Laboratory for Manufacturing and Productivity

The Laboratory for Manufacturing and Productivity (LMP) is an interdepartmental laboratory in the School of Engineering with three major goals: (1) the development of the fundamental principles of manufacturing systems, processes, and machines; (2) the application of those principles to the manufacturing enterprise; and (3) the education of engineering leaders.

With 13 faculty and senior research staff and 70 graduate students, the laboratory conducts research in the areas of design, analysis, and control of manufacturing processes and systems. This research is conducted through industrial consortia, sponsored research projects, and government grants. LMP's major areas of interest include production system design, precision engineering, three dimensional printing (3DP), rapid autonomous machining, reconfigurable tooling, droplet, based manufacturing, automatic identification, continuous casting monitoring, machine elements and systems design, complexity and system design, microelectromechanical systems (MEMS), nanomanufacturing, biological systems, renewable energy, and environmentally benign manufacturing (EBM). In addition, LMP works closely with many other departments, labs, and programs at MIT, including the Singapore–MIT Alliance (SMA), the Leaders for Manufacturing Program, and the Lean Aerospace Initiative. Many of our research projects are also with individual companies. In total, the laboratory works with about 50 different companies worldwide. Our government support, which is often coordinated with industrial support, comes from a variety of agencies: the Department of Defense, the National Science Foundation (NSF), the National Aeronautics and Space Administration, and the Department of

Hamad, Schifferli, Trumper, and Culpepper have all been actively engaged in undergraduate curriculum development.

Professor Jung, Hoon Chun has taken on an important leadership role in developing a new vision for nanomanufacturing for the lab. This work included the preparation of a white paper, a proposal, and a successful international conference. In addition, Professor Chun and his graduate student, Wayne Hsiao, received an Outstanding Technical Paper Award for their presentation of "Bouncing of Molten Solder Droplets during Solder Bump Formation" at the International Conference on Electronics Packaging in Tokyo, Japan.

Professor Culpepper has continued to build a research program in precision instrumentation and equipment for nanomanufacturing. He received a 2003 R&D 100 Award for his invention, the HexFlex Nanomanipulator, which enables six, axis manipulation with nanometer/micro, radian resolution. In February Professor Culpepper received a 2004 CAREER Award from the NSF Nanomanufacturing Program for his proposal, "Research and Education Plans for Modeling and Design of Fixtures and Six, axis Manipulators for Nanomanufacturing." He also received the Ruth and Joel Spira Teaching Award for balanced research and excellent, enthusiastic, and creative teaching. In July 2004 Professor Culpepper was appointed to the Rockwell International career development chair.

Within the last year, Professor Culpepper has served as member of the Program Committee for the 2004 American Society of Precision Engineering Conference and as an organizer for two sessions on Precision Compliant Mechanisms for the 2004 ASME Design Engineering Technical Conference. He was also appointed to chair of the Nanorobotics Technical Committee for the IEEE 2005 Nanoscale Devices and System Integration Conference.

Dr. Stanley B. Gershwin continues his high level of activity with the Singapore–MIT Alliance and on his research on complex manufacturing systems. His recent work has focused on the interaction between factory design and operation policies aimed at quality performance measures (yield and delivered quality) and those aimed at quantity performance measures (production rate, inventory, lead time). Corporate support for Dr. Gershwin's manufacturing systems research has been provided by General Motors.

Professor Timothy Gutowski's research effort now focuses primarily on the environmental aspects of manufacturing. His current work, supported by NSF, analyzes the life, cycle environmental footprint of alternative manufacturing processes, including electrical discharge machining, abrasive water, jet machining, grinding, milling, sand and die casting, injection molding, and advanced composites processing. New support this year, again from NSF, will focus on product design and materials recycling systems. He has recently developed product design for recycling guidelines.

Professor Kim Hamad, Schifferli, whose area involves the active control of biological systems at the molecular level, has been awarded an Office of Naval Research Young

Investigator Award and has recently contributed an invited contribution to the *Encyclopedia of Nanoscience and Nanotechnology*.

Professor David Hardt has taken a principal leadership role as liaison faculty in manufacturing to the Singapore–MIT Alliance. As part of his responsibilities, he has developed an MEng in manufacturing degree program for Singapore, taught simultaneously via internet at MIT and Nanyang Technological University in Singapore. This degree involves a highly integrated set of courses that cover topics from processing, equipment, automation, process control, systems, and product design to basic business issue. It has now been delivered to three classes of SMA students and will soon be offered at MIT in the Mechanical Engineering Department as an MEng degree. Professor Hardt has also expanded his research in process control to include problems in microembossing and to a generalization of the concept of "Cycle to Cycle" control.

Professor Sang, Gook Kim's research effort has been focused on the design and manufacture of multiscale systems from MEMS to nanotechnology. Novel functionalities have been created through his students' theses in optical, power, and radio frequency (RF) microelectromechanical systems. A new concept of carbon nanotube assembly has also been created, patented, and proved. His group is now developing a high aspect ratio nanopellet (a nanocandle) to enable a new kind of nano/bio imaging and handling instrument. His group designed and built a proprietary carbon nanotube–growing PECVD machine for their carbon nanotube research. The machine is now installed at the Exploratory Materials Laboratory, a class, 1000 clean room at Microsystems Technology Laboratories, for general users of MIT. He has compiled tiny technology researches in ME and posted a gateway web page at the ME home page (http://www.mit.edu/afs/athena/org/m/micronanosystems/www/TT/index.htm). Based on his work in tiny technologies, he and Professor Culpepper will be offering a new course this fall: 2.761 Multiscale System Design and Manufacturing. The course they developed is the first of its kind in the United States and will give LMP the lead in the educational initiative in nanomanufacturing.

Professor Samir Nayfeh has completed a novel bias, weaving system, upon which he is making three, dimensional fiber, reinforced composites with tailored multiaxial strength and stiffness. These preforms are the first of their kind. The machine and process solve the long, standing problem of creating delamination, free fiber, reinforced composites suitable for complicated three, dimensional stress states. Professor Nayfeh's work on machine dynamics has also received some recognition this year. Two papers on "Aerodynamic, Rotordynamic Interaction in Axial Compression Systems," co, authored with Jim Paduano of the MIT Gas Turbine Lab, have received the 2003 ASME Gas Turbine Award.

Professor Emanuel Sachs, the Fred Fort Flowers '41 and Daniel Fort Flowers '41 professor of mechanical engineering, is working on photovoltaics—solar panels that convert sunlight directly into electricity using semiconductor devices. Photovoltaics is already the energy source of choice for remote telecommunications and for rural electrification. Sachs' goal is to contribute to the realization of photovoltaics, which is cost competitive with electricity from fossil fuels. He is the inventor of the "string

ribbon" process for the manufacture of crystalline silicon substrates for solar cells. This process is being commercialized by Evergreen Solar of Marlboro, MA. In this technology, a flat, thin silicon sheet is grown directly from a melt of silicon, thereby obviating the need to slice and polish wafers from boules or blocks. He is also working on a low, cost/high, performance method to create the metal fingers atop solar cells—the fingers that collect the current from the cells.

Professor Sanjay Sarma, the Cecil and Ida Green career development professor, was recently awarded the Keenan Award for Innovation in Undergraduate Education. He has continued to be active in the Auto-ID Center, cofounded with his colleague Dr. David Brock. The center's mission is to create an intelligent infrastructure to connect physical objects to the internet and to each other. This consortium continues to grow, with applications to inventory control, material tracking and reordering, and material and product recycling. The center now has over 150 sponsors and has started a sister center at the University of Cambridge, England. Professor Sarma has also continued his work in computer-aided design/computer-aided manufacturing/computer numerical control and haptics. A new computer-aided design/computer-aided manufacturing system developed by his group is now in negotiation for licensing. He has also designed and constructed a new five-axis milling machine that combines parallel kinematics with serial kinematics.

Professor Alex Slocum continues his work with precision machine tools by helping Overbook USA develop a new linear, motor, driven, air, bearing, supported precision miniature OD/ID grinding machine. This new machine will specialize in the precision grinding of small parts, and it will be shown at the International Machine Tool Show in Chicago this September. The Nanogate was developed with an NSF grant, and it is the world's most precise nanofluidic flow control valve. The same physical structure is also the basis for an RF filter, which was then developed under a Deshpande Center grant. A team then formed "Active Spectrum" to create a business plan around the Nanogate and was in the finals of MIT's 50K competition. Active Spectrum will soon be a real company.

Professor Slocum's next big thing is a vision to help create a renaissance in the plastics industry by developing new ways to economically make molds and to create an entirely new class of precision plastic parts using his silicon insert molded plastics concept to create plastic parts with atomic accuracy features. This work is funded by NSF.

Professor Nam P. Suh has transformed the Manufacturing Institute into the Park Center for Complex Systems, which will continue to focus on complexity theories, the design of large engineering systems, and the application of engineering principles to natural systems, software systems, nanoscale systems, and cost estimation for large systems. He has completed his manuscript, *Complexity: Theory and Applications*, which will be published by Oxford University Press in 2004. He also coauthored a book entitled *Axiomatic Design and Fabrication of Composites* with Professor Dai Gil Lee of the Korea Advanced Institute of Science and Technology, which is in production at Oxford University Press.

David Trumper was promoted this year to the rank of professor. His research efforts center on the design of novel precision electromechanical systems. Most recently his group is studying fast tool servos for use in diamond turning machines. These fast tool servos are used to rapidly move a diamond tool during a lathe turning operation in order to allow the creation of controlled features on a turned surface. Such fast tool servos can be used in the production of spectacle lenses, contact lenses, off axis optics, optical films, and other applications requiring precisely contoured surfaces. Professor Trumper is also working in collaboration with Lawrence Livermore National Laboratory to develop fast tool servos for use in the fabrication of target spheres for use in the National Ignition Facility in the study of laser induced fusion reactions. He also has active projects for the creation of accurate atomic force microscopes and ultraprecision positioning stages.

Changes in the laboratory over the last year include Professor Trumper's promotion to full professor and Professor Sarma's leave to develop his Auto–ID technology full time.

Timothy G. Gutowski
Director
Professor of Mechanical Engineering

More information about the Laboratory for Manufacturing and Productivity can be found on the web at http://web.mit.edu/lmp/www/.