 35).
 Ohnesorge, F.; Binnig, G. Science 1993. 260, 1451-1456. (C56)
- C58)
- (Č59)
- Chnesorge, F.; Binnig, G. Science **1993**, 260, 1451-1456. Tang, H.; Joachim, C.; Devillers, J. Surf. Sci. **1993**, 291, 439-(C60) (C61)
- (C62)
- (C63)
- (Č64)
- Florin, E.-L.; Moy, V.; Gaub, H. Science **1994**, 264, 415-417. Lee, G. U.; Chrisey, L. A.; Colton, R. J. Science **1994**, 266, 771-773. (C65) (C66)
- Overney, R. M.; Takano, H.; Fujihira, M. Phys. Rev. Lett. 1994, 72, 3546-3549. (C67)
- (C68) Overney, R. M.; Meyer, E.; Frommer, J.; Güntherodt, H.-J. Langmuir 1994, 10, 1281–1286.
 (C69) Frisbie, C. D.; Rozsnyai, L. F.; Noy, A.; Wrighton, M. S.; Lieber, C. M. Science 1994, 265, 2071–2074.
 (C70) Biggs, S.; Mulvaney, P. J. Chem. Phys. 1994, 100, 8501–8505.

- (C71) Biggs, S.; Mulvaney, P.; Zukoski, C. F.; Grieser, F. J. Am. Chem. Soc. 1994, 116, 9150-9157.
 (C72) Tsao, Y.-H.; Evans, D. F.; Wennerström, H. Science 1993, 262, 547-550.

- (C73) Larson, I.; Drummond, C. J.; Chan, D. Y. C.; Grieser, F. J. Am. Chem. Soc. 1993, 115, 11885-11890.
 (C74) Mahoney, W.; Schaefer, D. M.; Patil, A.; Andres, R. P.; Reifenberger, R. Surf. Sci. 1994, 316, 383-390.
 (C75) O'Shea, S. J.; Welland, M. E.; Pethica, J. B. Chem. Phys. Lett. 1994, 223, 336-340.
 (C76) Sugawara, Y.; Ohta, M.; Hontani, K.; Morita, S.; Osaka, F.; Ohkouchi, S.; Suzuki, M.; Nagaoka, H.; Mishima, S.; Okada, T. Jpn. J. Appl. Phys., Part 1 1994, 33, 739-3742.
 (C77) Giessibl, F. J. Science 1995, 267, 68-71.
 (C78) Van Duyne, R. P.; Hulteen, J. C.; Treichel, D. A. J. Chem. Phys. 1993, 99, 2101-2115.
 (C79) Roark, S. E.; Rowlen, K. L. Chem. Phys. Lett. 1993, 212, 50-56.

- (C80) Chua, C. L.; Hsu, W. Y.; Lin, C. H.; Christenson, G.; Lo, Y. H. *Appl. Phys. Lett.* **1994**, *64*, 3640-3642.
 (C81) Baski, A. A.; Fuchs, H. *Surf. Sci.* **1994**, *313*, 275-288.
 (C82) Shen, J. X.; Wierman, K. W.; Zhang, Y. B.; Kirby, R. D.; Woollam, J. A.; Sellmyer, D. J. J. Appl. Phys. **1994**, *75*, 6670-672
- 6672Liu, G.-Y.; Fenter, P.; Chidsey, C. E. D.; Ogletree, D. F.; Eisenberger, P.; Salmeron, M. J. Chem. Phys. **1994**, 101, 4301-4306. (C83)
- (C84) Bourdieu, L.; Ronsin, O.; Chatenay, D. Science 1993, 259, 798-801.

- (C84) Bourdieu, L.; Ronsin, O.; Chatenay, D. Science 1993, 259, 798-801.
 (C85) Schwartz, D. K.; Viswanathan, R.; Garnaes, J.; Zasadzinski, J. A. J. Am. Chem. Soc. 1993, 115, 7374-7380.
 (C86) Schwartz, D. K.; Viswanathan, R.; Zasadzinski, J. A. N. Phys. Rev. Lett. 1993, 70, 1267-1270.
 (C87) Maliszewskyj, N. C.; Heiney, P. A.; Josefowicz, J. Y.; McCauley, J. P., Jr.; Smith, A. B., III Science 1994, 264, 77-79.
 (C88) Chi, L. F.; Anders, M.; Fuchs, H.; Johnston, R. R.; Ringsdorf, H. Science 1993, 259, 213-216.
 (C89) Zhu, Y.-M.; Wang, L.; Lu, Z.-H.; Wei, Y.; Chen, X. X.; Tang, J. H. Appl. Phys. Lett. 1994, 65, 49-51.
 (C90) Porter, T. L. Surf. Sci. 1993, 293, 81-85.
 (C91) Yang, J.; Laurion, T.; Jao, T.-C.; Fendler, J. H. J. Phys. Chem. 1994, 98 9391-9395.
 (C92) Lyubchenko, Y.; Shlyakhtenko, L.; Harrington, R.; Oden, P.; Lindsay, S. Proc. Natl. Acad. Sci. U.S.A. 1993, 90, 2137-2140.
 (C93) Lal, R.; Kim, H.; Garavito, R. M.; Arnsdorf, M. F. Am. J. Physiol. 1993, 265, C851-C856 (Cell Physiol. 34).
 (C94) Radmacher, M.; Fritz, M.; Hansma, H. G.; Hansma, P. K. Science 1994, 265, 1577-1579.
 (C95) Sharp, S. L.; Warmack, R. J.; Goudonnet, J. P.; Lee, I.; Ferrell, T. L. Acc. Chem. Res. 1993, 26, 377-382.
 (C96) Adam, P. M.; Salomon, L.; de Fornel, F.; Goudonnet, J. P. Phys. Rev. B 1993, 48, 2680-2683.
 (C97) Berndt, R.; Gaisch, R.; Gimzewski, J. K.; Reihl, B.; Schlittler, R. Schneider W. D.: Tschudy W. Science 1993, 262 Berndt, R.; Gaisch, R.; Gimzewski, J. K.; Reihl, B.; Schlittler, R. R.; Schneider, W. D.; Tschudy, M. Science 1993, 262, (C97)
- 1425 1427
- (C98) Müller-Pfeiffer, S.; Schneider, M.; Zinn, W. Phys. Rev. B 1994, 49, 15745-15752. (C99) Barnes, J. R.; O'Shea, S. J.; Welland, M. E. J. Appl. Phys. 1994,

- (C99) Barnes, J. R.; O'Shea, S. J.; Welland, M. E. J. Appl. Phys. 1994, 76, 418-423.
 (C100) Mamin, H. J.; Rugar, D.; Stern, J. E.; Fontana, R. E., Jr.; Kasiraj, P. Appl. Phys. Lett. 1989, 55, 318-320.
 (C101) Trautman, J. K.; Macklin, J. J.; Brus, L. E.; Betzig, E. Nature 1994, 369, 40-42.
 (C102) Hess, H. F.; Betzig, E.; Harris, T. D.; Pfeiffer, L. N.; West, K. W. Science 1994, 264, 1740-1745.
 (C103) Ambrose, W. P.; Goodwin, P. M.; Martin, J. C.; Keller, R. A. Phys. Rev. Lett. 1994, 72, 160-163.
 (C104) Ambrose, W. P.; Goodwin, P. M.; Martin, J. C.; Keller, R. A. Science 1994, 265, 364-367.

OPTICAL CHARACTERIZATION OF SURFACES

- (D1) Berkovits, V. L.; Paget, D. Appl. Surf. Sci. 1993, 65-66, 607-613.
- (D2) Yota, J.; Borrows, V. A. J. Vac. Sci. Technol. 1993, A11, 1083-1088.
- (D3) Chen, X.; Si, X.; Malhotra, V. J. Electrochem. Soc. 1993, 140, 2085-2088.
- Murad, S. K.; Wilkinson, C. D. W.; Wang, P. D.; Parkes, W.; Sotomayor-Torres, C. M.; Cameron, N. J. Vac. Sci. Technol. 1993, B11, 2237-2243. (D4)
- (D5) Peremans, A.; Guyot-Sionnest, P.; Tadjeddine, A.; Glotin, F.; Ortega, J. M.; Prazeres, R. Nucl. Instrum. Methods Phys. Res. 1993, A331, 28-29.
 (D6) Kamiya, I.; Aspnes, D. E.; Florez, L. T.; Harbison, J. P. Phys. Rev. B: Condensed Matter 1992, 46, 15894-15904.
 (D7) Richter, W. Philos. Trans. R. Soc. London 1993, 344, 453-457

- Sydor, M.; Engholm, J. R.; Dale, D. A.; Fergestad, T. J. Phy. Rev. B: Condens. Matter **1994**, 49, 7306–7312. Wang, Z.; Pan, S.; Huang, S.; Zhang, C.; Mu, S.; Zhou, X.; Jian, J.; Xu, G.; Chen, Z. J. Phys. D: Appl. Phys. **1993**, 26, 1493– (D8)
- (D9) 1498
- (D10) Brahim, O. L.; Emery, J. Y.; Jouanne, M.; Balkanski, M. Appl. Surf. Sci. 1993, 65-66, 479-481.

- (D11) Geurts, J.; Finders, J.; Muender, H.; Lueth, H.; Bickmann, K.; Hauck, J.; Brauers, A.; Leiber, J. Surf. Sci. 1992, 269–270, 529–532.

- (D12) Spitzer, J.; Fuchs, H. D.; Etchegoin, P.; Ilg, M.; Cardona, M.; Brar, B.; Kroemer, H. Appl. Phys. Lett. 1993, 62, 2274-2276.
 (D13) Bennett, B. R.; Shanabrook, B. V.; Wagner, R. J.; Davis, J. L.; Waterman, J. R. Appl. Phys. Lett. 1993, 63, 949-951.
 (D14) Wagner, J.; Alvarez, A. L.; Schmitz, J.; Ralston, J. D.; Koidl, P. Appl. Phys. Lett. 1993, 63, 349-351.
 (D15) Yang, M. J.; Wagner, R. J.; Shanabrook, B. V.; Moore, W. J.; Waterman, J. R. Xang, C. H.; Fatami, M. Appl. Phys. Lett. 1993, 63, 3434-3436.
 (D16) MacMillan, M. F.; Devaty, R. P.; Choyke, W. J. Appl. Phys. Lett. 1993, 62, 750-752.
 (D17) Kim, T. W.; Jung, J.; Kim, H. J.; Yoon, Y. S.; Kang, W. N.; Yom, S. S. Appl. Phys. Lett. 1993, 62, 1788-1790.
 (D18) Ruf, T.; Spitzer, J.; Sapega, V. F.; Belitsky, V. I.; Cardona, M.; Ploog, K. Phys. Rev. B: Condens. Matter 1994, 50, 1792-1806.
 (D19) Johnson, F. G.; Wicks, G. W. Appl. Phys. Lett. 1993, 63, 2402-2404.

- 404
- (D20) (D21)
- (D22)
- (D23)
- (D24)
- 2404. Spitzer, J.; Popovic, Z. V.; Ruf, T.; Cardona, M.; Notzel, R.; Ploog, K. Solid State Electron. 1994, 37, 753-756. Shanabrook, B. V.; Bennett, B. R. Phys. Rev. B: Condensed Matter 1994, 50, 1695-1700. Wagner, J.; Schmitz, J.; Ralston, J. D.; Koidl, P. Appl. Phys. Lett. 1994, 64, 82-84. Tran, C. A.; Brebner, J. L.; Leonelli, R.; Jouanne, M.; Masut, R. A. Phys. Rev. B: Condens. Matter 1994, 49, 11268-11271. Suilleabhain, L. C. O.; Hughes, H. P.; Churchill, A. C.; Ritchie, D. A.; Grimshaw, M.; Jones, G. A. C. Solid State Commun. 1993, 87, 517-521. Kelly, M. K.; Zollher, S.; Cardona, M. Surf, Sci. 1993, 285. 1993, 87, 517–521. Kelly, M. K.; Zollner, S.; Cardona, M. Surf. Sci. 1993, 285, 282–294. (D25)
- (D26)
- 222-294.
 Wormeester, H.; Wentink, D. J.; de Boeij, P. L.; van Silfhout, A. *Thin Solid Films* **1993**, 233, 14-18.
 Kuhnke, K.; Harris, A. L.; Chabal, Y. J.; Jakob, P.; Morin, M. *J. Chem. Phys.* **1994**, 100, 6896-6906.
 Jakob, P.; Chabal, Y. J.; Raghavachari, K.: Dumas, P.; Christman, S. B. *Surf. Sci.* **1993**, 285, 251-258.
 Fujita, K.; Hirashita, N. *Ipn. J. Appl. Phys.* **1994**, 33, 399-403. (D27)
- (D28)
- (D29)
- Auge, R., Finashid, H. Jp., J. Appl. 1992, 1034, 60, 603 403.
 Jakob, P.; Chabal, Y. J.; Kuhnke, K.; Christman, S. B. Surf. Sci. 1994, 302, 49-56.
 Jakob, P.; Chabal, Y. J.; Raghavachari, K.; Christman, S. B. Phys. Rev. B: Condens. Matter 1993, 47, 6839-6842.
 Hines, M. A.; Chabal, Y. J.; Harris, T. D.; Harris, A. L. Phys. Rev. Lett. 1993, 71, 2280-2283.
 Rappich, J.; Lewerenz, H. J.; Gerischer, H. J. Electrochem. Soc. 1993, 140, L187-L189.
 Nishida, M.; Okuyama, M.; Hamakawa, Y. Appl. Surf. Sci. 1994, 79-80, 409-415.
 Boonekamp, E. P.; Kelly, J. J.; van de Ven, J.; Sondag, A. H. M. J. Appl. Phys. 1994, 75, 8121-8127.
 Niwano, M.; Kageyama, J.-i.; Kinashi, K.; Sawshata, J.; Miyamoto, N. Surf. Sci. 1994, 301, L245-L249.
 Zazzera, L.; Evans, J. F. J. Vac. Sci. Technol., A 1993, 11, 934-939. (D30)
- (D31)
- (D32)
- (D33)
- (D34)
- (D35)
- (D36) (D37)
- 939.
- (D38) Ling, L.; Kuwabara, S.; Abe, T.; Shimura, F. J. Appl. Phys. 1993, 73, 3018-3022.
 (D39) Shirai, H. Jpn. J. Appl. Phys., Part 2 1994, 33, 94-97.
 (D40) Zhong, L.; Ling, L.; Shimura, F. Appl. Phys. Lett. 1993, 63, 99-101.
 (D41) Lingger, C. Daharaha, C. Phys. Rev. B.; Candum. Matture

- (D41) Licoppe, C.; Debauche, C. Phys. Rev. B.: Condens. Matter 1993, 47, 4327-4336.
 (D42) Daum, W.; Krause, H. J.; Reichel, U.; Ibach, H. Phys. Rev. Lett. 1993, 71, 1234-1237.
 (D43) Zhou, Z. H.; Aydil, E. S.; Gottscho, R. A.; Chabal, Y. J.; Reif, R. J. Electrochem. Soc. 1993, 140, 3316-3321.
 (D44) Schneider, T. P.; Montgomery, J. S.; Ying, H.; Barnak, J. P.; Chen, Y. L.; Maher, D. M.; Nemanich, R. J. Proc. -Electrochem. Soc. 1994, 94-97 (Proc. of the Third International Sym. on Cleaning Tech. in Semiconductor Device Manufacturing, 1993), 329-338.
 (D45) Pietsch, G. J.; Higashi, G. S.: Chabal, V. J. Anal. Proc. Y. L.
- 1993), 329-338.
 (D45) Pietsch, G. J.; Higashi, G. S.; Chabal, Y. J. Appl. Phys. Lett. 1994, 64, 3115-3117.
 (D46) Brault, P.; Mathias, J.; Laure, C.; Ranson, P.; Texier, O. J. Phys.: Condens. Matter. 1994, 6, L1-L6.
 (D47) Zhou, Z. H.; Yang, I.; Kim, H.; Reif, R. J. Vac. Sci. Technol., A 1994, 12, 1938-1942.
 (D48) Cricenti, A.; Selci, S.; Felici, A. C.; Ferrari, L.; Contini, G.; Chiarotti, G. Phys. Rev. B: Condens. Matter 1993, 47, 15745-15749

- [5749*.*
- Rossow, U.; Frotscher, U.; Esser, N.; Resch, U.; Mueller, Th.; Richter, W.; Woolf, D. A.; Williams, R. H. Appl. Surf. Sci. 1993, 63, 35-39. (D49)
- 63, 35-39.
 (D50) Borensztein, Y.; Alameh, R.; Roy, M. Phys. Rev. B: Condens. Matter 1993, 48, 14737-14740.
 (D51) O'Mahony, J. D.; McGilp, J. F.; Verbruggen, M. H. W.; Flipse, C. F. J. Surf. Sci. 1993, 287-288, 713-717.
 (D52) Richter, L. J.; Buntin, S. A.; Chu, P. M.; Cavanagh, R. R. J. Chem. Phys. 1994, 100, 3187-3200.
 (D53) Vuppuladhadium, R.; Jackson, H. E.; Boyd, J. T. J. Appl. Phys. 1993, 73, 7887-7893.
 (D54) Zheng, W. Q.; Lopez-Rios, T.; Fontaine, C.; Munoz-Yague, A.; Julien, C. Thin Solid Films 1993, 223, 143-145.
 (D55) Lu, G.; Crowell, J. E. J. Chem. Phys. 1993, 98, 3415-3421.

- (D56) Wu, Y. M.; Baker, J.; Hamilton, P.; Nix, R. M. Surf. Sci. 1993, 295, 133-142.
- (D57) Schorer, R.; Abstreiter, G.; de Gironcoli, S.; Molinari, E.; Kibbel,

- (D57) Schorer, R.; Abstreiter, G.; de Gironcoli, S.; Molinari, E.; Kibbel, H.; Presting, H. Phys. Rev. B: Condens. Matter 1994, 49, 5406-5614.
 (D58) Ichimura, M.; Moriguchi, Y.; Usami, A.; Wada, T.; Wakahara, A.; Sasaki, A. J. Electron. Mater. 1993, 22, 779-784.
 (D59) Dietrich, B.; Bugiel, E.; Osten, H. J.; Zaumseil, P. J. Appl. Phys. 1993, 74, 7223-7227.
 (D60) Yang, Y. L.; Struck, L. M.; Sutcu, L. F.; D'Evelyn, M. P. Thin Solid Films 1993, 225, 203-211.
 (D61) Struck, L. M.; D'Evelyn, M. P. J. Vac. Sci. Technol., A 1993, 11, 1992-1997.
 (D62) Dai, D. J.; Ewing, G. E. Surf. Sci. 1994, 312, 239-249.
 (D63) Heidberg, J.; Suhren, M.; Weiss, H. J. Electron Spectrosc. Relat. Phenom. 1993, 64-65, 227-237.
 (D64) Heidberg, J.; Schmicker, D.; Toennies, J. P.; Vollmer, R.; Weiss, H. J. Electron Spectrosc. Relat. Phenom. 1993, 64-65, 341-350.
 (D65) Berg, O.; Disselkamp, R.; Ewing, G. E. Surf. Sci. 1992, 277.
- (D65) Berg, O.; Disselkamp, R.; Ewing, G. E. Surf. Sci. 1992, 277, 8-20.

- (D66) Dai, O., D. Schman, K. 2001, Sci. 2019, Sci. 2019, 8-20.
 (D66) Dai, D. J.; Ewing, G. E. J. Chem. Phys. 1993, 98, 5050-5058.
 (D67) Heidberg, J.; Meine, D. Surf. Sci. 1992, 279, L175-L179.
 (D68) Bermudez, V. M. J. Phys. Chem. 1994, 98, 2469-2477.
 (D69) Purnell, S. K.; Xu, X.; Goodman, D. W.; Gates, B. C. J. Phys. Chem. 1994, 98, 4076-4082.
 (D70) Domen, K.; Akamatsu, N.; Yamamoto, H.; Wada, A.; Hirose, C. Surf. Sci. 1993, 283, 468-472.
 (D71) Wijekoon, W. M. K. P.; Koenig, E. W.; Hetherington, W. M., III; Salzman, W. R. Surf. Sci. 1993, 294, L929-L934.
 (D72) Wijekoon, W. M. K. P.; Koenig, E. W.; Hetherington, W. M., III; Salzman, W. R. Surf. Sci. 1993, 294, L929-L934.
 (D73) Aubuchon, C. M.; Davison, B. S.; Nishimura, A. M.; Tro, N. J. J. Phys. Chem. 1994, 98, 240-244.
 (D74) Kittaka, S.; Sasaki, T.; Fukuhara, N.; Kato, H. Surf. Sci. 1993, 282, 255-261.
 (D75) Paz-Pujalt, G. R.; Tuschel, D. D. Appl. Phys. Lett. 1993, 62,

- (D75)
- (D76)
- D77)
- (D78) (D79)
- 282, 255-261. Paz-Pujalt, G. R.; Tuschel, D. D. Appl. Phys. Lett. **1993**, 62, 3411-3413. Dubois, L. H.; Zegarski, B. R.; Nuzzo, R. G. J. Chem. Phys. **1993**, 98, 678-688. Anderson, M. R.; Gatin, M. Langmuir **1994**, 10, 1638-1641. Yip, C. M.; Ward, M. D. Langmuir **1994**, 10, 549-556. Chadwick, J. E.; Myles, D. C.; Garrell, R. L. J. Am. Chem. Soc. **1993**, 115, 10364-10365. Tang, X.; Schneider, T.; Buttry, D. A. Langmuir **1994**, 10, 2235-2240. Evans S. D. Ereeman, T. L.; Elvnn, T. M.; Batchelder, D. N.; (D80)
- (D81) (D82)
- (D83)
- 2235-2240. Evans, S. D.; Freeman, T. L.; Flynn, T. M.; Batchelder, D. N.; Ulman, A. Thin Solid Films 1994, 244, 778-783. Bent, S. F.; Schilling, M. L.; Wilson, W. L.; Katz, H. E.; Harris, A. L. Chem. Mater. 1994, 6, 122-126. Parikh, A. N.; Allara, D. L.; Azouz, I. B.; Rondelez, F. J. Phys. Chem. 1994, 98, 7577-7590. Hirschmugl, C. J.; Dumas, P.; Chabal, Y. J.; Hoffmann, F. M.; Suhren, M.; Williams, G. P. J. Electron Spectrosc. Relat. Phenom. 1993, 64-65, 67-73. Persson, B. N. J.; Volokitin, A. I. Surf. Sci. 1994, 310, 314-336. (D84)
- (D85)
- (D86) Lin, K. C.; Tobin, R. G.; Dumas, P. Phys. Rev. B: Condens. Matter 1994, 49, 17273-17278.
 (D87) He, J.-W.; Kuhn, W. K.; Goodman, D. W. Surf. Sci. 1993, 292,
- (D88) Kuhn, W. K.; He, J. W.; Goodman, D. W. J. Phys. Chem. 1994, 98, 259–263. Kuhn, W. K.; He, J. W.; Goodman, D. W. J. Phys. Chem. **1994**,
- (D89) 98, 264-269.

X-RAY TECHNIQUES

- (E1) Park, R. L.; Houston, J. E. Surf. Sci. 1971, 26, 664-666. Park, R. L.; Houston, J. E. J. Vac. Sci. Technol. 1974, 11, 1-18. Chopra, D. R.; Chourasia, A. R. Scanning Microsc. 1988, 2, 677-702. Chopra, D. R.; Chourasia, A. R. In Characterization of Semiconductor Surfaces; McGuire, G., Ed.; Noyes Publication: Park Ridge, NJ, 1989; Vol. 1, pp 289-327.
 (E2) Chopra, D. R. In Handbook on the Physics and Chemistry of Rare Earths; Gschneidner, K. A., Jr., Eyring, L., Eds.; North-Holland: Amsterdam, 1993; Vol. 16, pp 519-545.
 (E3) Nolting, W.; Geipel, G.; Ertl, K. Z. Phys. B: Condensed Matter 1993, 92, 75-89.
 (E4) Scheiners A.; Merz, H. Int. I. Mod. Phys. B 1993, 7, 337-

- (E4) Scheipers, A.; Merz, H. Int. J. Mod. Phys. B 1993, 7, 337– 340.

- (E12) Cui, S. Wuli 1993, 22, 87-91.
- (E13) de Boer, D. K. G.; van den Hoogenhof, W. W. Mater. Sci. Forum 1993, 133-136, 231-234.
- (E14) Crabb, T. A.; Gibson, P. N.; McAlpine, E. Corros. Sci. 1993, 34, 1541–1550.
- (E15) Day, A. E.; Laube, S. J.; Donley, M. S.; Zabinski, J. S. Mater. Res. Soc. Symp. Proc. **1993**, 285, 539-544.
- (E16) Aggarwal, S.; Goel, A. K.; Mohindra, R. K.; Ghosh, P. K.; Bhatnagar, M. C. Thin Solid Films 1994, 237, 175-180.
- (E17) Friesen, T.; Haupt, J.; Gibson, P. N.; Gissler, W. NATO ASI Ser., Ser. E 1993, 233, 475-480.
- (E18) Zhu, D.; Ridgway, M. C.; Elliman, R. G.; Williams, J. S.; Collins, G. Nucl. Sci. Technol. 1993, 4, 158-163.
- (E19) Chen, J.; Arwin, H.; Heim, M.; Sioeger, J. Key Eng. Mater. 1994, 89-91 (Silicon Nitride 93), 301-305.
- (E20) Makino, Y.; Setsuhara, Y.; Miyake, S. Nucl. Instrum. Methods Phys. Res. Sect. B 1994, 91, 696-700.
- (E21) Martinez, M. L.; Santiago, A. J. J.; Graham, W. R.; Heiney, P. A.; Siegal, M. P. J. Mater. Sci. 1994, 9, 1434–1440.
- (E22) Sakamoto, I.; Hayashi, N.; Tanoue, H. Surf. Coat. Technol. 1994, 65, 133-136.
- (E23) Perry, A. J.; Treglio, J. R.; Schaffer, J. P.; Brunner, J.; Valvoda, V.; Rafaja, D. Surf. Coat. Technol. 1994, 66, 377–383.
- (E24) Setsuhara, Y.; Ohsako, H.; Makino, Y.; Miyake, S. Surf. Coat. Technol. **1994**, 66, 495-498.
- (E25) Zhang, Q. Y.; Chen, B.; Li, G. B.; Jin, S.; Chen, F. X.; Yang, D. Z.; Zhu, Y. C. Surf. Coat. Technol. 1994, 66, 468-471.
- (E26) Chen, C. P.; Chang, Y. A.; Kuech, T. F. J. Vac. Sci. Technol. A 1994, 12, 1915–1919.
- (E27) Gissler, W. Surf. Interface Anal. 1994, 22, 139-148.
- (E28) Kuech, T. F.; Redwing, J. M.; Huang, J. W.; Nayak, S. Mater. Res. Soc. Symp. Proc. 1994, 334, 189-200.
- (E29) Werwa, E.; Seraphi, A. A.; Chiu, L. A.; Zhou. C.; Kolenbrander, K. D. Appl. Phys. Lett. **1994**, 64, 1821–1823.
- (E30) van Brussel, B. A.; De Hosson, J. Th. M. Appl. Phys. Lett. 1994, 64, 1585-1587.
- (E31) Takayama, T.; Seto, H.; Uchida, J.; Hinotani, S. J. Appl. Electrochem. 1994, 24, 131–138.
- (E32) Wang, H.; Ma, Z.; Allen, L. H.; Rigsbee, J. M. Mater. Res. Soc. Symp. Proc. 1993, 298, 235-239.
- (E33) Tosello, C.; Ferrari, F.; Brand, R.; Keune, W.; Marest, G.; El Khakani, M. A.; Parellada, J.; Principi, G.; Lo Russo, S. Nucl. Instrum. Methods Phys. Res., Sect B 1993, B80-B81, 417-420.
- (E34) Fontaine, A. In Neutron Synchrotron Radiation for Condensed Matter Studies; Baruchel, J., Ed.; Springer: Berlin, Germany, 1993; Vol. 1, pp 323-369. Rindby, A. X-ray Spectrom. 1993, 22, 187-191. Torok, S. B.; Van Grieken, R. E. Anal. Chem. 1994, 66, 186R-206R. Roberts, K. J. Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. A 1994, 248, 715-750. Bertagnolli, H.; Ertel, T. S. Angew. Chem., Int. Ed. Engl. 1994, 33, 15-37.
- (E35) Rehr, J. J.; Zabinsky, S. I.; Albers, R. C. Mater. Res. Soc. Symp. Proc. 1993, 307, 3-8.
- (E36) Tyson, T. A. Phys. Rev. B: Condens. Matter **1994**, 49, 12578-12589.
- (E37) Bauchspiess, K. R. Jpn. J. Appl. Phys., Part 1 1993, 32, 131– 133.
- (E38) Houde-Walter, S. N.; Inman, J. M.; Dent, A. J.; Greaves, G. N. J. Phys. Chem. 1993, 97, 9330-9336.
- (E39) Kizler, P. Phys. Rev. B: Condens. Matter 1993, 47, 5660-5669.
- (E40) Kuzmin, A.; Purans, J. J. Phys.: Condens. Matter 1993, 5, 2333-2340.
- (E41) Chartier, P.; Mimault, J.; Girardeau, T.; Jaouen, M.; Tourillon, G. J. Alloys Compd. 1993, 194, 77-85.
- (E42) Yao, M.; Kawakita, Y.; Nagaya, K.; Ohmasa, Y.; Tsuzuki, T.; Inui, M.; Endo, H. J. Non-Cryst. Solids 1993, 156-158, 555-558.
- (E43) Nakamura, K.; Nagumo, M. J. Non-Cryst. Solids 1993, 156– 158, 575–579.
- (E44) Almeida, R. M.; de Barros Marques, M. I.; Goncalves, M. C. J. Non-Cryst. Solids 1994, 168, 144–149.
- (E45) Harris, V. G.; Elam, W. T.; Koon, N. C.; Hellman, F. Phys. Rev. B: Condens. Matter 1994, 49, 3637-3640.
- (E46) Saiter, J. M.; Ma, Q.; Benazeth, S.; Belhadji, M.; Vautier, C. Mater. Lett. 1994, 19, 287–290.
- (E47) Yamamoto, H.; Nasu, H.; Matsuoka, J.; Kamiya, K. J. Non-Cryst. Solids 1994, 170, 87-96.
- (E48) Iwasawa, Y. NATO ASI Ser., Ser. C 1993, 398, 285–304. Moraweck, B. In Catalyst Characterization; Imelik, B., Vedrine, J. C., Eds.; Plenum: New York, 1994; pp 377–416.
- (E49) Berry, F. J.; Marco, J. F.; Steel, A. T. J. Alloys Compd. 1993, 194, 167–172.

- (E50) Caballero, A.; Villain, F.; Dexpert, H.; Lepeltier, F.; Didillon, B.; Lynch, J. Catal. Lett. **1993**, 20, 1–13.
- (E51) Arunarkavalli, T.; Kulkarni, G. U.; Rao, C. N. R. Catal. Lett. 1993, 20, 259-268.
- (E52) Li, P.; Chen, I. W.; Penner-Hahn, J. E. Phys. Rev. B: Condens. Matter 1993, 48, 10063-10073.
- (E53) Capitan, M. J.; Malet, P.; Centeno, M. A.; Munoz-Paez, A.; Carrizosa, I.; Odriozola, J. A. J. Phys. Chem. 1993, 97, 9233– 9240.
- (E54) Van Zon, F. B. M.; Maloney, S. D.; Gates, B. C.; Koningsberger, D. C. J. Am. Chem. Soc. 1993, 115, 10317–10326.
- (E55) Andrews, P.; Corker, J. M.; Evans, J.; Webster, M. J. Chem. Soc., Dalton Trans. 1994, 9, 1337–1347.
- (E56) Zhao, J.; Feng, Z.; Huggins, F. E.; Shah, N.; Huffman, G. P.; Wender, I. J. Catal. 1994, 148, 194-197.
- (E57) Martin, C.; Martin, I.; Rives, V.; Malet, P. J. Catal. 1994, 147, 465–475.
- (E58) Gloor, A. P.; Prins, R. J. Phys. Chem. 1994, 98, 9865-9873.
- (E59) Harada, M.; Asakura, K.; Toshima, N. J. Phys. Chem. 1994, 98, 2653-2662.
- (E60) Mustre, L. J.; Conradson, S. D.; Bishop, A. R.; Raistrick, I. D. Jpn. J. Appl. Phys. Part 1 1993, 32, 573-577.
- (E61) Renevier, H.; Hodeau, J. L.; Marezio, M.; Fontaine, A.; Michalowicz, A.; Tourillon, G. Phys. Rev. B: Condens. Matter 1993, 47, 11398-11410.
- (E62) Yamaguchi, H.; Nakajima, S.; Kuwahara, Y.; Oyanagi, H.; Syono, Y. *Physica C* **1993**, 213, 375–382.
- (E63) Akhtar, M. J.; Akhtar, Z. N.; Catlow, C. R. A. Physica C 1993, 209, 373–380.
- (E64) Bridges, F.; Li, G.; Boyce, J. B.; Claeson, T. Phys. Rev. B: Condens. Matter 1993, 48, 1266-1275.
- (E65) Kramer, M. J.; Margulies, L.; Arrasmith, S. R.; Dennis, K. W.; Lang, J. C.; McCallum, R. W.; Gallagher, P. K. J. Mater. Res. 1994, 9, 1661–1671.
- (E66) Booth, C. H.; Bridges, F.; Boyce, J. B.; Claeson, T.; Zhao, Z. X.; Cervantes, P. Phys. Rev. B: Condens. Matter 1994, 49, 3432-3442.
- (E67) Tan, G. O. Bull. Singapore Natl. Inst. Chem. **1993**, 21, 49-79.
- (E68) Hasnain, S. S. Pure Appl. Chem. 1994, 66, 51-56.
- (E69) Chen, J.; Christiansen, J.; Tittsworth, R. C.; Hales, B. J.; George, S. J.; Coucouvanis, D.; Cramer, S. P. J. Am. Chem. Soc. 1993, 115, 5509-5515.
- (E70) True, A. E.; Scarrow, R. C.; Randall, C. R.; Holz, R. C.; Que, L. J. Am. Chem. Soc. 1993, 115, 4246–4255.
- (E71) Persson, I.; Penner-Hahn, J. E.; Hodgson, K. O. Inorg. Chem. 1993, 32, 2497–2501.
- (E72) Chen, J.; Christiansen, J.; George, S.; Tittsworth, R.; Hales, B.; Campobasso, N.; Bolín, J.; Cramer, S. P. Mater. Res. Soc. Symp. Proc. 1993, 307, 63-68.
- (E73) Teranishi, T.; Harada, M.; Asakura, K.; Asanuma, H.; Saito, Y.; Toshima, N. J. Phys. Chem. 1994, 98, 7967-7975.
- (E74) Bertini, I.; Briganti, F.; Mangani, S.; Nolting, H. F.; Scozzafava, A. Biochemistry 1994, 33, 10777-10784.
- (E75) Inada, Y.; Sugimoto, K.; Ozutsumi, K.; Funahashi, S. Inorg. Chem. 1994, 33, 1875-1880.
- (E76) Mayanovic, R. A. Crit. Rev. Surf. Chem. 1993, 2, 63-89.
- (E77) Citrin, P. H. Surf. Sci. 1994, 299-300, 199-218.
- (E78) Lederer, T.; Arvanitis, D.; Comelli, G.; Troeger, L.; Baberschke, K. Phys. Rev. B: Condens. Matter 1993, 48, 15390–15404.
- (E79) Miyano, K. E.; Woicik, J. C.; Kendelewicz, T.; Spicer, W. E.; Richter, M.; Pianetta, P. Phys. Rev. B: Condens. Matter 1993, 47, 6444-6449.
- (E80) Kafader, U.; Tuilier, M. H.; Pirri, C.; Wetzel, P.; Gewinner, G.; Bolmont, D.; Heckmann, O.; Chandesris, D.; Magnan, H. Europhys. Lett. 1993, 22, 529-535.
- (E81) Purdie, D.; Prakash, N. S.; Purcell, K. G.; Wincott, P. L.; Thornton, G.; Law, D. S. L. Phys. Rev. B: Condens. Matter 1993, 48, 2275-2281.
- (E82) Tuilier, M. H.; Pirri, C.; Wetzel, P.; Gewinner, G.; Veuillen, J. Y.; Nguyen Tan, T. A. Surf. Sci. 1994, 307–309, 710–715.
- (E83) Oyanagi, H.; Sakamoto, K.; Shioda, R.; Sakamoto, T. Jpn. J. Appl. Phys. Part 1 1994, 33, 3545-3552.
- (E84) Heckmann, O.; Magnan, H.; le Fevre, P.; Chandesris, D.; Rehr, J. J. Surf. Sci. 1994, 312, 62–72.
- (E85) Yokoyama, T.; Hamamatsu, H.; Kitajima, Y.; Yagi, S.; Ohta, T. Surf. Sci. 1994, 313, 197-208.

A1950016A