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Structure and Dynamics of Material Surfaces, Interphase-Interfaces

and Finite Aggregates

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1. Objectives

The focus of the research program supported by this grant is the formulation, development, implementation and application of modeling strategies and large-scale computer simulation methods for studies of critical issues in three main areas:

(i) Physical and chemical properties of atomic and molecular clusters and the origins of size-evolutionary patterns of materials properties; charging and fission of atomic and molecular clusters; energetics, geometry, and electronic structure of metallic, ionic and semi-conductor clusters; cluster collisions and cluster reactions; metal-insulator transitions in finite systems; and nanocluster assemblies.

(ii) Tribological Interactions, Nanomechanics, Thin Film Lubrication, and dynamical and rheological properties of thin films of complex molecular liquids.

(iii) Surface processing, the stability of nanostructures on surfaces, the mechanical and electric properties of interfacial junctions, and the electric, magnetic and spectroscopic properties of nano- and micro-structures, such as dots, antidots and point-contacts.

During the current report period research efforts were aimed toward the above objectives.

2. Research Highlights

The research performed in this program, resulting in developments of simulation methodologies and investigations of the properties of materials with refined atomic-scale resolution, opens new avenues for preparation, fundamental understanding, and utilization of complex materials in advanced technologies, such as ultra high-density magnetic information storage and retrieval (thin-film boundary lubricated), high-performance engines, electronic device miniaturization, surface processing and damage annealing via heating, and novel materials

preparation via cluster assembly. Furthermore, the research performed provides deep insights into the energetics, structure and dynamics of complex materials systems, and the origins of size-evolutionary patterns of their properties.

In the following we highlight some of the research accomplishments:

(i) Mechanical and Electric Conductance Properties of Metallic Nanowires

Material systems of reduced size or dimensionality may, and often do, exhibit properties different from those found in the bulk. These include quantized conductance in point contacts and narrow channels whose characteristic (transverse) dimensions approach the electronic wavelength, localization phenomena in low-dimensional systems, and mechanical properties characterized by a reduced propensity for the creation and propagation of dislocations in small metallic samples. Such phenomena are of considerable scientific and technological interest, particularly in the area of miniaturized, highly compact, electronic devices.

We reported (Science 267, 1793 (1995), and J. Vac. Sci. Technol. B 13, 1280 (1995)) on investigations of the evolution of room-temperature electronic transport properties in Au nanowires, from quantized conductance [in $2e^2/h$ or $2(2e^2/h)$ steps, where h is Planck's constant] with a spatial periodicity of $\sim 2 \text{ \AA}$ during elongation of short ($\sim 50 \text{ \AA}$) wires, to the onset of localization in long ($100 \text{ \AA} < \ell < 400 \text{ \AA}$) ones. Combining electronic conductance measurements with molecular dynamics (MD) simulations of the wire elongation process reveals that for short wires, the periodic occurrence of quantized conductance, accompanied by characteristic "dips" [local conductance minima associated with the presence of disorder], is correlated with atomic-scale structural transformations that occur during the layer-by-layer order-disorder elongation process. The dominance of disorder and the onset of localization in long wires (longer than the localization length) are exhibited by a nonlinear dependence of the resistance R on the length of

the wire ℓ as it is pulled continuously [that is, $\ln R(\ell) \sim \ell^2$]. Moreover, current versus voltage data, recorded at selected stages in the elongation process, indicate gradual loss of metallic character as the long wire narrows.

(ii) Nano-Elastohydrodynamic Thin-Film Lubrication

The major development in the understanding of fluid film lubrication which has taken place during the second half of the 20th century was enabled by the recognition of the beneficial influence of both elastic deformations of the solids and the increase in viscosity of the lubricant with pressure in highly stressed lubricated machine elements. The consequent development of elastohydrodynamic lubrication (EHL) theory, and micro-EHL, allowed the design of machine elements and bio-tribological systems of improved efficiency and durability.

Certain current novel technologies (such as high density information storage and retrieval systems, and high performance engines), and those projected for the next century, present new tribological challenges due to the miniaturization of devices operating under extreme conditions. Motivated by such considerations, and by the recent emergence and proliferation of new experimental proximal probes allowing high resolution controlled measurements, our present theoretical investigations aim at providing insights into the atomic-scale fundamental processes of ultra thin-film lubrication, thus extending EHL into the nano-realm.

Atomic-scale structure, dynamics, flow and response characteristics of a thin film molecular hexadecane lubricant, confined and sheared by topographically nonuniform solid gold surfaces which slide at a relative velocity of 10 m/s, were investigated using molecular dynamics simulations.

Our findings (submitted and accepted to Science, 1995) pertaining to molecular ordering,

layering processes in lubricants confined and sheared at high velocities by topographically non-uniform solid surfaces and their correlation with oscillatory patterns in the friction force, lubricant-mediated structural transformations and modifications of the solid surfaces, dynamical formation of elastoplastic states of the lubricant due to extreme confinement between the sliding asperities, and the appearance of post-asperity-collision nano-scale cavitated zones, go beyond the predictions of continuum theories and provide the impetus for future experimental and theoretical investigations. Such investigations would include systems under various loads and different shearing velocities, lubrication under constant load conditions, thermal effects, three dimensional asperities, multi-asperity contacts, homogeneous lubricants of various chain lengths and molecular architectures, studies of lubricant mixtures, and lubricant degradation as well as tribochemical processes.

(iii) Superheating, Melting and Annealing of Metallic Surfaces, and the Stability of Metallic Structures on Surfaces

Methods of processing of materials surfaces via laser irradiation are of fundamental as well as technological and economic significance, since various physical and chemical surface properties (such as optical and electrical characteristics, corrosion resistance, composition, morphology, and structure) can be influenced and/or modified using such methods in a controlled and spatially selective manner. Furthermore, with the use of short laser pulses, detailed time-resolved experimental investigations of electron-phonon energy transfer mechanisms and relaxation times, and of the thermal and structural evolution of metal surfaces (disordering, melting, and most recently superheating of the Pb(111) surface, have been performed.

We reported (Phys. Rev. Lett. 71, 1023 (1993), and App. Surf. Sci. (in press, 1995)), on

molecular dynamics simulations of laser irradiation of copper surfaces, which differ from continuum treatments of such phenomena and previous simulations by explicitly including the temporal laser excitation of the electrons and their coupling to the microscopic dynamics of the nuclear degrees of freedom which are modeled using realistic interactions. Our simulations demonstrate that under irradiation conditions for which the Cu(110), as well as Cu(100), surfaces undergo melting, superheating of perfect as well as damaged Cu(111) occurs, in correspondence with recent experiments. Moreover, under the same conditions, a damaged Cu(111) surface (containing initially a large vacancy cluster and an adlayer island) superheats and anneals, restoring perfect crystalline order, via a nondiffusional mechanism involving local incorporation (embedding) of adlayer atoms and subsequent cooperative displacements of the host surface layer atoms to fill the vacancy region. This finding is of particular relevance in light of the experimental observations, where the sample surfaces are most likely to contain, even under equilibrium conditions, a certain fraction of spontaneously generated defects which could serve as nucleation centers for melting, and is related to the energetics of the (111) surface.

Basic and technological interest in the physical properties of small materials structures, and in locally controlled surface modifications, underlie intensifying research endeavors in this area. Using molecular dynamics (MD) simulations, we have explored the structure, energetics, dynamics, stability, and collapse mechanisms of surface-supported metallic nanostructures which are key issues in preparation, control, and exploitation of such structures (Phys. Rev. Lett. 73, 569 (1994)).

We showed that heterostructures, such as a three-dimensional (3D) crystalline gold cluster (dot) deposited on a Ni(100) surface, where the lattice mismatch is large (16%) and the surface energy of the nickel substrate is larger than that of the deposited Au dot, can collapse via a

nondiffusional solid-on-solid settling (SOSS) mechanism. The SOSS process involves a succession of layer-by-layer incorporations (embedment) of Au atoms from a given layer into the underlying Au layer, accompanied by subsequent cooperative stress relief via lateral displacements of atoms in the underlayer. These processes result ultimately in transformation of the initial 3D structure into a 2D adsorbed gold island whose area grows linearly with time. On the other hand a homostructure, e.g., a 3D crystalline gold cluster deposited on an Au(111) surface, adsorbs epitaxially (in registry) with the substrate, exhibits enhanced stability and collapses at elevated temperatures via a dislocation mediated settling (DMS) mechanism, involving vacancies generated by surface dislocations in the deposited Au cluster. These novel atomic-scale mass transport and collapse mechanisms and the interplay between interfacial energetics and structure which they portray, pertain to a number of interfacial processes (e.g., deposited nanostructures, thin-film growth, annealing of damage, surface manipulations, and nanoscale lithography).

(iv) All Quantum Molecular Dynamics Simulations (AQMD)

A novel method of simulations, combining electronic structure calculations of ground-state Born-Oppenheimer potential energy surfaces, with a quantum path-integral treatment of the ionic degrees of freedom, was developed and applied to protonated water (i.e., hydronium- H_3O^+) and small water clusters (Chem. Phys. Lett. 237, 161 (1995), and J. Phys. Chem. 99, 7731 (1995)).

The new method opens the way to ab-initio simulations of processes involving tunneling of light nuclei (such as protons in ice, aqueous reactions and certain atmospheric processes, and hydrogen transport in metals).

(v) Size-Evolutionary Patterns and Nanocrystals

Understanding the origins of size-evolutionary patterns of physical and chemical properties of clusters, from the molecular to the condensed phase regimes, is one of the main goals of research in the area of clusters. Two major accomplishments of the research, pertaining to this issue are:

(a) Investigations of electronic shell effects in triaxially deformed metal clusters elucidated the origin of odd-even oscillations observed in abundance and electronic spectra of such systems.

These calculations revealed that deformations of the cluster shapes, which destroy the previously assumed spherical symmetry, lift degeneracies in the electronic spectrum, and underlie the above mentioned oscillations (Phys. Rev. B 51, 1902 (1995)).

(b) The creation of perfect single crystallites, identically replicated in unlimited quantities, in a state that can be handled, manipulated, treated and understood, is an ultimate challenge of modern materials science with outstanding fundamental and potential technological consequences.

Combined theoretical and experimental efforts aimed at the synthesis, processing, isolation and characterization of monodispersed nanocrystalline gold assemblies resulted in a significant advance in this area of research. The theoretical studies revealed that the optimal structures of gold nanocrystals in the range of a few tenth to thousands of gold atoms, belong to a definite structural motif, consisting of finite fcc lattices with a truncated octahedral (and variants thereof) morphology. These theoretical predictions were verified by experiments (mass spectrometry, high-resolution electron microscopy, and x-ray diffraction) on fractionated samples of gold nanocrystals, passivated by self-assembled monolayers, which have been isolated as distinct, pure molecular materials of high intrinsic stability. Furthermore, theoretical and experimental investigations of three-dimensional superlattice assemblies of such passivated gold nanocrystals revealed distorted bcc superlattices, involving ordering of the molecules in the passivating layers.

These materials, which exhibit properties of solid state objects with highly quantized lattice structures, energy levels, and band fillings, are of great fundamental as well as technological interest due the potential ability to control magnetic, optical and transport properties via size-selection of the nanocrystalline building blocks (Nature, submitted, 1995).

3. Personnel

Research under this grant is performed by the Principal Investigator (Uzi Landman, Callaway Chair and Regents' Professor), two Senior Research Scientists (Robert N. Barnett, and Charles L. Cleveland), and a graduate student. Other members of the Center for Computational Materials Science directed by Landman, participate in various facets of the research program.

4. Publications

1. "Stability and Collapse Mechanisms of Adsorbed Metallic Structures", W. D. Luedtke and U. Landman, Phys. Rev. Lett. 73, 569 (1994).
2. "Phase Coexistence in Clusters", C. L. Cleveland, U. Landman, and W. D. Luedtke, J. Phys. Chem. 98, 6272 (1994).
3. "Aharonov-Bohm and Aharonov-Casher Tunneling Effects and Edge States in Double Barrier Structures", E. N. Bogachek and U. Landman, Phys. Rev. B 50, 2678 (1994).
4. "Molecular Evaporation and Condensation of Liquid n-Alkane Films", T. K. Xia and U. Landman, J. Chem. Phys. 101, 2498 (1994).
5. "Dimensionality Crossovers of the σ Plasmon in Coaxial Carbon Nanotubes", C. Yannouleas, E. N. Bogachek, and U. Landman, Phys. Rev. B 50, 7977 (1994).
6. "Properties of Metallic Nanowires: From Conductance Quantization to Localization",

- J. I. Pascual, J. Mendez, J. Gomez-Herrero, A. M. Baro, U. Landman, N. Garcia, W. D. Luedtke, E. N. Bogachek and H.-P. Cheng, *Science* 267, 1783 (1995).
7. "Studies of Excess Electrons in Sodium-Chloride Clusters and Excess Protons in Water Clusters", R. N. Barnett, H.-P. Cheng, H. Hakkinen and U. Landman, *J. Phys. Chem.* 99, 7731 (1995).
 8. "Electrical and Mechanical Properties of Metallic Nanowires: Conductance Quantization and Localization", J. I. Pascual, J. Mendez, J. Gomez-Herrero, A. M. Baro, U. Landman, N. Garcia, W. D. Luedtke, E. N. Bogachek, and H.-P. Cheng, *J. Vac. Sci. Technol. B* 13(3) 2498 (1995).
 - 9 "Electronic Shell Effects in Triaxially Deformed Clusters: A Systematic Interpretation of Experimental Observations", C. Yannouleas and U. Landman, *Phys. Rev. B* 51, 1902 (1995).
 10. "All Quantum Simulations: H_3O^+ and H_5O_2^+ ", H.-P. Cheng, R. N. Barnett, and U. Landman, *Chem. Phys. Lett.* 237, 161 (1995).
 11. "Energetics, Structure and Excess Electrons in Small Sodium-Chloride Clusters", H. Hakkinen, R. N. Barnett, and U. Landman, *Chem. Phys. Lett.* 232, 79 (1995).
 12. "Equilibrium Interphase-Interfaces and Premelting of the Pb(110) Surface", A. Landau, P. Wynblatt, H. Hakkinen, R. N. Barnett, and U. Landman, *Phys. Rev. B* 51, 10972 (1995).
 13. "Nanotribology: Mechanisms and Consequences", B. Bhushan, J. Israelachvili, and U. Landman, *Nature* 374, 607 (1995).
 14. "Edge States, Aharonov-Bohm Oscillations and Thermodynamic Properties of an Antidot in a Two-Dimensional Electron Gas", E. N. Bogachek and U. Landman, *Phys. Rev. B* (in press, 1995).

15. "Nano-Elastohydrodynamics: Molecular Dynamics Simulations of Asperity-Asperity Interactions in Lubricated Junctions", J. Gao, W. D. Luedtke, and U. Landman, Science (in press, 1995).
16. Nano-Crystal Gole Molecules", W. L. Whetten, J. Khoury, I. Vezmar, S. Murthy, C. L. Cleveland, W. D. Luedtke, and U. Landman, Nature (1995).

5. Presentations

(a) Conference Lectures (U. Landman)

- Invited Speaker, "International Conference on Surfaces and Thin Films, ICSFS-7", Hsinchu, Taiwan, December, 1994.
- Invited Speaker, MRS Meeting, Boston, December 1994.
- Invited Speaker, AAAS Annual Meeting, Atlanta, Georgia, January, 1995.
- American Physical Meeting (8 talks), San Jose, CA, March, 1995.
- Invited Speaker, American Chemical Society, Annaheim, CA, April, 1995.
- Invited Speaker, American Association of Black Physicists, Atlanta, GA, April, 1995.
- Invited Speaker, NATO Advanced Study Institute, International School of Solid State Physics, 6th Course, "Large Clusters of Atoms and Molecules", E. Majornan Centr for Scientific Culture, Erice, Italy, June, 1995.
- Invited Speaker, International Conference on "Physics of Sliding Friction", International Center for Theoretical Physics, Trieste, Italy, June, 1995.
- Invited Speaker, International Conference on "Computational Methods in Materials Science and Engineering", International Center for Theoretical Physics, Trieste, Italy, June, 1995.
- Invited Speaker, Gordon Conference on "Metal and Semiconductor Clusters", New Hampshire, August, 1995.
- Invited Speaker, "Tribology Workshop", Orono, Maine, August, 1995.
- Keynote Speaker, CCP5 Annual Meeting, "Advanced Computer Simulations of Materials", Daresbury, England, September, 1995.
- Keynote Speaker, International Conference on Clusters, Barcelona, Spain, September, 1995.
- Invited Speaker, 3rd International Symposium on Atomically Controlled Surfaces and Interfaces, Raleigh, N. C., October, 1995.

- (b) Several of our research findings were reviewed and/or highlighted by popular science

magazines, industrial, engineering, and R&D journals and news releases, and by the media. These include:

- Science News.
- Advanced Materials and Processing (June, 1995), p. 4.
- Industry Week (May 1, 1995), p. 46.
- Materials Research Society Bulletin (May, 1995).
- Inside R&D Magazine, (April 12, 1995).
- Appearance by U. Landman on the "Quirks and Quarks" program, broadcasted by the Canadian Broadcasting System, in February 1995.

6. Professional Appointments

- (i) Appointment of U. Landman in 1994 to the Editorial Board of "Tribology International".
- (ii) Appointment of U. Landman in 1994 to the Editorial Board of the Journal of Physical Chemistry.
- (iii) U. Landman was appointed in January 1995 as the Fuller E. Callaway Professor in Computational Materials Science, at the Georgia Institute of Technology.

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OF MATERIAL INTEREST

'Nanowire' dimensions influence properties

Electrical, mechanical, and other properties of microscopic wires change significantly as their widths narrow to the nanoscale—less than 10 atoms—report scientists from Georgia Institute of Technology, Atlanta, and Universidad Autonoma de Madrid, Spain, in the 24 March issue of *Science*.

Information about materials systems of greatly reduced dimensions is relevant to the production of advanced electronic devices because the need for miniaturization is driving engineers to design smaller and smaller components.

"Small is different," emphasizes Uzi Landman, director of Georgia Tech's Center for Computational Materials Science. "In the desire to reduce the size of electronic devices, there are certain effects pertaining to size and dimensions that must be considered. If you go below a certain limit of size, you should beware because the behavior of the system may not be what you would expect on the macroscopic level."

The researchers found that under certain conditions, the ability of these ultrathin "nanowires" to conduct electricity declines to the point that they resemble insulators.

Experiments: Scientists in Madrid created the nanowires by pushing the tip of a scanning tunneling microscope (STM) probe into a gold surface. As predicted by molecular dynamics simulations, the tip carried gold atoms with it when it was retracted, producing fine wires ranging in length from 5 to 40 nm (50 to 400 Å). As the tip was pulled back farther, the wire elongated and eventually broke.

Experimental measurements of electrical conductance during tip retraction also were compared with the results of molecular dynamics simulations. According to Landman, the elongation process revealed in the simulation involves periodic oscillations of the pulling force. "These oscillations," he says, "reflect the atomic-scale mechanism of elongation, which proceeds layer-by-layer

Molecular dynamics simulation shows the formation of a thin "nanowire" between a gold surface and the probe of an STM. Courtesy Georgia Institute of Technology, Atlanta.

as stress accumulates up to a certain limiting value. After that point, relief of the stress occurs through the formation of a new layer and a corresponding reduction in the diameter of the wire."

This process is reflected in nanowire conductance. "The current through the wire varies in a stepwise manner as a function of the tip displacement away from the substrate," explains Landman, "which translates into elongation of the wire. We saw that the jumps in the conductance occurred with a periodicity of about the interlayer spacing in the wire. Moreover, the conductance changed in each stage in steps whose height was one or two times a unit known as the 'conductance quantum,' a measure of electrical resistance in very small conductors."

The conductance measurements revealed a repeating pattern in which the conductance exhibited dips corresponding to enhanced degrees of disorder in the wires during elongation. The increases in the conductance subsequent to each of these dips were correlated with a restoration of a higher degree of order in the elongated wire.

A first: The researchers also observed nonlinear dependence of the electrical resistance as a function of the voltage across the wire. "While at a fixed point of elongation, short

wires (less than 5 nm) showed linear and regular ohmic characteristics," states the Georgia Tech researcher, "but the nature of the resistance trace changed as the wire became longer and more narrow, going through a stage in which it looked very much like a semiconductor." At lengths of 15 to 20 nm, the wires behaved more like insulators. The researchers subsequently related this behavior to a phenomenon known as "Anderson localization."

Landman believes this study is the first in which Anderson localization has been observed in a three-dimensional system at room temperature. The phenomenon had previously been observed only in one-dimensional "whiskers" at cryogenic temperatures.

The study's results have practical implications for designers of microelectronics equipment. "If we are to reduce the size of microelectronics systems, connecting wires between elements of such devices must be reduced in size, and, therefore, such quantization patterns of conductance could start to appear," says Landman.

For more information, contact Dr. Uzi Landman, Center for Computational Materials Science, Georgia Institute of Technology, Atlanta, GA 30332; tel: 404/894-3368; fax: 404/853-9958.

M R S BULLETIN

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Gold Nanowires Exhibit Insulating Properties

Researchers at the Georgia Institute of Technology and the Universidad Autonoma de Madrid in Spain have reported the results of experimental and supercomputer-based simulations of electronic transport and mechanical elongation in ultrathin metallic wires.

In the March 24 issue of *Science* the researchers reported that under certain conditions, the ability of the nanowires to conduct electricity declines to the point that they resemble insulators. Conductance of such atomic-scale gold wires depends on their length, lateral dimensions, the state of atomic order and disorder, and the elongation mechanism of the wires.

To study the phenomena, researchers at the Universidad Autonoma de Madrid created tiny nanowires by bringing the tip of a scanning tunneling microscope (STM) near a gold surface and applying an electrical voltage, or by pushing the tip into the surface, and then retracting the tip to carry away gold atoms in the form of tiny wires between 50 and 400 Å in length.

The researchers studied electrical conductance as they pulled the tip away from the surface, elongating and eventually breaking the nanowire. The experimental measurements were correlated with predictions obtained from molecular dynamics simulations performed by the Georgia Tech research group.

"The simulated elongation process reveals a mechanism exhibiting periodic oscillations of the pulling force," said Uzi Landman, director of Georgia Tech's Center for Computational Materials Science. "These oscillations reflect the atomic-scale mechanisms of elongation, which proceeds layer-by-layer as stress accumulates up to a certain limiting value. After that point, relief of the stress occurs through the formation of a new layer and a corresponding reduction in the diameter of the wire."

The elongation process is also reflected in the conductance of the nanowires.

The wire current varied in a stepwise manner as the wire narrowed. "We saw that the jumps in the conductance occurred with a periodicity of about the interlayer spacing in the wire," Landman said. "Moreover, the conductance changed in each stage in steps whose height was one or two times the conductance quantum, a measure of electrical resistance in very small conductors."

The conductance measurements revealed a repeating pattern in which the conductance exhibited dips corresponding to enhanced degrees of disorder in the wires during elongation. The increases in the conductance subsequent to each of these dips was correlated with a restoration of a higher degree of order in the elongated wire. Such a repeating pattern manifested itself as the thickness of the wire dropped below five to 10 atoms.

In wires between 50 and 400 Å in length, the researchers

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observed nonlinear dependence of the electrical resistance as a function of the voltage across the wire. As the length of the narrow wires increased, the conductance decreased and ultimately the wires behaved more like insulators than metallic conductors.

"While at a fixed point of elongation, wires that are short (less than 50 angstroms) showed linear and regular ohmic characteristics, but the nature of the resistance trace changed as the wire became longer and more narrow, going through a stage in which the wire looked very much like a semiconductor," Landman said. "Eventually, the very long wires—up to 150 or 200 Angstroms—began to appear insulating."

Based on the observations, the group developed a formula for the nonlinear behavior of the resistance of the long wires and related it to a phenomenon known as Anderson localization.

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Emerging Technologies

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PROPERTIES AT NANOSCALE

The molecular dynamics simulation shows the formation of a thin "nanowire" between a gold surface and an STM probe.

"SMALL IS DIFFERENT," CONCLUDES DR. UZI LANDMAN, DIRECTOR OF THE Georgia Institute of Technology's Center for Computational Materials Science, Atlanta. "In the desire to reduce the size of electronic devices, there are certain effects pertaining to size and dimensions that must be considered. If you go below a certain limit of size... the behavior of the system may not be what you would expect on the macroscopic level."

Smart Card

Prevents car theft

SHOWN IS THE SIEMENS CORP. CHIP card, one of two ways the company is using electronic transponders to fight car theft. The other incorporates the passive transponder in a key. In the U.S., Siemens Automotive, Auburn Hills, Mich., is teaming with a major key/lock supplier to the automotive industry.

Circle 26

Research synergy

Biologists and engineers team up

IN AN EFFORT TO BUILD RESEARCH synergy between biologists and engineers, the Massachusetts Institute of Technology has established a multidisciplinary Center for Biomedical Engineering under director Douglas A. Lauffenburger. Research at the Cambridge, Mass., center is organized in three areas—molecular engineering, cell and tissue engineering, and physiological systems engineering. All three will team in projects such as developing microrobotic surgical instrumentation.

Data warehousing

Relief or relic?

THE PROBLEM, SAYS FORRESTER Research, is that global data warehouses are often unused and ignored by end users who have neither the time nor the training to navigate these oceans of centralized data. In a new report, "Banquet for the Data Hungry," it argues that desktop tools plus "datamarts"—local databases targeted to specific end-user needs—better address corporate data-access needs, similar to specialized boutiques in a mall. But before building a datamart, it cautions that MIS must talk to the prospective end users. "Then it must extract and transform the data that specific end users need into usable formats and give these users the tools and training to get at the data."

STM video

Clarifying the image

WANT THE clearest still images possible from video? Take into account not only the motion between frames (a widespread practice), but also the motion that takes place while an image is captured, say researchers at the University of Rochester, N.Y. The technique has potential for forensics and satellite imaging, as well as the convergence of TV, computers, and video.