MATERIALS SCIENCE AND ENGINEERING DEPARTMENT

IOWA STATE UNIVERSITY

MSE ELEMENTS

Vol. 11, No. 2

MSE Professor Vladimir Tsukruk investigates ways to protect micro-electro-mechanical devices from the ravages of time and prolonged use.

700 nm DESIGNING POLYMERS

As microelectronic devices, used in everything from satellites to *in vivo* drug delivery systems, continue to shrink in size to the point of becoming imperceptible to the naked eye, MSE Professor Vladimir Tsukruk is investigating ways to protect them from the ravages of time and prolonged use.

"Our goal is to protect a new generation of micro-electro-mechanical systems (MEMS) that have moving parts in the range of several dozen micrometers, or the dimension of two strands of hair," explains Tsukruk.

A continuing National Science Foundation grant over the past six years has enabled Tsukruk to design sophisticated, ultrathin polymer coatings that help shield these incredibly small micromachines from a variety of mechanical, chemical, and environmental stresses.

"Although silicon is an ideal electronic material for sensors because of its capability for lithography and microfabrication, it does not interact very well with the environment. When you apply local stress, it cracks easily and is not chemically very stable," said Tsukruk. Much like lubricants in engines, polymer thin films protect the silicon surface in MEMS from electromechanical stress and surface damage caused by the friction of moving parts.

Coatings that are currently available have short life spans, and as a result chemical etchings on silicon surfaces wear out easily. Tsukruk's research focuses on engineering an interface with electronic materials that interacts ideally with the environment. Polymer thin films, says Tsukruk, offers an interface that is specially suited to the task of extending the life span and enhancing the performance factor of MEMS.

At his Surface Engineering and Molecular Assemblies Lab (SEMA), Tsukruk and a multi-disciplinary team of 12 postdoctoral, graduate, and undergraduate students from chemistry, chemical engineering, physics, and computer backgrounds are working on a variety of issues associated with interfacial polymer behavior at the nanoscale. Using advanced scanning probe microscopy (SPM), Tsukruk's group conducts studies on the microstructure of polymer molecular films and also probes their nano-mechanical and nanotribological properties. SPM has the capacity to recognize a single molecule and also monitor single molecular layers with nanoscale resolution under ambient conditions like gas, humid air, and under fluids.

So, what makes polymers a logical material for surface protection?

"Silicon inherently has a huge surface energy, so micro-particles in the air stick to its surface easily," said Tsukruk. This adhesion factor, moreover, results in their enormous attraction to each other, where the numerous moveable parts in microdevices have a tendency to cling to each other during the assembly process. Polymers, on the other hand, are known

Continued on page 6

Greetings from the MSE department!

We have accomplished a great deal in the department since last fall. In September, we successfully completed the ABET accreditation review under new EAC 2000 criteria. Although our new materials engineering curriculum didn't award its first diploma until three months after the ABET visit, the process we followed in developing and documenting the program was well received by the examiner. We have not received the official report yet, but we believe the visit went extremely well. Everyone involved in our curriculum development (faculty, students, the Industrial Advisory Council, and alumni) deserves a big "thank you." In particular, I want to extend my deepest appreciation to Professor **Kristen Constant** for the long hours she spent preparing the self-study document.

Fall semester began with a record number of freshmen. A significant fraction of the incoming students had enough credits through advanced placement courses and test-outs to be classified as sophomores at the end of their first semester. This indicates the superb quality of the incoming student body. We are indebted to Professor **Larry Genalo** for his outstanding recruitment efforts.

Our graduate enrollment is near an all-time high of 65 students. Based on the applicants so far, we expect to top this number next year. One significant accomplishment last semester was the restructuring of the graduate program. Professor **David Cann** and the Graduate Studies Committee revised the requirements for the Ph.D. degree. We believe the new guidelines, which have received overwhelming support from faculty and students, will improve the quality of our program and more effectively guide students toward their degrees.

Our faculty continue to achieve new milestones in innovative research, which includes Professor **Vladimir Tsukruk's** new project characterizing polymer thin films and their application in microelectronic devices. You can read more about this exciting research in this issue.

We are also embarking on an ambitious initiative to provide international experience for our students through exchange programs with the University of Limerick in Ireland and the University of Grenoble in France, in addition to those already in existence with Brunel University in England and Bogazici University in Turkey. We are looking for multinational companies that can provide work experiences to our students abroad.

Our students are also harvesting much-deserved scholarships, awards, and other recognitions. The fraction of our students receiving these awards is much higher than in any other engineering department at ISU. Again, this is a clear indication of our students' talent and hard work. We are especially proud that **Stephanie Connor** received the Dean's Leadership Award, one of only two awards given in the entire College of Engineering. We are indeed fortunate to have such excellent students!

Finally, we will be holding a reception at the American Ceramic Society's annual meeting in Indianapolis on Monday, April 23rd, in the Austin Room at the downtown Indianapolis Marriott hotel. Many of our faculty and students will attend. Please join us there.

Mufit Akinc, Professor and Chair

Down to the fundamentals in processing science

A Department of Energy program, initiated in Spring 2000, is offering exciting funding opportunities in the area of processing techniques of metals, alloys, polymers, and ceramics. The Process Science Initiative (PSI) is administered by the Materials Preparation Center, a DOE research facility at ISU that specializes in preparing small-scale quantities of high-purity, novel materials that aren't available from commercial sources. The primary emphasis of the initiative, which invites proposals from across the country, is to expand the knowledge base of processing science or the method by which materials are synthesized to give them specific properties such as their microstructure, strength, and formability.

"Ames Lab scientists and MSE faculty are quite active in process science research," said PSI Manager and MSE Assistant Professor **Brian Gleeson**, which explains the scope and number of past projects and those that have been funded recently.

The 2000 PSI projects included

- a study of the melt-spinning technique and solidification process of liquid metal, conducted by Adjunct Associate Professor **Matt Kramer** and a team of Ames Lab scientists
- an analysis of the properties of liquid interfaces that can eventually lead to a model of crystal shape development, headed by Assistant Professor **Ralph Napolitano**
- a project investigating the production process of zirconium-tungstate, a ceramic material that contracts rather than expands when heated. Combining this material with other metals opens exciting possibilities of being able to "tune" the composite material's coefficient of thermal expansion. This study was conducted by Assistant Professor **David Cann** and Adjunct Assistant Professor **Dan Sordelet**.
- a study of how the deformation process affects a compound to provide ductility to inherently brittle crystal structures. Conducted by MSE Distinguished Professor **Karl Gschneidner, Jr.**, the project could affect the deformation process of a material, from rolling it into sheets to forming tubes.

Projects for the year 2001 include a continuation of the first two research investigations mentioned here and new initiatives in polymer gels and high-pressure gas atomizers. Assistant Professor **Surya Mallapragada's** goal is to develop polymer gels that swell or contract in response to pH or temperature changes. One application for such polymers is in the area of *in vivo* drug delivery.

Toying with Technology

"Toying with Technology," an engineering literacy program for K-12 students, visited the Iowa School for the Deaf (ISD) in Council Bluffs last November.

Coordinator and MSE Professor Larry Genalo, **along with ISU education majors and undergraduate engineering lab assistants, used materials-based interactive demos to make the connection between classroom science and "real world" engineering problems that occur in situations like the Challenger explosion and the sinking of the Titanic. Students successfully designed, built, and operated mobile, autonomous robots made from LEGOs and completed problem-solving tasks using these robots. A grant from Iowa State University is providing $4,000 worth of equipment for ISD.**

"In general, both the robotics and the demos generate great interest in engineering among K-12 students. The ISD students were no different in this respect. It was different for us to watch them work silently in teams, communicating through sign language as they solved problems collaboratively," said Genalo.

Corrosion Workshop (at Rockwell Collins)

Remaining proactive to industry needs is an abiding interest and priority of the MSE department. Case in point is Assistant Professor Brian Gleeson's **five-week on-site oxidation and corrosion workshop at Rockwell Collins, which took place last fall.**

Gleeson traveled to Cedar Rapids once a week to teach an all-day intensive corrosion technology course. More than twenty Rockwell Collins engineers participated in this professional development venture that also incorporated graduate-level material for part-time students who are working toward advanced degrees.

"We sort of double-dipped with the workshop by offering extra hours for a graduate course," said Gleeson. Working with Nicole Cavanah, a Rockwell Collins employee and part-time master's degree student from MSE, Gleeson was able to accomplish goals suitable to both industry and the university.

Rockwell Collins engineers wanted to expand their knowledge of corrosion because many of their products are installed in locations susceptible to corrosive elements. "In a naval ship, for example, the sea atmosphere often leads to corrosion of communication equipment," explained Cavanah.

"I took the initiative to solicit interest from employees and their specific issues related to corrosion," said Cavanah. "Dr. Gleeson then developed a course appropriate for Collins' engineers." To this end, students brought in actual samples of corrosion they were experiencing in products. "We'd go through the material to see what was the likely cause for corrosion and what would be ways to mitigate the problem or what would be a better material to use."

On the flip side, the workshop itself became an ideal recruiting mechanism. Gleeson reports that a few of the Rockwell Collins employees signed up for MSE's graduate program. Mostly, Gleeson was pleased with the interaction where "you're always learning something new that adds to your existing knowledge." And Cavanah confidently speaks for the engineers when she says, "they found the class beneficial in ways they could apply their knowledge to the job."

A proposal by MSE Associate Professor Scott Chumbley **and MSE Chair** Mufit Akinc **will expand an existing exchange program with Brunel University in Uxbridge, England, giving students an opportunity to experience life in another country while they take a basic materials course for credit on its campus.**

To increase student participation in this international venture, MSE is also opening the program to the mechanical engineering and industrial and manufacturing systems engineering departments, whose curriculum may require a materials component.

The MSE proposal is a result of Project IMPACT (International Multi-Partner Action), a college initiative that encourages faculty and students to gain engineering-related experience abroad. The six-week course will be divided into four weeks of classes taught by MSE and Brunel faculty, followed by industry tours and a visit to historical and cultural sites.

Why Brunel?

"I visited Brunel University while on faculty improvement leave in 1992 and was impressed with the faculty, campus, and desire to interact with us," said Akinc. Moreover, the unique advantage of Brunel is its proximity to London, which means that students don't have to live in a large, expensive city to enjoy all its amenities.

Akinc sees several advantages: international experience for faculty, interaction that fosters future research collaboration, insights into industrial practices abroad, and opportunity to recruit highly qualified Brunel students to graduate programs here at ISU.

The plan also reinforces department objectives of increasing international exposure to faculty and students by more than 70 percent and firmly sets MSE on the path to achieving college goals for increasing overseas professional and academic experiences for faculty and students.

Students will attend a series of lectures on British and European history for an additional three credits to help them meet international perspectives requirements in their overall curriculum. An MSE faculty member will accompany the students as co-instructor and program coordinator for the entire six-week period.

"A course like this will provide opportunity for practically every engineering student to participate. In addition, these students will also be able to meet their social science and humanity elective as well as their diversity course requirements," said Akinc.

MSE faculty
on assignment in England

A six-month faculty improvement leave has taken MSE Associate Professor Scott Chumbley **to Petersborough, England. Chumbley is assisting the materials division of Perkins Engines, a manufacturer of small diesel engines, in its efforts to tackle a wide range of engine component failures and the problems that arise during the manufacturing process. Perkins was recently acquired by Caterpillar, which uses the engines in its line of small construction equipment.**

Chumbley's task centers on arriving at solutions through careful analysis and assessment of design and manufacturing problems. "In failure analysis, experience is everything," he explains. "It's easy to teach the techniques and the methods used to conduct a failure investigation." But more challenging, he adds, is the task of teaching "how to look at the evidence, recognize the primary failure, and determine secondary damage produced after the failure has occurred."

"We are also working on developing improved engine components, which, if successful, will be a major step forward for them," said Chumbley. Experiences accrued from this assignment include understanding the constraints and problems of manufacturing, applying knowledge gained to similar problems in industries and manufacturing practices close to home, and utilizing "real-world" engineering situations in the form of examples and problems within the classroom setting.

Professional insights aside, the fringe benefits of working abroad are fascinating memories that Chumbley is sure to bring back with him. To date, he reports visiting a Bronze-age site inhabited 3,000 years ago, ruins that existed long before Columbus discovered America, and traveling on old Roman roads. In fact, he adds, "people have a whole different perspective on history here."

MSE students abroad

Whether it's adjusting to the sound of an unfamiliar English accent, spotting marsupials on a different continent, or just getting a taste of university life elsewhere in the world, MSE students are there to experience it all. Here's what they have to share:

Rachel Neuendorf, **MSE junior, currently is studying materials engineering for a semester at the University of Wales in Swansea, Wales.**

"Most degrees are completed here within three years. All the classes are taught within the MatE department. You don't have to take any electives and will have the same schedule and are with the same students for all three years." Also, Neuendorf adds, "the campus is along the coast, which is quite a change from Lake Laverne!"

Bryce Campbell, **MSE senior, experienced life overseas two consecutive years. Summer of 1999 took him to Lyon, France, for eight weeks as part of the Iowa Regents Program.**

"I took classes on French history, geography, as well the language itself." The next summer, Bryce spent five months in Grenoble, France, where he attended the INPG (Institut National Polytechnique de Grenoble) summer program and interned with Schneider Electric for three months.

Alan Tkaczyk, **MSE senior, did a stint at the University of New South Wales in Sydney, Australia.**

"Since I wanted to go exploring a bit, the professor lent me his waders and, without issue, I roamed the swampland looking for native marsupials. That fantastic weekend showed me the power of teamwork that involved everyone with a few duties."

Dean's Leadership Award

For MSE senior **Stephanie Connor**, building leadership skills was a small matter of heeding some very sound advice. "I was very shy in high school, but my mom encouraged me to take speech to help me become comfortable talking in front of others," she said. Her confidence in public speaking has proved indispensable at Iowa State, but it is Connor's dedication, strong work ethic, and ability to inspire that has earned her college-wide recognition and respect.

Connor received the 2001 Dean's Leadership Award for leadership in college, university, community, and professional organizations.

Connor's list of activities at Iowa State is long and formidable. To name just a few—she was president of both the American Society of Materials (ASM) and the Keramos Engineering Honors Fraternity in the same year; Student Alumni Leadership Council co-chair and representative for 3 1/2 years; Honors Student Board treasurer; a residence hall representative; member of the ISU wind ensemble and symphonic band; and an intramural sports participant.

"Stephanie is a human dynamo, who has invigorated each of the many ISU organizations she has worked with during her four years here," said MSE Associate Professor Alan Russell.

Her academic accomplishments are no less impressive. Named to several honor societies and a recipient of four scholarships including the Iowa Academic Recognition scholarship, Connor has demonstrated exemplary academic performance during her years at ISU. She graduates this spring with a B.S. degree in materials engineering. Most students choose two of four areas of emphasis in the MatE curriculum. Connor chose three.

In the MSE department, Connor initiated a mentorship program for freshmen and sophomores to keep students academically motivated and on track. As president of ASM, she energized the organization to achieve national visibility by coordinating special events and increasing student participation. Her outstanding contributions to the materials science and engineering field earned her the 2000 ASM International Foundation scholarship.

"She leads by example and inspires others to become involved too," said MSE Associate Professor Scott Chumbley, who is Connor's academic advisor.

Future plans include completing the fundamentals in engineering exam series to get licensed as an engineer, after which she hopes to work for a few years with aspirations of acquiring an M.B.A. degree along the way. Success notwithstanding, Connor is appreciative of the support she has always received from MSE faculty. "Everybody makes a point to get to know you," she said. Most of all, she feels heartened to be recognized beyond department circles. "It means that I've created a visible impact on influencing others in a positive way," she said.

MSE

MSE is excited about its future home in Hoover Hall. Construction is likely to begin this summer, according to MSE Professor Steve Martin, who chairs the department's facilities and equipment committee.

"Hoover Hall will be a marvelous facility that will reflect MSE's academic presence in the college and university," said Martin. "It will also give a solid home and identity for our students."

Although construction has been delayed, it has allowed the department to rethink its use of Hoover Hall. MSE administrative and faculty offices will now be housed on the second floor of the three-story, 60,000 square-foot high-tech teaching and research facility. The third floor will be dedicated to the department's teaching and research programs. The first floor will be shared between industrial and manufacturing systems engineering and mechanical engineering disciplines and general classrooms.

In the original plan, the electronic, ceramics, polymers, and metallurgy programs were split between Gilman and Hoover Hall. Careful discussions involving students, faculty, and staff, combined with a 2,000-sq. ft. expansion, led to relocating all undergraduate classrooms and labs and research programs in need of space to Hoover. Support labs for thermal processing, mechanical characterization, SEM, x-ray, and thermal analysis will also be consolidated in Hoover. Total space occupied by MSE in the new building will be 17,000 square feet.

Space vacated in Gilman will remain with MSE to expand its research labs in metals, polymers, ceramics, and electronic materials. Gilman is ideally situated for faculty who work in collaboration with Ames Laboratory and ISU's chemistry and physics departments, said Martin.

Martin sees enormous benefits with this new configuration, from ease in recruiting and a sense of community to proximity to other engineering buildings and college administrative offices. And, yes, plans are still intact for a skywalk between Hoover and Howe, confirms Martin.

Hoover Hall comprises Phase II of the Engineering Teaching and Research Complex. The building has been named in honor of Donna and Gary Hoover, BSME'61, in recognition of their generous gift of $3 million to the College of Engineering. The total expected cost of the building is $27 million.

Hoover Hall *(update)*

Designing polymers

Continued from page 1

for their low surface energy. "Like Teflon reduces friction, coating silicon chips with polymers reduces the adhesion factor as well as the friction." In the case of silicon chips, moreover, polymers have to be applied to parts at the nano-scale level, where the gap between moveable parts is extremely minute.

Fabricating polymers that are uniquely suited to this task, says Tsukruk, entails several challenges, not just in design and methodology, but in their capability to bind with silicon to enable it to do its job. One method for developing specially tailored polymer coatings involves using a chemical deposition technique, called chemical self assembly. In this technique, the right set of molecules that operates within functional groups is used to form a robust and uniform molecular coating that is chemically grafted to the surface.

"A typical problem with nano-scale coatings is that they don't necessarily remain stable or uniform." In which case, it's all the more necessary, says Tsukruk, to "understand the chemical microstructure and properties of the polymer layering process." To this end, Tsukruk has developed a self assembly technique of flexible and compliant layers that give the coatings stability hitherto rarely achieved. This method has received enthusiastic reviews in materials science and engineering publications.

Currently, with support from his most recent NSF grant, Tsukruk is researching a new class of polymers, called hyperbranched and dendrimer polymers, whose tree-like molecular structure shows promise of forming well-organized, dense-ordered polymer layers with tailored surface chemical functionalities.

"Because of their unusual molecular architecture, these macromolecules behave uniquely as interfaces as was evident in a recent real-time x-ray study of their single molecular layer at Argonne National Laboratory's Advanced Photon Source facility," said Tsukruk.

Apart from polymer applications in the micro-electronics industry, Tsukruk is exploring their use in biomimetics or the biological thermal sensing arena. "The premise of this project is that there are many exciting things happening in nature that open up novel approaches to solving problems."

Tsukruk and colleagues are studying the night vision and heat detecting sensitivity of snakes with the ultimate goal of designing "soft-matter"-based thermal sensors. The project is funded by the U.S. Airforce for Scientific Research and is part of a consortium of four other centers, including the University of Texas at Austin, Texas A&M University, Florida Institute of Technology, and the Air Force Research Lab.

Other MEMS coatings

MSE Associate Professor Alan Russell and Mechanical Engineering Professor Pal Molian are studying the possibility of applying wear-resistant coatings to critical surfaces of MEMS devices using a newly discovered ultra-hard material based on $AlMgB_{14}$. In a project funded by the National Science Foundation, the investigators are applying thin layers of $AlMgB_{14}$ to silicon and other materials by pulsed laser deposition, then studying the crystal structure and wear properties of the coatings.

Honors and Awards

Secretary **Krista Briley** was a recipient of the ***Outstanding Service Award*** to the College of Engineering for academic year 2001. The determination of the award is made by Iowa State's engineering students.

Assistant Professor **David Cann**, Professor **Lawrence Genalo**, and Professor **Thomas McGee** were selected as ***Outstanding Materials Science and Engineering Professors*** by the Engineering Student Council. Cann also received a ***National Science Foundation CAREER Award*** that recognizes and supports early career development activities of faculty most likely to become academic leaders of the 21st century. He received $440,000 for five years for a project investigating semiconducting delafossite structures.

Undergraduate student **Crystal Castro** was selected as an invited speaker at the 2000 Order of the Knoll Banquet, where she was also a first time recipient of the ***Campaign Destiny Scholarship***. Castro will receive $1,000 from this new scholarship program established by alumni donors to Iowa State's Campaign Destiny.

Graduate students **Jane Clayton** and **Theron Lewis** each won an ***International Microelectronics and Packaging Society (IMAPS) Educational Foundation*** research grant in the amount of $6,000. They were among 12 IMAPS scholars selected this year in the U.S. Both have been invited to the IMAPS annual convention in October to present a report on their thesis research.

Undergraduate student **Stephanie Connor** was a recipient of the ***Wallace E. Baron All University Senior Award***. Connor is one of six seniors to receive the award. Winners are selected by nomination and determined by a committee consisting of the Alumni Association staff. Connor will be honored with a lifetime membership in the Iowa State University Alumni Association during a formal ceremony in April.

Assistant Professor **Brian Gleeson** was selected as an invited speaker for a third consecutive year at the Gordon Research Conference, a premier conference of international scientists and researchers. Gleeson's presentation is titled, "Compositional and microstructural changes during coating/substrate interdiffusion."

Professor **David Jiles** received ISU's ***2001 Outstanding Achievement in Research Award***.

Assistant Professor **Surya K. Mallapragada** is a recipient of the ***2001 Early Achievement in Research Award***.

Assistant Professor **Ralph Napolitano** was a recipient of the ***Council of Outstanding Young Engineering Alumni 2000 Award*** from Georgia Institute of Technology College of Engineering.

MSE Associate Professor **Alan Russell** set a world record of 5,361 points in the 50–54 age group by winning the ***Masters National Indoors Heptathlon*** championship, held recently at Lewis University. The previous record was set in 1997.

Adjunct Assistant Professor **John E. Snyder** was named to ***Who's Who in Science and Engineering*** and ***Who's Who in America*** for 2001 and 2002. Snyder also was awarded a senior membership in the Institute of Electrical and Electronics Engineers (IEEE).

Undergraduate student **Jason R. Thomas** was named ***ASM International Foundation National Merit Scholar***.

Doctoral student **Yun Tian** received the ***Magnetic Materials Producers Association Scholars Award*** for 2001. The award holds a $5,000 stipend and an invitation to MMPA's spring meeting in South Carolina, where Tian will present a summary of his doctoral research. Tian was one of two chosen nationwide from a pool of 20 applicants.

Brad Tischendorf, a doctoral student, was recently awarded first place in a graduate student poster paper competition at the 12th Annual Rio Grande Regional Symposium on Advanced Materials for his paper on the structure and dynamics of glass-polymer composites.

Undergraduate student **Alan H. Tkaczyk** was one of only three students nationwide selected to receive the ***ASM International Foundation Award*** for $2,000. The award recognizes extraordinary contributions in the areas of scholarship, leadership, and service in materials science and engineering. **Stephanie Connor**, highlighted in the last issue of *Elements* for this award, was also one of the three selected.

Student leadership awards were presented this year at the College of Engineering Leadership Banquet to the following: **Justin Riney** and **Tiffany Byrne** for AcerS, **Stephanie Connor** and **Jessica Woolm** for ASM, **Gabriel Weigelt** for Engineering Student Council, and **Stephanie Connor** and **Joe Schramm** for Keramos.

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JOIN US IN INDIANAPOLIS!

ACerS MSE Alumni and Friends Reception

Monday,
April 23, 2001
6:00–7:30 p.m.

Downtown Indianapolis Marriott Hotel
Austin Room
Indianapolis, Indiana

The American Ceramic Society

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MSE AWARDS BANQUET

Thursday,
April 5, 2001
6:00–9:00 p.m.

Gateway Center/ Holiday Inn
Garden Room
Ames, Iowa

ASM/TMS, AcerS, and Keramos student alumni reception

Saturday,
April 21, 2001
5:00 –8:00 p.m.

Memorial Union, ISU
Campanile Room
Ames, Iowa

IOWA STATE UNIVERSITY