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OFFICE OF NAVAL RESEARCH

FINAL REPORT

PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/STUDENTS REPORT

for

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"Surface Chemistry and Diffusion of Single Molecules"

This grant is jointly funded by the National Science Foundation as
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PART I
Objectives, Approach, Scientific Conclusions

1. Objectives

We study the motion and dynamics of atoms and molecules on surfaces in order to assess the roles played by active surface sites such as steps, defects, and phase boundaries in this motion. Surface mobility is critical in such areas as surface chemistry, film growth, etching, corrosion, and the creation and stability of nanoscale structures. We seek atomic level information on the specific rates and mechanisms of this motion, and to determine the nature of the interactions which determine these.

2. Approach

Our understanding of surface motion is developed using a unique variable low temperature ultrahigh vacuum scanning tunneling microscope which can operate using a dc tunneling current when studying conducting and semiconducting substrates, and using a microwave frequency ac tunneling current when studying insulators. The tunable microwave frequency modulation allows chemical differentiation, investigations of the motion of surface charge, and local "electrochemical" measurements of the gas-solid and vacuum-solid interfaces. We also use an ultrastable low temperature ultrahigh vacuum scanning tunneling microscope. All instruments are equipped with a complement of surface analytical tools so as to enable comparison and relation to more conventional macroscopic measurements.

3. Scientific Conclusions

We have demonstrated the first direct measurement of nonzero accommodation lengths upon adsorption, in this case for Xe on Pt{111} at 4K. By showing that surface diffusion is slow on the time scale of our experiments (hopping rates <1/hour), we have shown that the distribution of atoms on the surface is due to motion upon adsorption. Thus we have been able to show that Xe atoms travel hundreds of Ångstroms across the surface upon adsorption. See highlighted publication.

We have discovered a new surface diffusion mechanism in which diffusion occurs via motion of substrate-adsorbate complexes. We used the STM to record a series of "stop-action movies" of self-assembled monolayers of alkanethiols on Au{111}. The rate of motion was determined by the reduction in the substrate-substrate bond strengths balanced by the attractions between the adsorbate molecules. This mechanism leads to a means of controlling the rates of motion of the complex by tuning the attractive interactions between the complexes. See highlighted publication.

We have extended atomic resolution imaging and spectroscopy to insulator surfaces using a newly developed microwave frequency tunable alternating current scanning tunneling microscope. We have recorded the first atomic resolution images in this frequency range. We have also shown that we can differentiate between closely related molecules based on their microwave frequency AC tunneling spectra. See highlighted publication.

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PART II

Publications, Presentations, Patents, Reports, and Personnel

1. Papers submitted to refereed journals, but not yet published

P. S. Weiss, *Analytical Applications of Scanning Tunneling Microscopy*, Trends in Analytical Chemistry, in press (February, 1994).

Scanning Tunneling Microscopy of Self-Assembled Monolayers of Alkanethiols on Gold, S. J. Stranick, M. M. Kamna, K. R. Krom, A. N. Parikh, D. L. Allara, and P. S. Weiss, Journal of Vacuum Science and Technology B, in press.

S. J. Stranick, A. N. Parikh, D. L. Allara, and P. S. Weiss, *Phase Separation of Mixed-Composition Mixed Self-Assembled Monolayers into Nanometer Scale Molecular Domains*, S. J. Stranick, A. N. Parikh, Y.-T. Tao, D. L. Allara, and P. S. Weiss, submitted to Journal of the American Chemical Society.

S. J. Stranick, A. N. Parikh, D. L. Allara and P. S. Weiss, *A New Mechanism for Surface Diffusion: Motion of a Substrate-Adsorbate Complex*, submitted to Physical Review Letters.

M. J. Abrams and P. S. Weiss, *Studying Transient Mobility and Energy Loss Using Scanning Tunneling Microscopy*, submitted to Surface Science.

J. A. Meyer, S. J. Stranick, and P. S. Weiss, *The Formation of Striped Surface Phases by Short-Range Forces*, submitted to Physical Review Letters.

2. Papers published in refereed journals

J. A. Meyer, S. J. Stranick, J. B. Wang, and P. S. Weiss, *Field Emission Current-Voltage Curves as a Diagnostic for Tips for Scanning Tunneling Microscope Tips*, Ultramicroscopy **42-44**, 1538 (1992).

D. M. Eigler, P. S. Weiss, E. K. Schweizer and N. D. Lang, *Scanning Tunneling Microscopy of Xe at 4K*, Physical Review Letters **66**, 1189 (1991).

J. A. Meyer, *Extracting Interaction Energies from Scanning-Tunneling- and Field-Ion-Microscopy Data*, Physical Review Letters **69**, 784 (1992).

P. S. Weiss and D. M. Eigler, *Adsorption and Accommodation of Xe on Pt(111)*, Physical Review Letters **69**, 2240 (1992).

S. J. Stranick, P. S. Weiss, A. N. Parikh, and D. L. Allara, *Alternating Current Scanning Tunneling Spectroscopy of Self-Assembled Monolayers on Gold*, Journal of Vacuum Science and Technology A **11** 739 (1993).

J. A. Meyer, *Extraction of Information from Scanning Tunneling Microscope Images*, Surface Science Letters **284**, L416 (1993).

P. S. Weiss and D. M. Eigler, *Site Dependence of the Apparent Shape of a Molecule in STM Images: Benzene on Pt(111)*, Physical Review Letters **71**, 3139 (1993).

3. Books or chapters submitted, but not yet published

None.

4. Books or chapters published

P. S. Weiss and D. M. Eigler, *What is Underneath? Moving Atoms and Molecules to Find Out*, in NATO ASI Series E: Applied Sciences 235, Nanosources and Manipulations of Atoms Under High Fields and Temperatures: Applications, Vu Thien Binh, N. Garcia and K. Dransfeld, eds., 213 (Kluwer Academic, 1993).

5. Printed technical reports and non-refereed papers published

None.

6. Patents

None.

7. Invited Presentations

E. I. Dupont de Nemours, Experimental Station, "Scanning Tunneling Microscopy at 4K," P. S. Weiss, Wilmington, DE, February 19, 1991.

Pennsylvania Junior Science and Humanities Symposium, "Scanning Tunneling Microscopy," P. S. Weiss, University Park, PA, November 5, 1991.

30th Eastern Analytical Symposium, "What Can We Learn with a Scanning Tunneling Microscope?" P. S. Weiss, Somerset, NJ, November 14, 1991.

American Chemical Society, Princeton Section Meeting, "Studying Single Molecules with the Scanning Tunneling Microscope," P. S. Weiss, Princeton, NJ, March 26, 1992.

Perkin Elmer Corporation, "Studying Single Molecules with the Scanning Tunneling Microscope," P. S. Weiss, Eden Prairie, MN, January 23, 1992.

Calvin College, "Scanning Tunneling Microscopy," P. S. Weiss, Grand Rapids, MI, February 27, 1992.

Hope College, "Scanning Tunneling Microscopy," P. S. Weiss, Holland, MI, February 27, 1992.

Fritz-Haber-Institut der Max-Planck-Gesellschaft, Surface Science Seminar, "Studies of Adsorption, Accommodation, and Imaging at 4K with an STM," P. S. Weiss, Berlin, Germany, March 9, 1992.

Eastman Kodak Laboratories, "Studying Single Molecules with the Scanning Tunneling Microscope," P. S. Weiss, Rochester, NY, May 27, 1992.

University of Delaware, College of Marine Studies, "Applications of Information Theory to Surface Science," J. A. Meyer, Lewes, DE, June 1, 1992.

Dow Chemical Company, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Midland, MI, July 20, 1992.

Hewlett-Packard Laboratories, "Low Temperature and Alternating Current Scanning Tunneling Microscopy," P. S. Weiss, Palo Alto, CA, July 22, 1992.

E. I. Dupont de Nemours, Experimental Station, "Chemical Identification at Interfaces," P. S. Weiss, Wilmington, DE, July 28, 1992.

Centre Nationale de la Recherche Scientifique, Paris-area Physics Colloquium, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Paris, France, September 16, 1992.

Unité Mixte de Recherche Centre National de la Recherche Scientifique - Saint-Gobain, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Aubervilles, France, September 17, 1992.

Universität Basel, Institut für Physik, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Basel, Switzerland, September 21, 1992.

IBM Zürich Research Laboratory, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Rüschlikon, Switzerland, September 22, 1992.

Universität Konstanz, Fakultät für Physik, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Konstanz, Germany, September 24, 1992.

University of Washington, Physical Chemistry Seminar, "Studying Single Molecules with a Scanning Tunneling Microscope," P. S. Weiss, Seattle, WA, October 28, 1992.

Battelle Pacific Northwest Laboratories, "Studying Single Molecules with a Scanning Tunneling Microscope," P. S. Weiss, Richland, WA, October 29, 1992.

AT&T Bell Laboratories, Murray Hill, Surface Science Seminar, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Murray Hill, NJ, November 2, 1992.

Union Carbide, "Expanding Scanning Tunneling Microscopy to Study Insulators and Single Molecules," P. S. Weiss, Charleston, WV, November 5, 1992.

Hewlett-Packard Laboratories, "Microwave Frequency AC Scanning Tunneling Microscopy and Spectroscopy," P. S. Weiss, Palo Alto, CA, March 12, 1993.

Kenan Analytical Award Symposium, "AC Scanning Tunneling Microscopy and Spectroscopy," S. J. Stranick and P. S. Weiss, Union Carbide, Charleston, WV, April 21, 1993.

Mid-Atlantic Regional American Chemical Society Meeting, "AC Scanning Tunneling Microscopy and Spectroscopy of Insulators," P. S. Weiss, Hempstead, NY, June 4, 1993.

Tohoku University, Institute for Materials Research, "AC Scanning Tunneling Microscopy and Spectroscopy," P. S. Weiss, Sendai, Japan, August 16, 1993.

National Institute for Advanced Interdisciplinary Research and the Electrotechnical Laboratory, "AC Scanning Tunneling Microscopy and Spectroscopy," P. S. Weiss, Tsukuba, Japan, August 17, 1993.

AT&T Bell Laboratories, Murray Hill, Surface Science Seminar, "AC Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Murray Hill, NJ, September 8, 1993.

Columbia University, Department of Chemistry Colloquium, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulators," P. S. Weiss, New York, NY, September 9, 1993.

25th Central Regional American Chemical Society Meeting, "AC Scanning Tunneling Microscopy and Spectroscopy of Insulators," P. S. Weiss, Pittsburgh, PA, October 5, 1993.

Naval Research Laboratory, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulating Films and Solids," P. S. Weiss, Washington, DC, October 12, 1993.

University of Delaware, Department of Chemistry, Physical Chemistry Seminar, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulating Films and Solids," P. S. Weiss, Newark, DE, October 13, 1993.

University of Wisconsin, Madison, Department of Chemistry, Analytical Chemistry Seminar, and Department of Materials Science and Engineering Seminar, "AC Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Madison, WI, October 21, 1993.

Université de Paris VII, Groupe de Physiques des Solides, "AC and Conventional Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Paris, France, November 2, 1993.

University of Nijmegen, Department of Physics Seminar, "AC and Conventional Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Nijmegen, The Netherlands, November 3, 1993.

Ecole Normale Supérieure de Lyon, Department of Theoretical Chemistry Seminar, "AC and Conventional Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Lyon, France, November 5, 1993.

Centre d'Etudes Nucléaires de Saclay, "AC and Conventional Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Gif-sur-Yvette, France, November 8, 1993.

University of Maryland, Department of Chemistry, Physical Chemistry Seminar, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulating Films and Solids," P. S. Weiss, College Park, MD, November 10, 1993.

Alfred University, Chemistry Seminar, "Scanning Tunneling Microscopy," P. S. Weiss, Alfred, NY, December 6, 1993.

University of Illinois, Champagne-Urbana, Department of Chemistry, "AC and Conventional Scanning Tunneling Microscopy of Insulating Films and Solids," P. S. Weiss, Champagne-Urbana, IL, February 2, 1994.

Ithaca College, Department of Chemistry, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulators," S. J. Stranick, Ithaca, NY, February 8, 1994.

207th Meeting of the American Chemical Society, "Conventional and AC Scanning Tunneling Microscopy of Insulating Films and Solids," S. J. Stranick, L. A. Bumm, L. E. L. Reynolds, P. S. Weiss, San Diego, CA, March 16, 1994.

1994 March Meeting of the American Physical Society, "AC Scanning Tunneling Microscopy and Spectroscopy of Insulating Films and Solids," P. S. Weiss, Pittsburgh, PA, March, 1994.

1994 March Meeting of the American Physical Society, Division of Chemical Physics Awards Ceremony, "Structure, Motion, and Defects in Self-Assembled Monolayers," S. J. Stranick, M. M. Kamna, M. T. Cygan, A. N. Parikh, D. L. Allara, and P. S. Weiss, Pittsburgh, PA, March, 1994.

Rutgers University, Department of Chemistry Colloquium, "Frontiers of Scanning Probe Microscopy," P. S. Weiss, Piscataway, NJ, April 12, 1994.

8. Contributed Presentations

STM'91, 6th International Conference on Scanning Tunneling Microscopy/Spectroscopy, "Field Emission Spectroscopy as a Diagnostic for Tips for Scanning Tunneling Microscopy," J. A. Meyer, S. J. Stranick, J. B. Wang, and P. S. Weiss, Interlaken, Switzerland, August 13, 1991.

1992 March Meeting of the American Physical Society, "Extraction of Interaction Parameters from Real Space Images," J. A. Meyer, Indianapolis, IN, March 16, 1992.

52nd Annual Conference on Physical Electronics, "Short-Range Forces, Long-Range Order," J. A. Meyer, S. J. Stranick, J. H. Ferris, III and P. S. Weiss, Irvine, CA, June 24, 1992. *52nd Annual Conference on Physical Electronics Program*, E-5 (1992).

NATO Advanced Research Workshop on Manipulations of Atoms under High Fields and Temperatures: Applications, "What is Underneath? Moving Atoms and Molecules to Find Out," P. S. Weiss and D. M. Eigler, Lyon, France, July 8, 1992.

Penn State REU Symposium, "Accommodation Length in Surface Adsorption," M. J. Abrams and P. S. Weiss, University Park, PA, August 14, 1992.

39th National Meeting of the American Vacuum Society, "Microwave Frequency AC STM," S. J. Stranick and P. S. Weiss, Chicago, IL, November 9, 1992. *39th National Symposium of the American Vacuum Society*, 108 (1992).

Gordon Research Conference on Frontiers of Scanning Tunneling Microscopy, "Tunable Microwave Frequency AC Scanning Tunneling Microscopy," S. J. Stranick and P. S. Weiss, Ventura, CA, March 18, 1993. Poster and accompanying talk.

Eighth Annual Graduate Research Exhibition, "The AC Scanning Tunneling Microscope: A New Tool for Studying Insulators," S. J. Stranick and P. S. Weiss, University Park, PA, March 19-20, 1993. Poster.

1993 March Meeting of the American Physical Society, "Tunable Microwave Frequency AC Scanning Tunneling Microscopy," S. J. Stranick and P. S. Weiss, Seattle, WA, March 24, 1993. *Bulletin of the American Physical Society* **38**, 403 (1993).

1993 March Meeting of the American Physical Society, "AC Scanning Tunneling Microscopy and Spectroscopy of Self-Assembled Monolayers," P. S. Weiss, S. J. Stranick, A. N. Parikh, and D. L. Allara, Seattle, WA, March 24, 1993. *Bulletin of the American Physical Society* **38**, 539 (1993). Poster.

Workshop on Alkali Metal Adsorption: The Physics and Chemistry of Alkali Metals in Less-Than-Three Dimensional Structures, "A Low Temperature, Extreme High Vacuum, Tunable Alternating Current Scanning Tunneling Microscope," M. M. Kamna, S. J. Stranick, and P. S. Weiss, University Park, PA, June 18, 1993. Poster and accompanying talk.

53rd Annual Conference on Physical Electronics, "Structure, Motion, and Defects in Self-Assembled Monolayers," S. J. Stranick, M. M. Kamna, P. S. Weiss, A. N. Parikh, and D. L. Allara Troy, NY, June 22, 1993. *53rd Annual Conference on Physical Electronics Program* (1993).

National Nanofabrication Facility Network Site Visit, "AC Scanning Tunneling Microscopy: A New Tool for Studying Insulators," S. J. Stranick and P. S. Weiss, Cornell University, Ithaca, NY, August 3, 1993.

STM'93, International Conference on Scanning Tunneling Microscopy, "Scanning Tunneling Microscopy and Spectroscopy of Self-Assembled Monolayers," P. S. Weiss, S. J. Stranick, A. N. Parikh, and D. L. Allara, Beijing, China, August 11, 1993. *STM '93 Book of Abstracts*, 198 (1993). Poster.

STM'93, International Conference on Scanning Tunneling Microscopy, "AC Scanning Tunneling Microscopy and Spectroscopy," P. S. Weiss and S. J. Stranick, Beijing, China, August 12, 1993. *STM '93 Book of Abstracts*, 86 (1993).

Manhattan Poster Project in Philadelphia, Northeastern Regional Graduate Physical Chemistry Poster Session, "Conventional and AC Scanning Tunneling Microscopy of Insulating Films and Solids," S. J. Stranick and P. S. Weiss, Philadelphia, PA, November 13, 1993.

Manhattan Poster Project in Philadelphia, Northeastern Regional Graduate Physical Chemistry Poster Session, "A Low Temperature Ultrahigh Vacuum Alternating Current Scanning Tunneling Microscope," M. M. Kamna, S. J. Stranick, and P. S. Weiss, Philadelphia, PA, November 13, 1993.

1994 March Meeting of the American Physical Society, "Structure, Motion, and Defects in Self-Assembled Monolayers," S. J. Stranick, M. M. Kamna, M. T. Cygan, A. N. Parikh, D. L. Allara, and P. S. Weiss, Pittsburgh, PA, March, 1994.

1994 March Meeting of the American Physical Society, "Studying Transient Mobility and Energy Loss Using Scanning Tunneling Microscopy," M. G. Youngquist, J. H. Ferris, III, M. J. Abrams, and P. S. Weiss, Pittsburgh, PA, March, 1994.

1994 March Meeting of the American Physical Society, "An Improved Broadband Microwave Frequency AC Scanning Tunneling Microscope," L. A. Bumm, S. J. Stranick, and P. S. Weiss, Pittsburgh, PA, March, 1994. Poster.

1994 March Meeting of the American Physical Society, "Low Temperature and Ultrahigh Vacuum Tunable AC Scanning Tunneling Microscopy," M. M. Kamna, S. J. Stranick, L. E. L. Reynolds, and P. S. Weiss, Pittsburgh, PA, March, 1994. Poster.

9. Honors/Awards/Prizes

Michael J. Abrams, Undergraduate Coworker — CRC Freshman Award (top freshman in the Chemistry Department).

Michael J. Abrams, Undergraduate Coworker — Eberly College of Science Alumni Society Award (top freshman in the Eberly College of Science).

Joseph A. Meyer, Postdoctoral Associate — Alexander von Humboldt Foundation Fellowship.

Stephan J. Stranick, Graduate Research Assistant — Wheeler P. Davey Fellowship of the Penn State Eberly College of Science.

Stephan J. Stranick, Graduate Research Assistant — First Prize for the Physical Sciences, Eighth Annual Graduate Research Exhibition.

Stephan J. Stranick, Graduate Research Assistant — Kenan Analytical Award of the Union Carbide Corp.

Stephan J. Stranick, Graduate Research Assistant — Shell Foundation Graduate Fellowship.

Stephan J. Stranick, Graduate Research Assistant — Sigma Xi Graduate Research Award.

Stephan J. Stranick, Graduate Research Assistant — American Physical Society, Divisions of Chemical Physics Travel Award.

Paul S. Weiss, Assistant Professor — National Science Foundation Presidential Young Investigator Award, 1991–1996.

Paul S. Weiss, Assistant Professor — Appointed leader of the Materials Chemistry Group for 1992–1993 and 1993–1994.

Paul S. Weiss, Assistant Professor — Chosen by NAS/NRC Board on Chemical Sciences and Technology as U.S. Observer at the IUPAC Meeting on Chemical Research Applied to World Needs, Lisbon, Portugal.

10. Post-doctoral Associates Funded Through the ONR/NSF Contracts

Joseph A. Meyer, Ph.D. in Physics, Brown University (currently a Humboldt Fellow at the University of Ulm)

Michael G. Youngquist, Ph.D. in Chemistry, Cal Tech.

11. Graduate Students Funded Through the ONR/NSF Contracts

James H. Ferris, III

Marilyn M. Kamna

Stephan J. Stranick

12. Undergraduate Students Funded Through the ONR/NSF Contracts

Michael J. Abrams

Renée M. Itle

Abner Mintz (currently a graduate student in chemistry at Cal Tech)

PART III Transitions

AT&T Bell Laboratories

AT&T Bell Laboratories has provided substantial research support (\$75,000) and has followed with interest each of the projects in our laboratory. The PI has given a series of seminars there and is now beginning a collaboration with Dr. Eric Betzig and Dr. Steven Burratto (near-field optical microscopy).

Dow Corp.

The PI has visited the analytical group and others at Dow's Midland, MI research facility. We have identified scientifically and technologically interesting samples to study with the ACSTM, but have not yet found a way to clear these for shipment to our laboratory.

Dupont Co.

We collaborate with two scientists, Dr. Don Coulman and Dr. Sau Lan Tang. These collaborations involve understanding imaging using STM, AFM, and ACSTM. A graduate student, Jim Ferris, spent the summer at Dupont Experimental Station in Wilmington, DE working with Don Coulman and supported by Dupont. Several samples of scientific and technological importance have been sent to us for examination. Don Coulman will be coming to our laboratory for an extended visit. He has previously visited two times; Sau Lan Tang has visited once. The PI has made two visits to Dupont and has presented seminars both times.

Eastman Kodak

Eastman Kodak has provided direct research support (\$30,000) and has followed several of the projects in our laboratory. Their interests are in understanding STM imaging, in the ACSTM, in the dynamics we have observed, and also in self-assembled monolayers. They have provided key information on some of their technologies and suggested a number of interesting experiments.

Galileo Electro-Optics Corporation

Galileo is interested in our field emission and field ion microscopy work and has provided two detectors for this.

Hewlett-Packard

(directly and through a consortium of American Cyanamid, Amoco, Dow, Ecogen, Hewlett-Packard, International Minerals & Chemical, Agricultural Research & Development called *Biotechnology Research and Development Corporation*)

Support has been in microwave equipment and in grants (\$450,000). This support has been instrumental in developing the tunable ACSTM. This grant support is expected to continue in another three year cycle. In addition, we have been given access to all HP Labs facilities, expertise, and personnel. We have had a two day visit from three experts from HP Labs in the area of microwave engineering, scanning probe microscopy, and analytical techniques. We have regular communication and reciprocal visits.

IBM

Theory supporting our experimental STM images of adsorbates has been provided by Dr. Norton Lang of IBM Yorktown Heights in a continuing collaboration and by Peter Blöchl and his group at IBM Zürich. In addition the PI is part of a five-member team recently awarded a parallel processing IBM SP-1 for computational support of our molecular imaging.

Shell Development Co.

The PI visited Shell Development Co. Westhollow Research Center twice in order to keep them current in STM and ACSTM research. Casual contact with their analytical group, especially Dr. David Denley, is maintained.

Union Carbide

The PI and one student have both visited the West Virginia research facilities of Union Carbide. Contact with the analytical group and the catalysis research group is maintained. The main interests of Union Carbide are in understanding STM images, in the ACSTM, and in surface dynamics on the atomic scale.

PART IV

Administrative Information, Project Description and Highlights

1. Administrative Information

a. Principal Investigator

Paul S. Weiss

b. Current Telephone Numbers and Electronic Mail Address

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c. Cognizant ONR Scientific Officer

John Pazik

Cognizant NSF Program Directors

Steven Bernasek and Henry Blount

2. Project Description

We study the motion and dynamics of atoms and molecules on surfaces in order to assess the roles played by active surface sites such as steps, defects, and phase boundaries in this motion. Surface mobility is critical in such areas as surface chemistry, film growth, etching, corrosion, and the creation and stability of nanoscale structures. Our understanding of surface motion is developed using a unique variable low temperature ultrahigh vacuum scanning tunneling microscope which can operate using a dc tunneling current when studying conducting and semiconducting substrates, and using a microwave frequency ac tunneling current when studying insulators. The tunable microwave frequency modulation allows chemical differentiation, investigations of the motion of surface charge, and local "electrochemical" measurements of the gas-solid and vacuum-solid interfaces.

3. Highlighted Publications

S. J. Stranick, A. N. Parikh, D. L. Allara and P. S. Weiss, *A New Mechanism for Surface Diffusion: Motion of a Substrate-Adsorbate Complex*, submitted to Physical Review Letters.

We have discovered a new surface diffusion mechanism in which diffusion occurs via motion of substrate-adsorbate complexes. We recorded stop-action movies of self-assembled monolayers on Au{111}. We monitored the motion of the underlying Au substrate through the monolayer films and showed that the Au motion was dramatically reduced by the attachment of the thiols and that the observed rates were consistent with the motion of the complex. In a related publication (Stranick *et al.*, submitted to Journal of the American Chemical Society), we showed that mixed composition self-assembled monolayers phase segregate on the nanometer scale. These observations are extremely important in the application of self-assembled monolayers to nanotechnology.

P. S. Weiss and D. M. Eigler, *Adsorption and Accommodation of Xe on Pt{111}*, Physical Review Letters **69**, 2240 (1992).

We have measured the (unambiguous) first non-zero accommodation lengths — the distance that surface adsorbates travel after trapping on a surface but before accommodating to the surface temperature (a related publication on this subject by Abrams and Weiss is in revision for Surface Science). We showed that even for rare gas atoms, step and defect sites are the most reactive on the surface.

S. J. Stranick, P. S. Weiss, A. N. Parikh, and D. L. Allara, *Alternating Current Scanning Tunneling Spectroscopy of Self-Assembled Monolayers on Gold*, Journal of Vacuum Science and Technology **A 11** 739 (1993).

We showed the apparent chemical sensitivity of our tunable microwave frequency alternating current scanning tunneling microscope. This was done by imaging and recording AC tunneling spectra on self-assembled monolayers of alkanethiols where the terminal groups of the thiols was varied.