MTL MICRONOTES
The annual news magazine of the Microsystems Technology Laboratories FALL 2009

CELEBRATING
MTL'S 25 YEARS

MTL at 25

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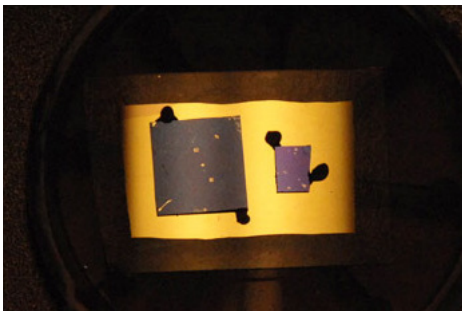

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MTL Micronotes
Volume Three, Issue One • Fall 2009

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ON THE COVER:

Iconic MTL photo of a process engineer at a wafer cleaning station in TRL. (Photo / Hutchins Photography, Inc.)

INTRODUCTION

Welcome to the 2009 edition of the Microsystems Technology Laboratories (MTL) magazine, *MTL Micronotes*. In our 25th anniversary year, we continue our active research agenda with new research programs, two new faculty members, several major awards, and a new MIG member.

This past year, 35 core faculty engaged in many exciting research initiatives, including areas related to electronic device fabrication, integrated circuits and systems, photonics, microelectromechanical systems (MEMS), and molecular and nanotechnologies. Around 80 affiliate faculty members benefited directly from MTL's fabrication and/or CAD infrastructure. More than 550 researchers conducted research at MTL.

I would like to introduce and welcome two new faculty members. Dana Weinstein, Assistant Professor of Electrical Engineering, and core member of MTL, completed her Ph.D. in Applied Physics at Cornell. Her research focuses on RF MEMS and hybrid NEMS-semiconductor devices for wireless communication and signal processing. Li-Shiuan Peh, Associate Professor of Computer Science and Engineering, resident member of CSAIL, and core member of MTL, comes from Princeton and received her doctorate from Stanford. Her interests include power-aware interconnection networks, parallel architectures, and networking in general.

The Navy's Department of Naval Research named Tomás Palacios, Assistant Professor of Electrical Engineering, one of 15 new Young Investigators. Joel Dawson, Associate Professor of Electrical Engineering, was named a recipient of a Presidential Early Career Award for Scientists and Engineers, the highest honor the US government bestows on young professionals in the early stages of their independent research careers. The White House award ceremony occurs this fall.

Prof. Hae-Seung "Harry" Lee became an MTL Associate Director in May. Director of the MTL Center on Circuits and Systems, Prof. Lee is working on industrial relations and MTL publications. The Associate Directors include Mr. Samuel Crooks (MTL Administrative Officer and Associate Director of Finance), Prof. Jesus del Alamo (Associate Director of Computation), Dr. Vicky Diadiuk (Associate Director for Fabrication Operations), and Prof. Judy Hoyt (Associate Director of Fabrication and MTL Safety Officer).

MTL hosted exciting technical events and seminars this year. Collaborating with the School of Engineering [SoE], MTL co-hosted the inaugural lecture in SoE's new Distinguished Lecture Series. Irwin Jacobs MS '57 Ph.D. '59, co-founder of Qualcomm, gave a talk entitled "From Information Theory Courses at MIT to Providing Chips and Technology for a World with Four Billion Cellular Subscribers: Memories and a Look Ahead." Inclement weather changed the venue of MTL's Annual Research Conference (MARC 2009) to MIT's Stata Center; over 200 attendees participated. MARC offers a unique opportunity to learn about research in MTL's diverse areas, and it encourages interaction within MTL. Special thanks go to Prof. Joel Voldman, Steering Committee Chair, and all volunteers. MTL also held a two-day workshop, "Next-Generation Medical Electronics," with a panel discussion by leading experts and a lively poster session. Our MTL Seminar Series, organized by the MTL Seminar Committee and chaired by Prof. Joel Dawson, continued to feature exciting presentations. I thank Prof. Dawson for his excellent leadership for the past 3 years. Tomás Palacios is the chair of the MTL Seminar Committee as of Fall 2009.

The MTL community greatly benefits from the generous financial support of the MIG, which provides subsidies for device and circuit research. In addition, MIG members donate equipment, contribute directed fellowships and provide fabrication access to state-of-the-art technologies. I welcome Veeco Instruments to the MIG. Veeco is a leading provider of Metrology and Process Equipment solutions for the materials science, precision manufacturing, semiconductor, data storage, wireless, lighting and solar industries. This partnership strengthens MTL's efforts in areas such as nanotechnology, energy, MEMS, and compound semiconductors, among others.

Our Industrial Advisory Board (www-mtl.mit.edu/mig/iab.html) provides significant assistance in shaping MTL's vision. We continued our successful MTL Days at MIG companies, visiting Qualcomm and NEC while holding the Veeco Day in MTL. Students benefit greatly from the opportunity to give detailed presentations to industry experts. These visits result in increased collaborations between MTL and the MIG companies.

MTL remains the home of the Materials, Structures, and Devices Center, managed by the Semiconductor Research Corporation. Dimitri Antoniadis continues to direct it through the next phase, which begins in November. MTL also plays major roles in two of the other centers (IFC and C2S2).

More globally, the International Iberian Nanotechnology Laboratory (INL) and MIT began a major new collaboration that will enrich each institution's research activities in nanoscience and nanotechnology. The institutions created MIT-INL, an education and research enterprise focused on nanotechnology. The collaboration will enable approximately $35 million of sponsored research with MIT in its first five years.

We enjoy hearing from alumni. Please register to receive MTL publications (www-mtl.mit.edu). We hosted another successful alumni event at ISSCC 2009; over 100 people attended. Please contact me with suggestions to improve MTL. I am eager to hear from you.

Sincerely,
Anantha P. Chandrakasan
Director, MTL

MTL Welcomes Veeco Instruments to its Industrial Group

by TOMÁS PALACIOS, ASSISTANT PROFESSOR

The Microsystems Technology Laboratories (MTL) at the Massachusetts Institute of Technology and Veeco Instruments (Plainview, NY) have recently announced that Veeco Instruments has joined the Microsystems Industrial Group (MIG), an exclusive member industry consortium.

The MIG was founded in the 1980s to support MTL infrastructure and provide direction to the Microsystems Technology Laboratories' research and educational objectives in consultation with the faculty. Veeco Instruments is a leading provider of Metrology and Process Equipment solutions for the materials science, precision manufacturing, semiconductor, data storage, wireless, lighting and solar industries. This partnership with MTL will strengthen MTL's efforts in areas such as nanotechnology, energy research, microelectromechanical systems (MEMS) and compound semiconductors, among others. Veeco Instruments decided to join the MIG following participation in a number of preliminary technical meetings over the past year.

"We are enthusiastic about this collaboration and the synergy it will bring to both parties," said Dr. Erik Novak, Director of Applications and Technology in Veeco Instruments. Dr. Dong Chen, Principal Scientist at Veeco Instruments and Industrial Advisory Board member of MTL, added that "many of MTL's challenging projects will benefit from our precision measurement capabilities and the relationship will provide us the opportunity to better engage with the research community in many areas that are important to our business."

"This is a great opportunity for Veeco to formalize our collaboration with Microsystems Technology Laboratories and the other leading companies and institutions that make up the Microsystems Industrial Group," said Mark R. Munch, Ph.D., Executive Vice President, Veeco Metrology. "The precision measurement capabilities of our optical profilers and atomic force microscopes will assist the advancement of research and development in energy generation and storage, biological microelectromechanical systems (bioMEMS), and other emerging industrial markets. In addition, this gives Veeco yet another important means of remaining connected with the research community and the technological needs of tomorrow."

Vicky Diadiuk (left) and Dong Chen of Veeco Instruments.

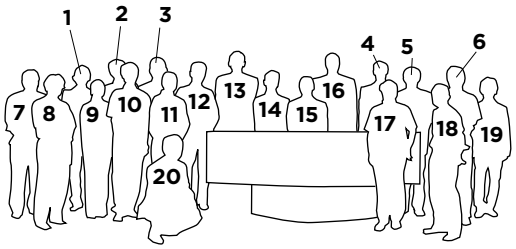
Researchers get a demonstration of Veeco tools in the ICL.

Tomás Palacios (left) and Dong Chen.

All photos / Paul McGrath

Professor Anantha P. Chandrakasan, Director of MTL, commented, "We are excited that Veeco Instruments has joined the MIG. We look forward to a productive collaboration with Veeco in a number of research areas, including nanotechnology, advanced metrology, bioMEMS characterization, and compound semiconductor devices." Professor Palacios, MTL faculty liaison to Veeco Instruments, added, "Recently we celebrated Veeco Day at MTL. It was a terrific event, with excellent participation by students, faculty and Veeco engineers. It gave us a chance to identify collaboration opportunities, to outline future joint projects and allowed MTL students and faculty to learn more about Veeco Instruments. A great experience for everyone."

(Photo/NEC)



AS NUMBERED:

1. Naotaka Sumihiro, NEC
2. Shigeyuki Miyamoto, NEC
3. Xiaolong Hu, MIT
4. Ben Moss, MIT
5. Yoshihiro Hayashi, NEC Electronics
6. Fujio Okumura, NEC
7. Yasunori Mochizuki, NEC
8. Shinichi Yorozu, NEC
9. Yajun Fang, MIT
10. Sungwon Chung, MIT
11. Vivienne Sze, MIT
12. Will Chung, MIT
13. Jesus del Alamo, MIT
14. Jungwoo Joh, MIT
15. Kerry Cheung, MIT
16. Vladimir Stojanović, MIT
17. Takemitsu Kunio, NEC
18. Shuichi Tahara, NEC
19. Hidenori Shimawaki, NEC
20. Jun'ichi Sone, NEC

MTL Day at NEC

by JESUS DEL ALAMO, PROFESSOR

On September 21, 2008, eight graduate students and two faculty from MTL visited NEC Tsukuba Research Laboratory in Tsukuba, Japan. NEC Corporation is a Japanese member of the Microsystems Industrial Group and this was the first MTL visit to NEC. On MIT's side, the visit had been organized by Prof. Judy Hoyt, the Faculty Liasion for NEC at MTL. On NEC's side, the visit was organized by Dr. Jun'ichi Sone, VP of NEC's Central Research Laboratories.

Profs. Jesus del Alamo and Vladimir Stojanović were the participating faculty from MTL. In addition to Dr. Sone, NEC participants included Dr. Takemitsu Kunio, Associate Senior VP and Executive Manager of the NEC's Central Research Laboratories; Dr. Shuichi Tahara, General Manager of NEC Nano Electronics Research Laboratories; and Dr. Yasunori Mochizuki, General Manager of NEC Device Platforms Research Laboratories. Both of these labs are located in Tsukuba. The day was managed by Dr. Shinichi Yorozu, Senior Manager of NEC Nano Electronics Research Laboratories.

After introductions, Dr. Sone gave a broad overview of research activities at NEC, noting their wide scope and international character. This was followed by three technical talks from NEC researchers on silicon photonics, optical interconnects, and quantum computing and an overview of the research interests of NEC Electronics Corporation, a member company of the NEC Group. Visits to various labs and an opportunity to talk to NEC researchers followed. The labs supported research on bioplastics, ubiquitous battery, carbon nanotube electronics and quantum computing.

The MIT portion of the visit was kicked off after lunch by Prof. del Alamo, who gave a brief overview of MTL and summarized the interactions between NEC and MTL. He also talked about III-V CMOS, one of his current research projects. Prof. Stojanović summarized his research on the interconnection problem in large scale ICs. This was followed by talks by the eight participating students. These spanned the broad range of research activities of MTL, from GaN FETs to gas analyzer MEMS, from wideband power amplifiers to low-power video coding.

The day was concluded with a sumptuous reception and dinner that brought all participants into animated and cordial conversations.

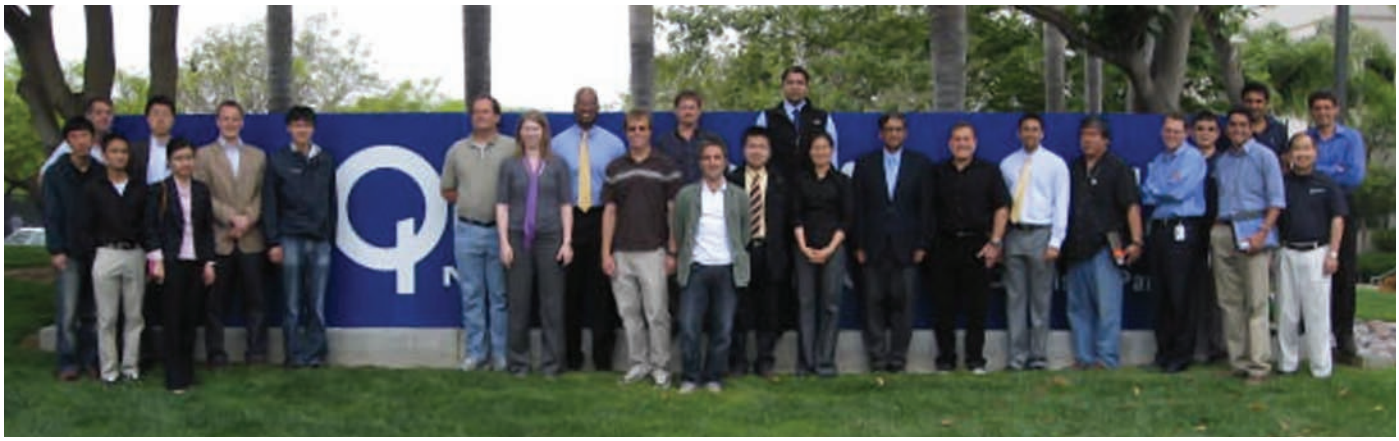
agenda

9:00	Takemitsu Kunio, Jun'ichi Sone, NEC; Opening Address
9:30	Masafumi Nakada, NEC, "Silicon photonics activities in NEC"
9:50	Tomoyuki Hino, NEC. "Activity of Optical Interconnection"
10:10	Yasunobu Nakamura, NEC, "Superconducting quantum computing technology"
10:30	Yoshihiro Hayashi, NEC electronics, "LSI technology"
11:00	Break
11:10	Lab tour
12:30	Lunch
1:30	Prof. Jesus del Alamo, MIT, "IIII-V CMOS: Challenges and Opportunities"
2:00	Prof. Vladimir Stojanović, MIT, "The Interconnect Problem: From Emerging Devices to Energy-efficient Networks"
2:30	Will Chung (Palacios), "GaN Electronics for High power and High Frequency Applications"
2:50	Jungwoo Joh (del Alamo), "Degradation Mechanisms in GaN High Electron Mobility Transistors"
3:10	Ben Moss (Stojanović), "Photonic Interconnects for Manycore Processor to DRAM Networks"
3:30	Break
3:50	Vivienne Sze (Chandrakasan), "Low Power Video Coding"
4:10	Sungwon Chung (Dawson), "Energy-efficient Digital Predistortion for Wideband Handset Power Amplifiers"
4:30	Xialong Hu (Berggren), "Superconductive Nanowire Single-photon Detectors"
4:50	Kerry Cheung (Akinwande), "Chip-Scale Quadrupole Mass Filters for a Micro-Gas Analyzer"
5:10	Yajun Fang (Masaki), "Machine Vision for Intelligent Transportation Systems"
5:30	Discussion & wrap up
6:00	Banquet

MTL Day at Qualcomm

by JOEL DAWSON, ASSOCIATE PROFESSOR

On May 27th, Qualcomm hosted a group of MTL students at their company headquarters in San Diego, CA. The visit was the latest in a series of collaborative events between Qualcomm and MTL since Qualcomm became a member of the MIG in the fall of 2008. Dr. Josephine Bolotski, an MIT alumna now working with Qualcomm, organized the event together with Dr. Rob Gilmore (also an MIT alumnus) of Qualcomm. As part of her duties for Qualcomm, Dr. Bolotski has been a Visiting Scientist in Bldg. 38 since January of 2009, spending one day a week here. Dr. Gilmore is no stranger to MTL himself, having visited on a number of occasions. He has even served as a guest lecturer in Prof. Dawson's High Speed Communications Circuits class.



ABOVE, FROM LEFT: Sungwon Chung, Danny Butterfield (rear), Philip Godoy, David He (rear), Yan Li, Robert Pilawa, Jack Chu, Jeff Levin, Josephine Bolotski, Joel Dawson, John Sutton, David Bahnemann (rear), Jorge Garcia, Han Wang, Masood Qazi, Vivienne Sze, Anantha Chandrakasan, Rob Gilmore, Nigel Drego, Ernie Ozaki, John Smee, Bo Sun (rear), Mohamed Abu-Rahma, Kamal Sahota (rear), Gary Osumi, and Babak Aryan. (Photo / Qualcomm)

agenda

9:00 Josie Bolotski (Qualcomm), Welcome and Introduction

9:20 Vivienne Sze (Chandrakasan), "Ultra-low-power Parallel Video Decoding"

9:40 Masood Qazi (Chandrakasan), "Statistical SRAM Optimization"

10:00 Break

10:15 Manish Kothari (Qualcomm), "A Primer on Mirasol Displays"

10:45 Nigel Drego (Boning), "Characterization and Mitigation of Process Variation in Digital Circuits & Systems"

11:05 Yan Li (Stojanović), "Yield-driven Robust Iterative Circuit Optimization"

11:25 Ernie Ozaki (Qualcomm), "eZone: Wireless power"

12:00 Lunch and presentation by Rob Gilmore on Qualcomm Research Directions

1:00 Robert Pilawa (Perreault), "A Two-stage Converter for Low-voltage Power Delivery"

1:20 Jack Chu (Lee), "Zero-crossing ADC"

1:40 Jeff Levin (Qualcomm), "NEO: A General Purpose Learning Machine Modeled on the Human Neo-Cortex"

2:10 Sungwon Chung (Dawson), "Digitally assisted subsampler for RF power amplifier linearization"

2:30 Philip Godoy (Dawson), "Outphasing Energy Recovery Amplifier with Resistance Compression for Improved Efficiency"

2:50 David He (Sodini), "An Organic Thin-film Transistor Circuit Array for Large-area Temperature-sensing"

3:10 Han Wang (Palacios), "Graphene Ambipolar Electronics"

3:30 Break and student speaker Q&A

4:00 Students depart for Lab tours and demos

4:00-5:30 MTL Summary and Discussion of Next Steps

4:00 Joel Dawson and Anantha Chandrakasan (30 min. each), "Overview of MTL Research"

5:00 Speaker Q&A - Qualcomm's ongoing work with MTL, and how to become involved. Rob Gilmore (Qualcomm)

5:15 Open Discussion

Profs. Anantha Chandrakasan and Joel Dawson of MTL also helped to organize the visit, recruiting a group of ten students to give presentations on their work at MTL. The Boning, Chandrakasan, Dawson, Palacios, Perreault, Sodini, and Stojanović groups all sent representatives to San Diego to share their recent work. In addition, Profs. Dawson and Chandrakasan gave overview talks on their group activities and on the broader MTL mission.

There were at least two objectives for this visit. One objective was to foster active collaborations between Qualcomm, an MTL supporter, and MTL. The other objective was the professional development of the graduate students at MTL. "Events like this are always valuable for students," said Prof. Dawson. "Presenting to an industry audience, often before you have your final results, and being an ambassador on behalf of your group very naturally broadens your research perspective. Also, the feedback from practicing engineers is exactly what we all need. After all, our goal is to positively impact engineering practice."

Participants from both Qualcomm and MTL judged the event to be a tremendous success. "It was a great opportunity for Qualcomm engineers to learn about the work going on at MTL in a very customized and targeted format," said Dr. Bolotski. "There was a lot of person-to-person interaction that we hope will lead to stronger collaborations down the line."

IN THE NEWS

MTL Team wins School of Engineering's 2009 Infinite Mile Award

The MTL operations team of Dan Adams, Ryan O'Keefe, and Tim Turner (pictured left to right; photo, Gary Riggott) was given the Infinite Mile Award for Team Excellence from the MIT School of Engineering during the school's ninth annual awards ceremony on April 29, 2009. The team was cited by Personnel and Operations Administrator Debroah Hodges-Pabon for "[being] instrumental in supporting operational and educational goals of MTL and the Institute. They also provide additional help upon request with major MTL events." The Infinite Mile program, launched in 2001 by MIT, is meant to provide opportunities to recognize and reward members of MIT's administrative staff, support staff, service staff, sponsored research staff, and, when appropriate, faculty and academic staff.

Joel Dawson receives award from White House

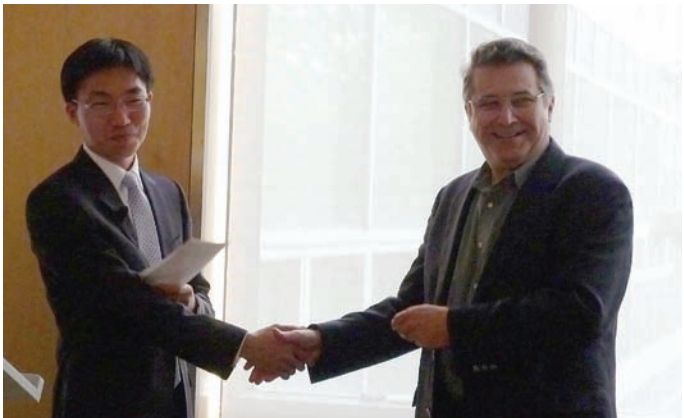
Joel Dawson was one of 100 researchers named by President Obama as recipients of the Presidential Early Career Awards for Scientists and Engineers, the highest honor bestowed by the United States government on young professionals in the early stages of their independent research careers on July 9, 2009. The recipient scientists and engineers will receive their awards in the Fall of 2009 at a White House ceremony.

The awards, established by President Clinton in February 1996, are coordinated by the Office of Science and Technology Policy within the Executive Office of the President. Awardees are selected on the basis of two criteria: Pursuit of innovative research at the frontiers of science and technology and a commitment to community service as demonstrated through scientific leadership, public education, or community outreach. Winning scientists and engineers receive up to a five-year research grant to further their study in support of critical government missions.

ABOVE: Professor Joel Dawson, recipient of a Presidential Early Career Award (PECASE) in his office at MIT. (Photo / Tony Rinaldo)

4th Annual Senturia Prize for Outstanding Thesis in Micro/Nanosystems

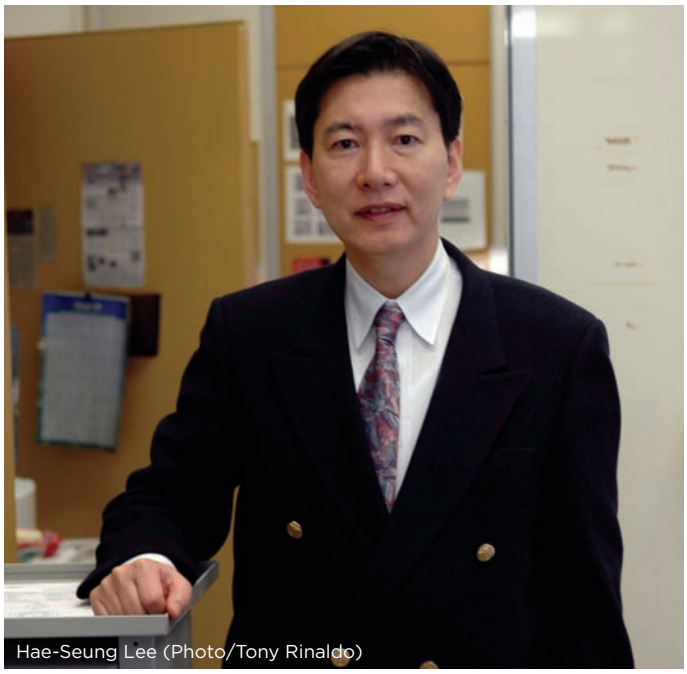
May 14, 2009



ABOVE: Chang Young Lee (left) and Professor Stephen Senturia. (Photo / Sang Wook Kang)

Chang Young Lee was the fourth recipient of the annual Senturia Prize for Outstanding Thesis in Micro/Nanosystems, held in conjunction with the Micro/Nano-technology Seminar Series (MNSS). This prize is awarded yearly to a graduating doctoral student whose thesis has made outstanding contributions to the field. In addition to receiving an honorarium, Lee presented a lecture on his research, "Understanding and tuning the molecular interaction with single-walled carbon nanotubes for gas sensing applications," at the MNSS seminar on May 14, 2009.

The MNSS is a multi-departmental School of Engineering seminar series focused on fundamental micro- and nano-technology and its applications in sensing and actuation, thermal and life sciences and energy, among many others. It is co-sponsored by the Department of Mechanical Engineering, MEMS@MIT, RLE and MGH. The Senturia Prize is named in honor of retired MIT faculty member Prof. Stephen Senturia.


Hae-Seung Lee (Photo/Tony Rinaldo)

Prof. Hae-Seung Lee named newest MTL Associate Director

Prof. Hae-Seung "Harry" Lee was named as a new Associate Director of Sponsor Relations and Publications for the Microsystems Technology Laboratories. The announcement was made by the MTL Director, Prof. Anantha Chandrakasan, via an e-mail sent to the MTL Community on May 11, 2009.

"It is my pleasure to announce a new Associate Director for MTL, Prof. Hae-Seung "Harry" Lee. Harry, who currently serves as the Director of the MTL Center on Circuits and Systems, will be involved in a number of core MTL activities, including helping with industrial relations and MTL publications," said Chandrakasan in his e-mail.

Lee has pioneered several analog-to-digital circuit techniques such as digital calibration and comparator-based switched-capacitor design and has demonstrated benchmark results. Although Lee's research focus is in integrated circuit design, he also has a background in fabrication. As a graduate student at U.C. Berkeley, Lee developed a new CMOS process flow for the then-new 3-inch fab and fabricated an A/D converter chip which achieved unprecedented 15-bit accuracy. Lee also developed a BiCMOS process in MTL's Integrated Circuit Laboratory (ICL) in the 1980s.

Lee will join the other Associate Directors, Prof. Judy Hoyt (Associate Director of Fabrication and MTL Safety Officer), Prof. Jesus A. del Alamo (Associate Director of Computation), Dr. Vicky Diadiuk (Associate Director for Fabrication Operations) and Mr. Samuel Crooks (MTL Administrative Officer and Associate Director of Finance).

Voldman wins Young Innovator Award at MicroTAS 2008


Prof. Joel Voldman (Photo/Paul McGrath)

Associate Professor of Electrical Engineering and Principal Investigator in the Research Laboratory of Electronics and the Microsystems Technology Laboratories Joel Voldman was awarded the Young Innovator's Award—for exceptional technical advancement and innovation early in his career—at the 12th International Conference on Miniaturized Systems for Chemistry and Life Sciences, MicroTAS, sponsored by the American Chemical Society (ACS). Voldman is the first recipient of this award.

Chandrakasan honored for semiconductor work


Left to right: SIA Chairman Hector Ruiz, Anantha Chandrakasan, and SIA President George Scalise. (Photo/SIA)

Anantha Chandrakasan received the Semiconductor Industry Association (SIA) University Researcher Award on March 12, 2009. Chandrakasan, the Joseph F. and Nancy P. Keithley Professor of Electrical Engineering, was honored for his work in micro-power design, wireless micro-sensor arrays and ultra-wideband radios. The SIA University Researcher Award was established in 1995 to recognize lifetime research contributions to the U.S. semiconductor industry by university faculty. The awards were presented at the annual SIA conference in Washington.

Bulović named MacVicar fellow

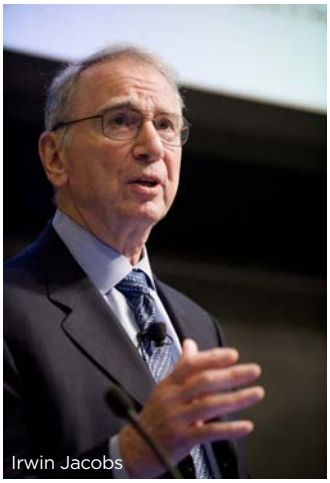

Vladimir Bulović (Photo/Donna Coveney)

Professor Vladimir Bulović is one of two professors from the School of Engineering who were named MacVicar Faculty Fellows this year in recognition of their innovative teaching practices and accomplishments. Bulović, the KDD Associate Professor of Communications and Technology, earned BS (1991), MA (1995) and Ph.D. (1998) degrees from Princeton University. He joined the MIT faculty in 2000. Bulović's research interests include studies of physical properties of nanodot composite thin films and structures, and development of novel optoelectronic organic and hybrid nanoscale devices. In 2004, he was named as one of the TR100, *Technology Review* magazine's annual list of top young innovators in technology.

Irwin Jacobs

School of Engineering Distinguished Lecturer

On February 19th, 2009, Dr. Irwin Jacobs MS '57 Ph.D. '59, co-founder and CEO of Qualcomm, gave the inaugural talk for the School of Engineering Distinguished Lecture Series, titled "From Information Theory Courses at MIT to Providing Chips and Technology for a World with Four Billion Cellular Subscribers: Memories and a Look Ahead." Dr. Jacobs discussed how he got where he is now; some things he learned along the way; and the past, current and new technologies his companies have and are working on to take the world into new areas of wireless communications.



Irwin Jacobs

All photos / Justin Knight

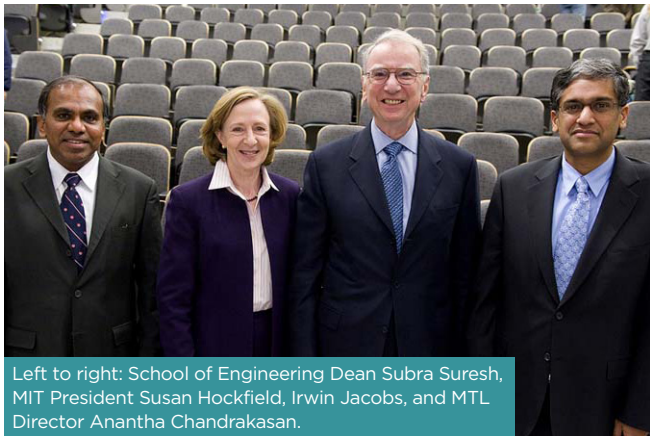
Irwin Mark Jacobs
MS '57 Ph.D. '59

Irwin Jacobs is co-founder and chairman of Qualcomm Incorporated, a pioneer and world leader of code division multiple access (CDMA) digital wireless technology. He served as CEO of the company from its founding in 1985 until July 2005. He formed his first company, Linkabit Corporation, in 1969. It merged with M/A-COM in 1980 and Jacobs served as a director until he resigned and ostensibly retired in April 1985. Three months later, however, he conceived the CDMA/Qualcomm concept, and led the company into mobile satellite communications and digital wireless telephony on an international scale. Today, Qualcomm has annual sales of more than $10 billion.

A former EECS faculty member at MIT and at the University of California, San Diego, in 1965 Jacobs coauthored *Principles of Communication Engineering* with Jack Wozencraft, a textbook on digital communications that is still in wide use today. Jacobs was elected to the National Academy of Engineering in 1982, and was named its chair in May 2008. He has won many awards for his work, including the National Medal of Technology Award in 1994, the highest honor bestowed by the President of the United States for extraordinary achievements in the commercialization of technology.

Dr. Jacobs speaks to a full house in MIT's lecture hall 10-250.

Anantha Chandrakasan (left), Josie Ammer-Bolotski (center), and Irwin Jacobs shortly before the lecture



Left to right: School of Engineering Dean Subra Suresh, MIT President Susan Hockfield, Irwin Jacobs, and MTL Director Anantha Chandrakasan.

A wafer made by the Microsystems Technology Laboratories to commemorate Dr. Jacob's talk at MIT.

MIT Engineering and the International Iberian Nanotechnology Laboratory launch research collaboration

The International Iberian Nanotechnology Laboratory (INL) and the Massachusetts Institute of Technology began a major new collaboration on May 30, 2009 that will enrich each institution's research activities in nanoscience and nanotechnology.

The two institutions will create MIT-INL, a new education and research enterprise focusing on nanotechnology. The collaboration will create 10 senior research positions for scientists who will launch an aggressive new nanotechnology research agenda, and it will enable approximately $35 million (25 million euro) of new sponsored research with MIT in its first five years. José Rivas, Director-General of INL, and Subra Suresh, Dean of Engineering at MIT, formalized the agreement at a signing ceremony on May 30, 2009 in Lisbon.

This is the INL's first major alliance with an American academic institution. Conceived in 2005-06, founded in 2007, built in 2008-09 and opened in 2009, INL is an international research facility located in Braga, Portugal, and is a joint project of the governments of Portugal and Spain. The MIT-INL agreement leverages the Institute's especially strong reputation in materials science, engineering, nanotechnology and biotechnology.

"INL is the first nanotechnology laboratory in the world with international legal status," said INL Council President, Luis Magalhães. "We offer in nanotechnology an open and flexible environment for researchers of any nationality to work together in world-leading projects." Models for the MIT-INL collaboration can be found in other international laboratories such as CERN in Geneva, for particle physics, and EMBL in Heidelberg, for molecular biology.

"The INL aims to promote nanoscience and nanotechnology through strategic collaborations that can lead to practical applications," said Rivas. "This bilateral co-operation between MIT and INL represents a watershed for both institutions, and it opens a number of opportunities for increasing competition, new research projects, and the potential for mobility and exchange between researchers."

"This new collaboration provides a unique opportunity for faculty and students at MIT to engage in exciting new fundamental research with the potential for great societal impact," said Suresh, who is a bio-nanotechnology researcher as well as the Ford Professor of Engineering at MIT. "This enterprise will build on MIT's world-renowned expertise in nanotechnology, and it will help create a major new international research center that will draw talent from all over Europe and beyond."

As part of the first step in their collaboration, the organizers of MIT-INL have already selected a number of current MIT research projects, in the Microsystems Technology Laboratories and the Materials Processing Center, to benefit from MIT-INL. These projects include research on nanoparticles that can selectively adsorb water contaminants, autonomous microsystems that can move around water supplies and sense contaminants (while sustaining themselves on power scavenged from their environments), new materials for energy storage, revolutionary tools and technologies for monitoring our food supply, and others.

There will be an Institute-wide call for additional proposals in the near future. MIT faculty will also play a key role in helping develop new capabilities at the INL facilities, and in the training programs for scientists and students on the MIT campus and at the INL. In addition, INL will immediately begin recruiting senior researchers to work in new applications and technologies in nanoscience and nanotechnology.

Professor Anantha Chandrakasan, Director of the Microsystems Technology Laboratories, will serve as MIT's inaugural Director of MIT-INL; Professor Carl Thompson, Director of the Materials Processing Center, will serve as Co-director. They will work closely with Paulo Freitas, Deputy Director-general of INL.

—MIT NEWS OFFICE; MAY 30, 2009; updated 6/1/2009; http://web.mit.edu/newsoffice/2009/inl-0530.html

Clip art /istockphoto.com

MIG Annual Meeting: January 31, 2009

TOP, CLOCKWISE AROUND TABLE: Francesco Pappalardo, STMicroelectronics; Rob Gilmore, Qualcomm; Peter Holloway, National Semiconductor; Takemitsu Kunio, NEC; George Bourianoff, Intel; Brad Scharf, Analog Devices, Dennis Buss, Texas Instruments; Dong Chen, Veeco; Anantha Chandrakasan, MIT.

Bottom: The MARC 2009 Presentation Award winners. Front row: Tim Heidel, Ivan Nausieda, Denis Daly, Joyce Chen, Daniel Finchelstein, Nicole DiLello, Daniel Nezich, and Meekyung Kim. Back row, standing: M. Scott Bradley, Matthew Panzer, Joseph Kovac, Joel Voldman, Anantha Chandrakasan, Dennis Buss, and Omair Saadat. (Photos / Paul McGrath)

Read more about MARC 2009 on pp. 12-13.

ABOVE, FROM LEFT: Laura Fujino, Anantha Chandrakasan, David He, Mahmut Sinangil, Kenneth Smith, Bonnie Lam, and Yildiz Koken. (Photo / Debroah Hodges-Pabon)

ISSCC 2009 — *Debroah Hodges-Pabon*

On February 9, 2009 MIT faculty, students, alumni as well as industry members gathered at the San Francisco Marriott Hotel. The Center for Integrated Circuits and Systems, under the direction of Professor Hae-Seung Lee, hosted this year's ISSCC hospitality reception, bringing together over 125 people.

Professor SeongHwan Cho states, "It's always great to see old friends, I think we should have it every year. It's also nice to get to know new people and share information."

Melinda Wong Jankowski adds, "Attending ISSCC 2009 was an invaluable opportunity to reconnect with colleagues, see what kind of projects they're working on, and find out about the latest developments in the field. Although in general ISSCC attendance was down this year, it's amazing how the same people return year after year!"

Faculty Promotions

Effective July 1, 2009, these MTL faculty members have received the following promotions:

Promotions to Associate Professor with tenure

- Marc Baldo
- Karl Berggren
- Jongyoon Han
- Joel Voldman

Promotions to Associate Professor without tenure

- Joel Dawson
- Jing Kong
- Vladimir Stojanović

Congratulations to our faculty!

MTL Workshop on Next-Generation Medical Electronic Systems

By CHARLES G. SODINI. LEBEL PROFESSOR, EECS

SEATED ABOVE, LEFT TO RIGHT: Grace Peng, Tom O'Dwyer, Tim Denison, Carole Carey, Alice Chiang, and Seema Deshpande. (Photo / Paul McGrath)

In December 2008, the Microsystems Technology Laboratories presented a workshop converging experts from academia, the semiconductor and medical device industries, the medical profession and the Department of Defense. The objective was to exchange technical ideas and explore collaboration opportunities to define directions related to future health care systems.

The two-day workshop commenced with a panel discussion moderated by Prof. Charlie Sodini and titled "The Next Semiconductor Opportunity: Medical Electronics and Systems." The panelists included Carole Carey, Director of the Food and Drug Administration's Center for Devices and Radiological Health; Alice Chiang, Chairman and CEO of Terason Corporation; Tim Dennison, Senior IC Engineering Manager for Electronic Neuromodulation, Medtronic; Seema Deshpande, General Manager of Texas Instruments Medical/High Reliability Business; Tom O'Dwyer, Director of Technology for Health Care at Analog Devices; and Grace Peng, Program Director in the National Institute of Biomedical Imaging and Bioengineering at the NIH. This all-star cast provided a lively discussion of the role played by semiconductor technology in non-invasive diagnostics, continuous sensing, implantable medical devices, and portable instruments including medical ultrasound imaging. One of the most important outcomes of this panel discussion was an understanding that government agencies look forward to funding research integrating the physical and engineering

ABOVE: An attendee speaks with Jose Bohorquez (right) during the workshop. (Photo / Paul McGrath)

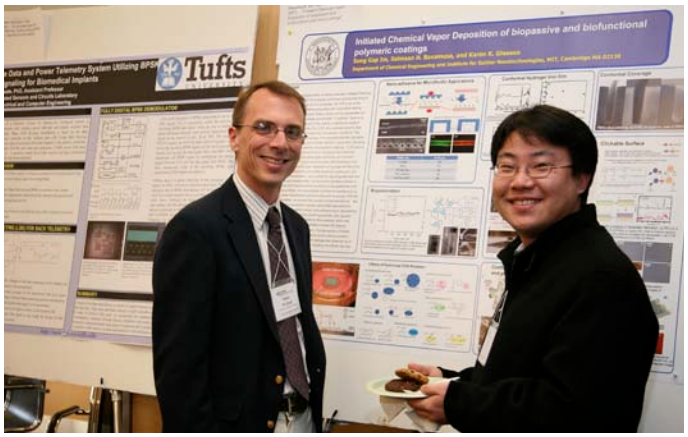
sciences with the life sciences. The panel also acknowledged the FDA's commitment to help product development become more predictable and less costly and also reduce the time from design concept to a safe, effective, and reliable product. Dinner followed the panel discussion, and it was clear that the attendees were energized and looking forward to a full day of technical talks.

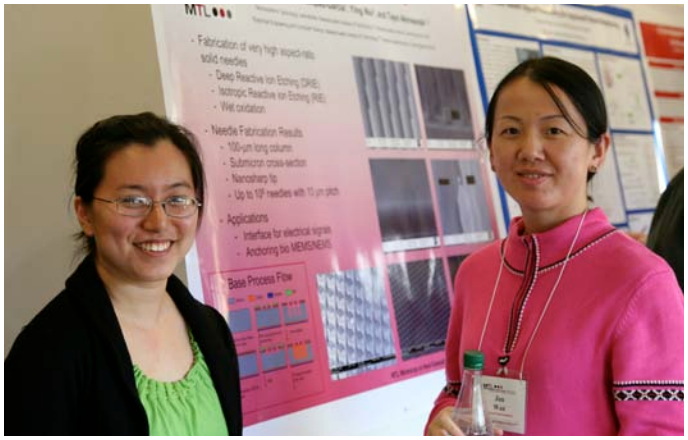
Anantha Chandrakasan, Director of MTL and Program Chair, opened the first session of the workshop; it contained overviews from DARPA personnel, leading semiconductor industry experts, and physicians. A clear message was conveyed: new emerging medical technology will require drastic reduction in power dissipation and size while increasing computation power and ease of use. Dr. Julian Goldman discussed how medical devices must change from operating independently using proprietary interfaces and move toward ease of integration with various vendor equipment software and system design. He said, "As inter-operability standards and technologies are developed, it is important to drive solutions from a needs perspective rather then a technology perspective." A total of 18 talks were given during this workshop on topics ranging from wearable patient monitoring systems to interfaces between the body and electronic systems, including retinal prosthesis and electrical impedance myography. State-of-the-art research components and platforms were also presented.

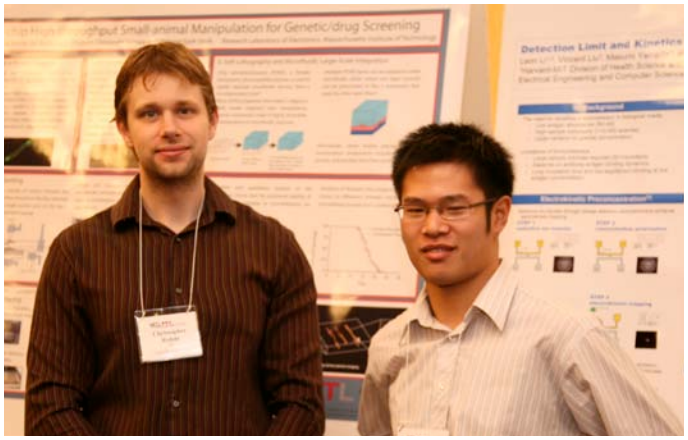
The highlight of the workshop was the lunchtime poster session, which was preceded by nineteen one-and-a-half-minute-long, highly energized advertisements by the poster presenters. Presenters came from not only local universities, but also as far away as KAIST in Daejeon, Korea. This poster session allowed the attendees to have informal interaction with the young researchers working in this exciting field.

The MTL/MIG Industrial Advisory Board applauded the success of the workshop and asked that a second one be planned. The next workshop on Medical Electronic Systems is scheduled to be held December 3rd & 4th, 2009 at MIT. For information on this workshop, contact Debroah Hodges-Pabon at debb@mtl.mit.edu.

The next workshop on Medical Electronic Systems will take place at MIT on December 3rd & 4th, 2009. For more information, visit http://www-mtl.mit.edu/medical







PHOTOS, FROM TOP: James Weiland (left) and Sung Gap Im.
MIDDLE: Ying Niu and Jun Wan.
BOTTOM: Christopher Rohde (left) and Vincent Liu.

(All photos / Paul McGrath)

MARC 2009

by NICOLE DILELLO, MARC2009 CO-CHAIR

I'd like to say that this year's installment of the MTL Annual Research Conference, or MARC, went off without a hitch, but unfortunately, a large hitch occurred.

A blizzard blew through Cambridge, MA on the morning of January 29 – just when the buses were set to leave from campus and drive to Waterville Valley, NH. The conference organizers decided that the snow made travel too dangerous and that the conference should be re-located to campus at the last minute. It took some frantic planning, especially on behalf of Debroah Hodges-Pabon, Sam Crooks, and Joel Voldman, but the entire technical program was squeezed into one day.

The theme of this year's MARC was "MTL@25," commemorating the 25th anniversary of MTL's creation. To highlight this, there was a lunchtime panel with MTL alumni at various stages in their careers. The panel consisted of Emily Cooper, Ph.D. '03, now at Intel; Hasan Nayfeh, Ph.D. '03, now at IBM; Roxann Broughton-Blanchard, Ph.D. '99, now at Analog Devices; Lalitha Parameswaran, Ph.D. '97, now working on biosensors at Lincoln Laboratory; Kenneth O, Ph.D. '89, a professor at the University of Florida; and Dennis Buss, Ph.D. '68. The panel gave students insights as to potential careers open to MTL alumni and also about what research was like at MTL up to 25 years ago.

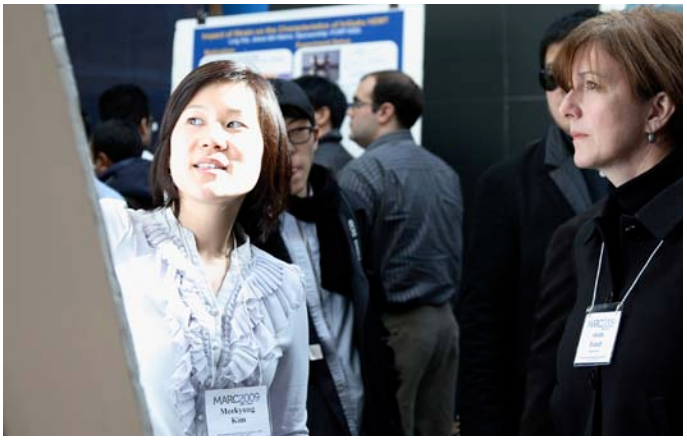
The snow didn't deter Mark Bohr, a Senior Fellow at Intel, who delivered the morning keynote. His talk was entitled, "The New Era of Scaling in an SoC World."

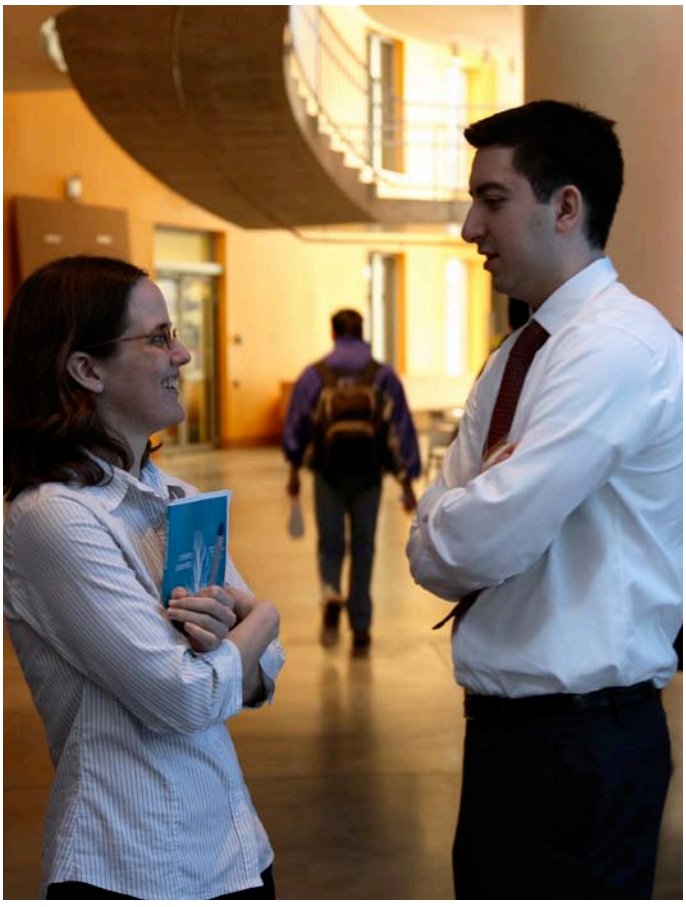
The highlight of MARC is always the technical portion of the program. Led by Ivan Nausieda and Nicole DiLello, this year's program featured 75 presentations by MTL students and postdocs. Presentations were divided into five sessions: MEMS and BioMEMS, Electronic Devices, Circuits and Systems, Energy and Photonics, and Nanotechnology. The re-naming of some of the sessions this year reflects the changing landscape of research here at MTL, especially the increased focus on energy.

The winners of this year's presentation awards, sponsored by Texas Instruments, were the following:

- Joseph Kovac
- Denis Daly
- Omair Saadat
- Han Wang
- Meekyung Kim
- Daniel Finchelstein
- Joyce Kwong
- Shalom Goffri
- M. Scott Bradley
- Matthew Panzer

CLOCKWISE FROM TOP RIGHT: Manish Goel and Michael Georgas look on as Tania Ullah explains her work to Paul Basset of Qualcomm and Rasmus Haahr. Meekyung Kim (left) explains her research to Susan Feindt of Analog Devices. Usha Gogigeni discusses her poster with an interested observer. Student Co-chairs Nicole Dilello (left) and Ivan Nausieda. (All photos / Paul McGrath)

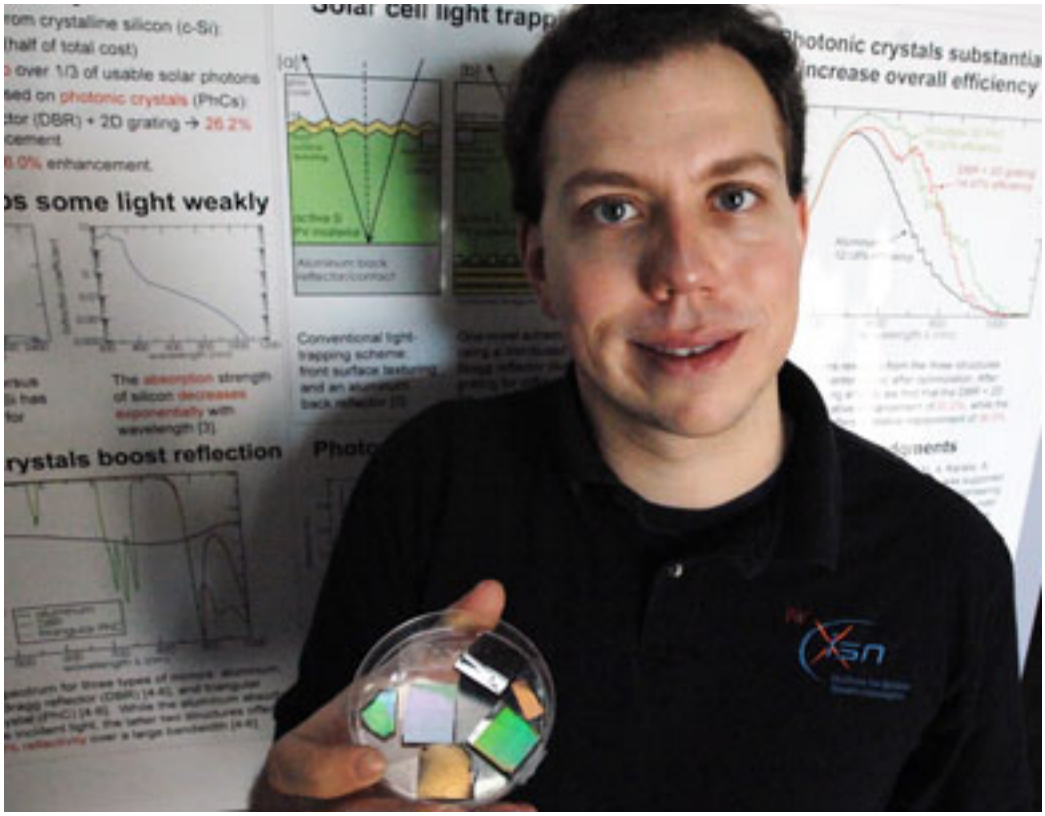




Boosting the power of solar cells

New research could lead to higher output, lower cost

by DAVID CHANDLER, MIT NEWS OFFICE



Research Lab of Electronics post-doc Peter Bermel.
(Photo / Donna Coveney)

New ways of squeezing out greater efficiency from solar photovoltaic cells are emerging from computer simulations and lab tests conducted by a team of physicists and engineers at MIT.

Using computer modeling and a variety of advanced chip-manufacturing techniques, they have applied an antireflection coating to the front, and a novel combination of multi-layered reflective coatings and a tightly spaced array of lines—called a diffraction grating—to the backs of ultrathin silicon films to boost the cells' output by as much as 50 percent. The carefully designed layers deposited on the back of the cell cause the light to bounce around longer inside the thin silicon layer, giving it time to deposit its energy and produce an electric current. Without these coatings, light would just be reflected back out into the surrounding air, said Peter Bermel, a postdoctoral researcher in MIT's Research Laboratory of Electronics who has been working on the project.

"It's critical to ensure that any light that enters the layer travels through a long path in the silicon," Bermel said. "The issue is how far does light have to travel [in the silicon] before there's a high probability of being

absorbed" and knocking loose electrons to produce an electric current. The team began by running thousands of computer simulations in which they tried out variations in the spacing of lines in the grid, the thickness of the silicon and the number and thicknesses of reflective layers deposited on the back surface. "We use our simulation tools to optimize overall efficiency and maximize the power coming out," Bermel said. "The simulated performance was remarkably better than any other structure, promising, for 2-micrometer-thick films, a 50 percent efficiency increase in conversion of sunlight to electricity," said Lionel Kimerling, the Thomas Lord Professor of Materials Science and Engineering, who directed the project. The simulations were then validated by actual lab-scale tests. "The final and most important ingredient was the relentless dedication of graduate student Lirong Zeng, in the Department of Materials Science and Engineering, to refining the structure and making it," Kimerling said. "The experiments confirmed the predictions, and the results have drawn considerable industry interest." The team reported the first reduction to practice of their findings on Dec. 2, 2008 at the Materials Research Society's annual meeting in Boston. A paper on their findings was accepted for publication in *Applied Physics Letters*.

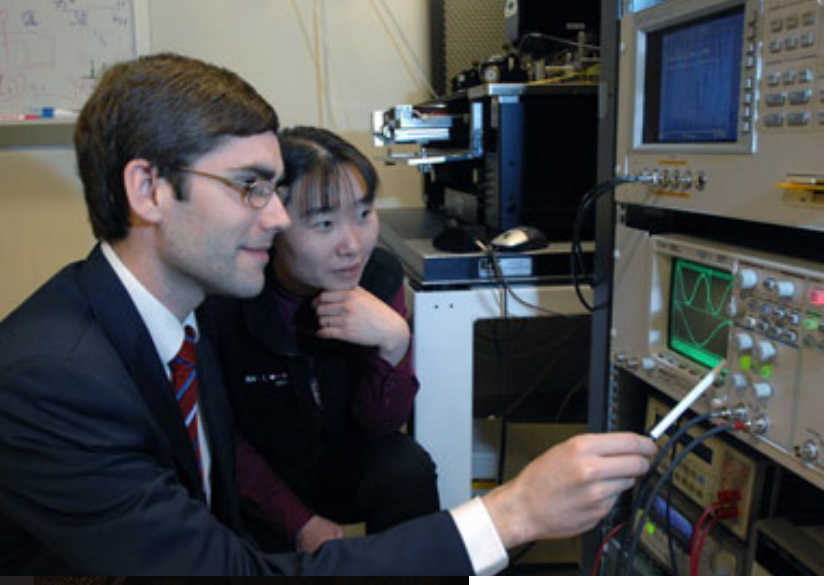
The work is just a first step toward actually producing a commercially viable, improved solar cell. That will require additional fine-tuning through continuing simulations and lab tests, and then more work on the manufacturing processes and materials. "If the solar business stays strong," Kimerling said, "implementation within the next three years is possible."

The MIT Deshpande Center selected the project for an "i-team" study to evaluate its business potential. The team analyzed the potential impact of this efficient thin solar cell technology and found significant benefits in both manufacturing and electrical power delivery, for applications ranging from remote off-grid to dedicated clean power. And the potential for savings is great, because the high-quality silicon crystal substrates used in conventional solar cells represent about half the cost, and the thin films in this version use only about 1 percent as much silicon, Bermel said.

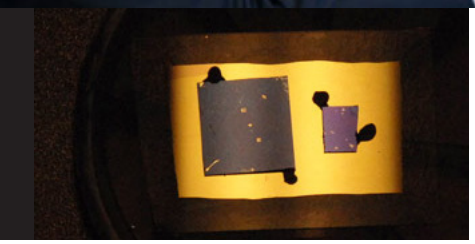
This project, along with other research work going on now in solar cells, has the potential to get costs down "so that it becomes competitive with grid electricity," Bermel said. While no single project is likely to achieve that goal, he said, this work is "the kind of science that needs to be explored in order to achieve that." In addition to Kimerling, Bermel and Zeng, the work was done by John Joannopoulos, the Francis Wright Davis Professor of Physics, and by Research Engineer Bernard A. Alamariu, Research Specialist Kurt A. Broderick, both of the Microsystems Technology Laboratories; postdoctoral associate Jifeng Liu; Ching-yin Hong, former Ph.D. student Yasha Yi, and Research Associate Xiaoman Duan of the Materials Processing Center. Funding was provided by the Thomas Lord Chair in Materials Science and Engineering, the MIT-MIST Initiative, the Materials Research Science and Engineering Center Program of the NSF and the Army Research Office through the Institute for Soldier Nanotechnologies.

"The experiments confirmed the predictions, and the results have drawn considerable industry interest."

—Lionel Kimerling



LEFT: EECS Assistant Professor Tomás Palacios, left, and Associate Professor Jing Kong examine oscilloscope traces showing the doubling in frequency of an electromagnetic signal processed through their experimental graphene microchip. (Photo / Donna Coveney)



ABOVE: The graphene microchip. (Photo / Donna Coveney)

New material could lead to faster chips

Graphene may solve communications speed limit

by DAVID CHANDLER, MIT NEWS OFFICE

New research findings at MIT could lead to microchips that operate at much higher speeds than is possible with today's standard silicon chips, leading to cell phones and other communications systems that can transmit data much faster.

The key to the superfast chips is the use of a material called graphene, a form of pure carbon that was first identified in 2004. Researchers at other institutions have already used the one-atom-thick layer of carbon atoms to make prototype transistors and other simple devices, but the latest MIT results could open up a range of new applications.

The MIT researchers built an experimental graphene chip known as a frequency multiplier, meaning it is capable of taking an incoming electrical signal of a certain frequency for example, the clock speed that determines how fast a computer chip can carry out its computations -- and producing an output signal that is a multiple of that frequency. In this case, the MIT graphene chip can double the frequency of an electromagnetic signal. Frequency multipliers are widely used in radio communications and other applications. But existing systems require multiple components, produce "noisy" signals that require filtering and consume large power, whereas the new graphene system has just a single transistor and produces, in a highly efficient manner, a clean output that needs no filtering.

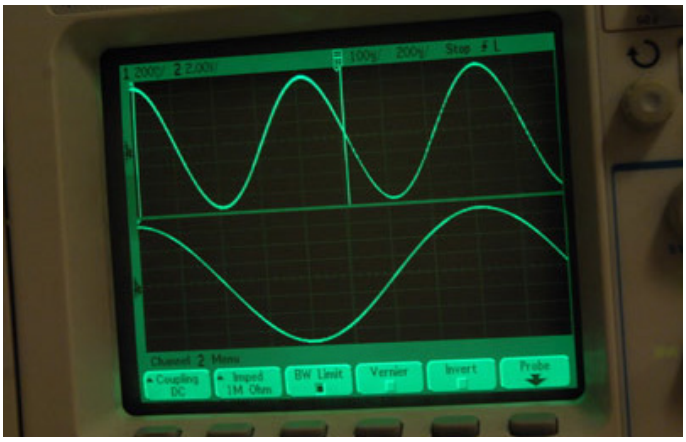
The findings were reported in a paper in the May issue of *Electron Device Letters* and also in a talk at the American Physical Society Meeting in May 2009 by Tomás Palacios, Assistant Professor in MIT's Department of Electrical Engineering and Computer Science and a core member of the Microsystems Technology Laboratories. The work was done by Palacios along with EECS Assistant Professor Jing Kong and two of their students, Han Wang and Daniel Nezich.

"In electronics, we're always trying to increase the frequency," Palacios says, in order to make "faster and faster computers" and cellphones that can send data at higher rates, for example. "It's very difficult to generate high frequencies above 4 or 5 gigahertz," he says, but the new graphene technology could lead to practical systems in the 500 to 1,000 gigahertz range.

"Researchers have been trying to find uses for this material since its discovery in 2004," he says. "I believe this application will have tremendous implications in high-frequency communications and electronics." By running several of the frequency-doubling chips in series, it should be possible to attain frequencies many times higher than are now feasible.

While the work is still at the laboratory stage, Palacios says, because it is mostly based on relatively standard chip processing technology he thinks developing it to a stage that could become a commercial product "may take a year of work, maximum two." This project is currently being partially funded by the MIT Institute for Soldier Nanotechnology and by the Interconnect Focus Center program, and it has already attracted the interest of "many other offices in the federal government and major chip-making companies," according to Palacios.

Graphene is related to the better-known buckyballs and carbon nanotubes, which also are made of one-atom-thick sheets of carbon. But in those materials, the carbon sheets



ABOVE: Oscilloscope traces showing the doubling in frequency of an electromagnetic signal processed through their experimental graphene microchip. (Photo / Donna Coveney)

are rolled up in the form of a tube or a ball. While physicists had long speculated that flat sheets of the material should be theoretically possible, some had doubted that it could ever remain stable in the real world.

"In physics today, graphene is, arguably, the most exciting topic," Palacios says. It is the strongest material ever discovered, and also has a number of unsurpassed electrical properties, such as "mobility"—the ease with which electrons can start moving in the material, key to use in electronics—which is 100 times that of silicon, the standard material of computer chips.

One key factor in enabling widespread use of graphene will be perfecting methods for making the material in sufficient quantity. The material was first identified, and most of the early work was based on, using "sticky tape technology," Palacios explains. That involves taking a block of graphite, pressing a piece of sticky tape against it, peeling it off and then applying the tape to a wafer of silicon or other material.

But Kong has been developing a method for growing entire wafers of graphene directly, which could make the material practical for electronics. Kong and Palacios' groups are currently working to transfer the frequency multipliers to these new graphene wafers.

"Graphene will play a key role in future electronics," Palacios says. "We just need to identify the right devices to take full advantage of its outstanding properties. Frequency multipliers could be one of these devices."

ABOVE: Tomás Palacios file photo, February 2008. (Photo / Tony Rinaldo)

Palacios named ONR Young Investigator

JUNE 5, 2009—The Navy's Office of Naval Research (ONR) has named Tomás Palacios, an Assistant Professor of Electrical Engineering and Computer Science, as one of its 15 new Young Investigators.

The ONR program is designed to attract young scientists and engineers who show exceptional promise for outstanding research and teaching careers. Palacios was selected from a group of 193 applicants for the honor, which includes a three-year research grant worth up to $510,000.

Palacios' work under the program will be on "Multi-Terahertz Nitride Transistors: Probing the Ultimate Limit of Deeply-Scaled Device Technology." The project aims to understand the limits of high-frequency electronics and to demonstrate record transistors that can revolutionize wireless communications, terahertz imaging and sensing.

MTL at 25

by Elizabeth Fox, Ph.D.

Wearing "bunny suits," booties, and hoods, MIT researchers build rocket engines on microchips. They fabricate nanodevices to implant in hawk moth pupae, design low-power analog integrated circuits to advance electronic products, assemble devices to characterize plasma during space missions, and use one-molecule-thick graphene for next-generation transistor technology. Located in the Gordon Stanley Brown Building (Building 39), the Microsystems Technology Laboratory (MTL) aims well ahead of industry's 3-5 year product timeline. MTL graduates a stream of well-prepared students, attracts industry support, and inspires new technology. It also produces award-winning papers, sponsors the Microsystems Annual Research Conference (MARC), publishes the *MTL Annual Report* and *Micronotes*, and presents a Seminar Series. MTL's Outreach Program allows other universities and government labs access; the Fabrication Facilities Access Program offers resources for industry. As MTL celebrates its twenty-fifth anniversary, three themes emerge: shared facilities, idea innovation, and sustained growth.

This page: Iconic MTL photo of a process engineer at a wafer cleaning station in TRL. (Photo / Hutchins Photography, Inc.)

(Photo / MTL archives)

FROM LEFT TO RIGHT: Joel Moses, David Saxon, Gordon Stanley Brown, Jean Brown, Paul Gray, and Gerry Wilson at the dedication of Building 39 in 1984.

Associate Provost Martin Schmidt (Sc.D. '88), who was the third director of MTL, calls MTL an "incubator… the modern-day water cooler. We've seen all sorts of examples where students from different disciplines start talking to each other and sparks will fly." MTL allows students to make devices on the scale of neurons. Achieving those scales, Schmidt says, "opens up a whole set of things you can do." Dr. Vicky Diadiuk (BS '72, Sc.D. '78), Associate Director for Fabrication Operations, displays micro-reactors the size of shirt buttons and talks excitedly about micro-energy-harvesters. Noting that MTL has annual contracts for over $14 million worth of research effort and enables almost $50 million worth, she says, "that leverage tells you that we're really helping lots of people within the Institute." She adds, "as typical engineers, we sometimes neglect publicizing our own achievements." MTL's culture includes the joke that other labs' devices might echo a famous ad, saying "MTL inside." Thirty-five core faculty, over 500 students, and many affiliates have used the facilities this past year. Intensive planning, dedicated directors, active students and faculty, and generous contributors created MTL's success. Appreciating MTL's myriad accomplishments requires reviewing its growth, challenges, and occasional bumps along the way.

"The future of electronics was entirely integrated electronics, not simply separate components on a printed circuit board, and… for the foreseeable future silicon was going to be the material of choice."

—PAUL GRAY

REALIZING THE NEED

The idea of building a facility grew out of conversations in the EECS Department. In the 1960s, MIT opted against having a silicon fab. By the late 1960s, former MIT President Paul Gray recalls, "the future of electronics was entirely integrated electronics, not simply separate components on a printed circuit board, and… for the foreseeable future silicon was going to be the material of choice." With the VLSI boom of the 1970s, faculty interested in microelectronics banded together. Professor Emeritus Stephen Senturia says MTL

started conceptually in 1978 through the collaboration of Richard Adler (BS '42, Sc.D. '49), who had developed an undergraduate course on transistors and solid-state electronics in a small lab in Building 13; consecutive EECS Department Heads Wilbur Davenport, Jr., and Gerald "Gerry" Wilson; and Paul Penfield, who was Associate Head until 1978 and managed MIT's VLSI Program. Penfield saw the need to connect the design and fabrication sides. He recalls thinking, "if we were really going to be a major player…, we had to have both the fabrication facility and the design approach."

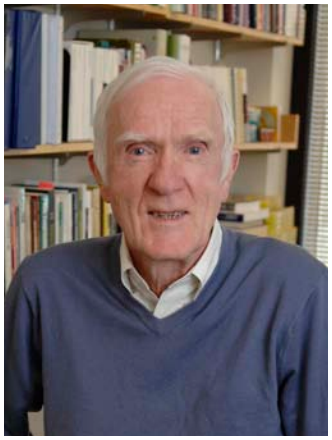
A "gang of four" professors started meeting: Senturia; Dimitri Antoniadis, the "hard-core silicon hire" of 1978; Rafael Reif, who came in 1980, and Clifton "Clif" Fonstad, a 1970 hire who specialized in compound semiconductors. Henry "Hank" Smith from Lincoln Lab also participated. Over weekly brown-bag lunches (continued as "Microlunches"), the four realized their need to cooperate. Senturia claims, "the Microlunch is the reason for MTL's success. We talk to each other. We don't always agree with each other, but we talked, built a sense of shared responsibility for our fate. Talk produced "the emotional commitment to sharing central facilities," Senturia states.

Talk continued after Charles Sodini, a circuits expert, arrived. Several debates arose. Core faculty would use the facility as their primary research location; others could become users. Senturia said that skeptics imagined affiliates might not pay enough, so the core would have to carry costs. Optimists thought, "if you build it, they will come." Ultimately, all agreed that a fab was vital for the future. Former President Gray explains that without fabrication facilities, MIT could not take students to the highest understanding and sophistication about integrated circuits (ICs). He says that while industry fabricated ICs with a standard process, "they were not prepared to handle the range of parameter changes the students… and faculty wanted to make in order to try different design considerations." Therefore, thorough innovation required on-site research fabrication facilities.

VISION, FUNDRAISING, and DESIGN

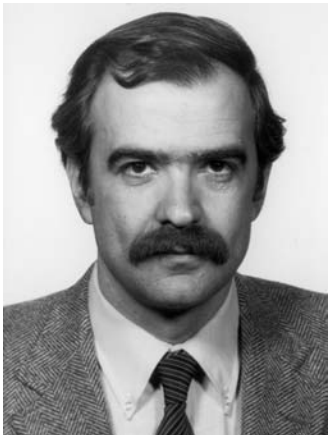
The department envisioned providing advanced research facilities and creating technologies industry could use. Adler, Wilson, Penfield, and others agreed: a fab would be necessary for MIT to be competitive in semiconductor research. In March 1980, then-Chancellor Gray gave permission to start fundraising. Adler and Penfield, with Antoniadis and Wilson, led intensive efforts; (soon-to-be) President Gray helped. They raised $13 million, exceeding the goal. Companies that contributed an initial fee and annual support formed the Microsystems Industrial Group (MIG), with special access to seminars and publications and contact with MTL affiliates.

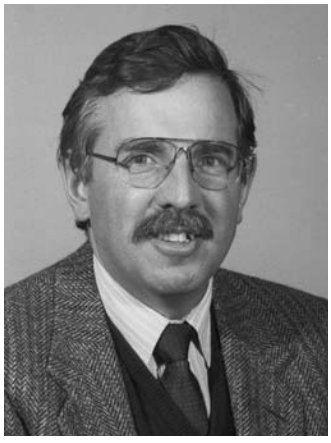
In 1979, Penfield told Antoniadis that MIT would build a fab; Antoniadis would be MTL's Founding Director, in charge of laboratories and facilities. With Assistant for Operations Anthony Colozzi, Antoniadis viewed industrial and academic labs and considered MIT spaces. Building 39 met the criteria. Its central location provided access to multiple departments, e.g., Materials Science, Chemical Engineering, and EECS. Antoniadis, Colozzi, and Symmes Maini



TOP: Dimitri Antoniadis. SECOND FROM TOP: Paul Penfield. (Photos / Tony Rinaldo)

BELOW, LEFT TO RIGHT: Dimitri Antoniadis, Clif Fonstad, Stephen Senturia, and Rafael Reif, the "Gang of Four." (Photos/ MTL archives)






(Photo/Len Rubenstein)

"It was fairly easy to assemble a group [of faculty] and convey something exciting, get good ideas, and get money for them."

—RAFAEL REIF

& McKee Associates designed everything (except the elevators), exceeding existing specifications for Class 10 and 100 cleanrooms. Creating a state-of-the-art facility on six floors was "something that had never been done," Colozzi says.

1979–1990
FIRST DIRECTORSHIP: Dimitri Antoniadis

Dimitri Antoniadis became Director of MTL in December of 1979. He credits Penfield, Director of the Microsystems Research Center and responsible for relationships with the MIG, with "driving the resurgence of silicon technology at MIT." Penfield "reach[ed] out to Chemical Engineering and Materials Science, anyone who benefited from the ubiquity of silicon… he was a coordinator, a facilitator." Penfield created the Seminar Series and Research Reviews. As MTL geared up, two new major national programs were created and became early sponsors of MTL research: the Semiconductor Research Corporation (SRC) and SEMATECH, both pre-competitive consortia, in which normally competitive industries funded research to build the country's research basis and workforce.

Silicon research was Antoniadis' main goal, achieved by combining the push for new facilities with a faculty hiring drive. Antoniadis expanded Building 13's lab before the 1984 move to Building 39. He also helped recruit Rafael Reif, Charles Sodini, and Hae-Seung "Harry" Lee, a circuit researcher who considered MIT "nirvana." They worked with Herb Sawin, Hank Smith, and Carl Thompson in an SRC-funded research Center of Excellence. Mentioning Anthony Colozzi along with early faculty and staff, Antoniadis says, "The laboratory is not the result of any one person's efforts; many people contributed both in its establishment and in its subsequent running."

Occupying the new lab was "like getting a 747," says Research Specialist Paul McGrath; "you've got to learn how to fly it. It's easier said than done." Processing steps occur in specific sequences, creating complicated traffic patterns and varying costs. As the lab ramped up, Antoniadis hired a manager, Paul Maciel, since running a service laboratory with an eventual staff of 25 required a more hierarchical organization. With the help of Professors Antoniadis, Reif, and Sodini and Dr. Prabha Tedrow, the lab developed a complementary metal-oxide semiconductor (CMOS) process to establish a 1.5-micron baseline technology and the necessary discipline in the operation of the facility.

Director for eleven years, Antoniadis is happy with his accomplishments and MTL's standing today. He established the *MTL Annual Report* in 1986. That inaugural issue lists almost 100 abstracts covering 8 areas: IC, integrated sensors, solid state devices, power devices, submicron structures, fabrication technology, computer-aided fabrication, and materials. Twelve faculty, 20 research staff, 16 support staff, and 110 students worked in 3 major research labs: the Integrated Circuits Laboratory (ICL), Technology Research Laboratory (TRL), and Submicron Structures Laboratory (SSL, now the Nanostructure Lab, NSL). Antoniadis notes that MTL was "inextricably linked with the Submicron Structures Laboratory that Hank Smith established before MTL. It was, in fact, a very important piece in the lab's early credibility, putting MTL very soon at the level of its peers."

Antoniadis agrees with Senturia that commitment to sharing resources gave everyone faith. MTL was silicon-centric under his leadership; he sees the need to continue refocusing and upgrading. However, MTL's intellectual environment may matter most. He states, "By far the most rewarding [part] has been my experience with my graduate students. That doesn't necessarily have much to do with the facility itself, but this is where we all play."

1990–1999
SECOND DIRECTORSHIP:
Richard Adler and Rafael Reif

Richard Adler, chosen as MTL's next director in charge of relationships with the MIG, briefly shared directorship with Antoniadis, starting in 1989. Sadly, Adler passed away in February, 1990. The third-floor Adler Conference Room commemorates his contributions to MTL. Penfield, at that time EECS Department Head, asked Rafael Reif to take over. While Antoniadis oversaw MTL's coming-on-board phase, Reif directed it through significant changes. His Directorship

combined responsibilities for the MIG and the facilities. The lab that he inherited targeted mostly silicon-based research, with several large programs funded by the SRC. Later, research expanded into semiconductors other than silicon. Much effort went into updating equipment. Reif says, "we got donations of fancy toys that we needed… basically an expansion of [its] capabilities… the lab was also growing in terms of research volume and space needs."

Reif remembers his Directorship for the challenge not of attracting research volume but of maintaining and increasing the number of companies in the MIG. As he recalls, "It was fairly easy to assemble a group [of faculty] and convey something exciting, get good ideas, and get money for them." Reif ran an SRC program; a Center of Excellence sponsored by SEMATECH, a consortium of semiconductor industries, government, and academia; and later a Microelectronics Advanced Research Corporation (MARCO)-sponsored center, which continues under today's Director. He also ran an Engineering Research Center for Environmentally Benign Semiconductor Manufacturing, funded by the NSF and SRC. The goal of the center was to find ways to limit water consumption and carbon use as well as reduce exhaust affecting the ozone layer. Charlie Sodini did a "tremendous amount of work with [MIG] companies to keep them as members," Reif reports. "Charlie did a great deal for MTL during my years as MTL Director. In fact, although formally he was the Associate Director, in practice he was more of a Co-Director. He was in charge of all the operations of MTL and of all the technical staff, and we made all important decisions jointly. In my view, MTL would not be what is today without his immense and selfless contributions." Reif negotiated MTL's transition in 1995 from a lab reporting to EECS to an interdepartmental lab reporting to the Dean of the School of Engineering. After eight and half years as Director, Reif became Associate Head of EECS. Now Provost, Reif considers MTL a "very dynamic group of faculty who always come up with new ideas, [who] continually reinvent themselves… so it's always desirable to work with them." He says that keeping MTL working at full capability is on the Institute's list of priorities.

1999-2006
THIRD DIRECTORSHIP: Martin Schmidt

Now-Associate Provost Schmidt joined the MIT faculty in 1988. After he became Director in early 1999, he says, MTL "switched from having a heavy focus on the semiconductor portfolio to a broadening focus of greater diversity and faculty from many disciplines." Schmidt considers the switch beneficial. In the mid-90s, approximately ninety students used the lab annually. He says they "were almost entirely single-disciplinary engineering students doing research. By the time I exited, a huge diversity of 29 different labs and centers were doing research in the facilities. We had graduate students from every department in the School[s] of Science and Engineering." The number of users ballooned to about 500. Schmidt states, "Supporting the diversity of research in some respects was the challenge of our time."

Schmidt confronted the growing pains of dramatically increasing use. Shortly after he became Director, he says, several students "wrote a fairly thoughtful, detailed, and pointed letter to me detailing their concerns about where we were headed with the facility and what was not working." Professor Jesus del Alamo (now Associate Director for Computation) chaired a committee to study the concerns, involve students, and recommend actions. Schmidt says, "They provided some pretty strong recommendations and we tried to integrate [them] into our operations… To the students' credit, they were very thoughtful in the way they surfaced the problems." The MTL culture of shared facilities was reinforced, as was the commitment to maintaining a world-class technical support staff and attention to fostering a unique community spirit among MTL's growing user population.

Schmidt evolved the lab's operational model to support a broader focus while retaining the semiconductor research core. Eventually, circuits and systems faculty found that making complicated chips in deep submicron technologies for advanced circuit research exceeded MTL's capabilities. As the need for IC manufacturing in circuits research became more sophisticated, Schmidt explains, researchers "started engaging in collaboration with industry partners who provided access to state-of-


(Photo/Tony Rinaldo)

"We had graduate students from every department in the School[s] of Science and Engineering."

—MARTIN SCHMIDT

ABOVE: Prof. Richard Adler. Adler briefly shared the directorship of MTL with Dimitri Antoniadis.

the-art manufacturing capability. That was very sensible; it enabled MIT to continue to do state-of-the-art research while not having to have that extraordinarily expensive equipment." The shift from a CMOS-centered facility to a broader, diversified facility was thus natural. For closer interaction between MIG companies, Schmidt created customization for MIG companies, who may designate a portion of their contribution to a group or center within MTL. He comments, "the MIG brings great resources; it makes perfect sense to organize the structure of the resources so that the interests of a company and researchers get aligned."

Schmidt feels he successfully navigated the period of rapid growth through diversification. He aimed to reconcile researchers' needs while avoiding redundancy. Because MTL was—and remains—the most utility-intensive building on campus, Schmidt felt it was incumbent upon MIT to squeeze the most out of it. During the rapid expansion into photonics and bioengineering during the 1990s, interest recurred in creating new facilities. Schmidt adapted MTL to suit research in specific directions and grew the infrastructure to accommodate newcomers. He takes pride in MTL's high-caliber staff, retained through the bubble economy, and its sense of community. He encouraged rituals and processes to foster the commitment to shared facilities; he cites moving MARC off campus, instituting a regular "users only" meeting where fab users get together to discuss processing and make recommendations to the fab management, and upgrading successfully to 6" wafers. "MTL has been a great investment," he says; the Institute recognizes the "need to make a new investment in [creating] facilities that carry us to the next level."

2006–present
CURRENT DIRECTORSHIP:
Anantha Chandrakasan

Three years into his tenure, Anantha Chandrakasan is excited about the prospects of ultra-low-power devices that dramatically reduce power dissipation for emerging systems (e.g., medical devices), biological micro-electromechanical (BioMEMS) devices, communications, and circuits and systems. The question in the 1980s was how to build CMOS chips; he says, "now it's all about system integration: materials, devices, and circuits, not just about components." This year's *Annual Report* contains over two hundred abstracts. Chandrakasan aims to foster interdisciplinary programs and enable exciting research in all dimensions: biomedical, energy, water, transportation, and communications. He wants to transition technology beyond prototyping to everyday use. For example, wearable medical monitoring platforms could become available for home use.

Chandrakasan has added several activities to help enhance MTL's visibility and attract new MIG members. The year he became Director, he instituted the publication of *Micronotes* and expanded MTL's web presence. The MARC became a student-run conference, one of Chandrakasan's most gratifying accomplishments during his time as Associate Director. Last December, he and a committee organized a fully-subscribed workshop, "Next-Generation Medical Electronic Systems." Under his directorship, Taiwan Semiconductor Manufacturing Company, STMicroelectronics, Qualcomm, and Veeco joined the MIG. New collaborations between MTL and MIG companies give faculty access to the most advanced industrial chip-making technology. They also provide opportunities for company personnel to participate in MTL's most exciting research. MTL Days, which he created, match students focusing on fabrication, chip design, and systems with appropriate MIG companies. Students present work-in-progress to MIG companies across the country and as far away as Japan, receive feedback, and gain exposure to practical problems.

Chandrakasan also directs MIT's new collaboration with the International Iberian Nanotechnology Laboratory. Prof. Hae-Seung "Harry" Lee, who became an MTL Associate Director in May, will be focusing on further fostering industrial relations. His own work exemplifies creative research. For four years, Lee has focused on designing radically new analog integrated circuits. His zero-crossing-based circuit

LEFT TO RIGHT: Rafael Reif, Anantha Chandrakasan, and Duane Boning.

has tremendous benefits: chief among them is an order of magnitude reduction in power consumption compared to other circuits of similar functionality. With new research directions, MTL continues to share its facilities, innovate, and grow.

As of November 2009, MTL hosts one of six centers in the Focus Center Research Program (FCRP), sponsored by the Semiconductor Research Corporation fund; Antoniadis directs the Materials, Structures and Devices center. MTL plays major roles in two other centers in the FCRP program, too. In these and most projects, research takes a long view, aiming ten years ahead.

Given all these activities, Environmental Health and Safety Officer Pat Burkhart takes understandable pride in MTL's safety record; MTL won an Environmental Health and Safety award last year. MTL has engaged in the education of future MTL users. With enthusiasm, Burkhart displays a silicon wafer etched with pictures of the forty high-school participants in this summer's Women in Technology program. All students received one of three sets of custom etched wafers depicting the program participants.

This is an example of MTL reaching out to future technologists. Each year, about seventy undergraduate students in course 6.152J fabricate MOS capacitors, MEMS cantilevers, and microfluidic devices in MTL.

MTL now stands before a variety of monumental opportunities. Chandrakasan thinks CMOS work will continue with a broad range of applications. MTL's access to the most advanced fabrication processes positions it enviably. He anticipates more biomedical work, leveraging MTL's proximity to local hospitals, clinicians, semiconductor manufacturers, bioengineering, and the Harvard-MIT Health Sciences and Technology program. Directions include low-energy electronics; energy generation, storage, and conversion; and energy-scavenging of vibrations, solar power, and body heat. Chandrakasan says he believes MTL can save energy by applying its expertise in electronics, materials, and processing technology to a variety of systems. With creative faculty, great students, superb staff, and industry's support, MTL will continue to generate the explosion of research ideas with which it began. MTL's bunny-suited researchers create the future.

"Now it's all about systems: material, devices, and circuits, not just components but system integration"

—ANANTHA CHANDRAKASAN

ALUMNI UPDATE

Micronotes Technical Liaison Ted Equi talks with six MTL alumni about their jobs, lives, and MTL.

MARK ARMSTRONG • Ph.D. 1999 Mark Armstrong has been at Intel Corporation in Hillsboro, OR, since he graduated, starting in the 130nm node and subsequently working on 90nm (Strained-Si), 45nm (HiK-MG) and now 32nm nodes. He says, "The most rewarding aspect of this job, by far, is working with the extremely talented engineers here. The ability of engineers to tackle and solve seemingly unsolvable problems never ceases to amaze me." As a Device Engineer at Intel's Portland Technology Development, Mark found that he never stops learning about how to attack key issues, leaving no stone unturned until the problem is solved. Being involved with advanced technology is very interesting. In particular, the implementation of strained-Si was rewarding, as that was his thesis topic at MTL, which enabled him to contribute to this effort. Mark identifies the most memorable experience at MIT as the time he spent several months getting some strained-Si films through the fab in order to make some ring-oscillators, only to have the devices turn out completely dead. He learned to take a more bite-size approach to getting results. When he switched from working on III-V devices to Si, he discovered that he enjoyed working in a large team environment.

Words of Wisdom for the MTL community:
"Take the time to learn the basics of your field. I still get wrong answers from Ph.D. job applicants about how a diode works!"

WENDI HEINZELMAN • Ph.D. 2000 "Working with students is a constant source of satisfaction," says Wendi Heinzelman about her roles at the University of Rochester—as Associate Professor of Electrical and Computer Engineering and of Computer Science and as Dean of Graduate Studies for Arts, Sciences and Engineering. Wendi enjoys the challenge of wearing multiple hats and balancing the demands of teaching, research in the areas of mobile ad hoc networks and wireless sensor networks, writing papers and proposals, community outreach, and budget management. Developing new programs to support graduate students, helping to make their programs more productive and enjoyable, is rewarding. Prior to joining the faculty at University of Rochester in 2001, she and her husband Steve traveled to Africa, Nepal, and India and then took a sabbatical in 2008 to the University of Canterbury in Christchurch New Zealand. From her time at MTL, Wendi remembers working with her advisor Anantha Chandrakasan. "He was a fantastic advisor and set me on the path of researching wireless sensor networks, a novel area at the time. His vision clearly set the course of my current career path."

Words of Wisdom for the MTL community:
"Understand your own career goals and aspirations and make decisions to best support those goals. It's so important to do what you love and love what you do—this will make all the difference in your future happiness!"

CRAIG KEAST • SM 1989, Ph.D. 1992 Craig Keast attributes much of his professional growth to his experiences at Lincoln Laboratory and MIT (MTL). "The breadth and depth of the research activities at the Lab" is what he finds challenging and interesting. Currently he serves as the Associate Head of the Solid State Division and the Director of Operations for the Microelectronics Laboratory at MIT Lincoln Laboratory. His responsibilities include research in high-performance imaging sensors, deeply scaled silicon microelectronics, solid-state lasers, optoelectronics, superconductive devices, and biological sensors. After completing an undergraduate degree in psychology and biology, he worked for several years prior to joining MIT Lincoln Laboratory as a semiconductor research technician. While there he developed a strong interest in electrical engineering and started to take a course a semester as a Special Student at MIT. He left Lincoln Laboratory to become a full time graduate student in the MTL. He completed his SM, EE, and Ph.D. in four years and returned to Lincoln Laboratory, first as a member of the technical staff in the Submicrometer Technology Group, but later serving as Director of Operations for the Microelectronics Laboratory (MEL) and the Leader of the Advanced Silicon Technology Group.

Words of Wisdom for the MTL community:
"Take time to enjoy the everyday interactions with your fellow graduate students. These peer-to-peer interactions form an important cornerstone of the MTL educational process."

KEEP IN TOUCH!

We want to hear from our alumni! To send us notes, pictures, stories, updates, or any other good news, please contact us!
http://mtlweb.mit.edu/alumni.html

JEN LLOYD • Ph.D. 1997 As an Engineering Manager in the RF and Networking Components (RFNC) business unit at Analog Devices, Jen Lloyd leads a development team focused on analog and wireline products. Since graduating from MIT/MTL, Jennifer has stayed in the Boston area, working at Analog Devices in multiple product groups designing communications data converters and wireline transceivers. Jen says, "Since Analog Devices doesn't have a dedicated R&D department, my group has to balance the need to get products to market with the need for forward looking technology development." While she was doing her research at MTL, she developed a broader technical background through weekly interactions with students and professors from other research groups. Jen recalls, "The best day of my graduate career was getting a working prototype of a multi-chip pressure sensor in collaboration with another graduate student, Lalitha Parameswaran. The sensing system was based on a sigma-delta ADC and a MEMs pressure sensor fabricated in the MTL. Seeing bits come out of the electrical side was amazing!"

Words of Wisdom for the MTL community: "Take advantage of the time in graduate school when you have the freedom to explore a broad technical area. Embrace the opportunities to collaborate and brain storm with your fellow graduate students. Figure out what you love to do and where you are most creative, and then steer your focus in that direction."

ROB GILMORE • SB 1976, SM 1977 Although Rob Gilmore's time at MIT precedes the formation of MTL, he has engaged many members of the MTL community, working closely with Professors Charlie Sodini and Anantha Chandrakasan for multiple years. Rob is currently Vice President of ASIC Engineering, Corporate Research and Development at Qualcomm. Rob played an active role in establishing the partnership that resulted in Qualcomm becoming an MTL sponsor and MIG member. "Contributing to projects, working with universities and helping to define future technologies for Qualcomm" are what keep Rob's position challenging and interesting. After graduate studies at UC Berkeley, Rob has been in the forefront of communications technologies, founding a number of companies. He was Employee Number 9 at Qualcomm, where he participated in many "firsts." Rob organized the VLSI department, later known as QCT. Rob has also involved other members of the Qualcomm community to participate in MTL research. Although Rob's Qualcomm responsibilities keep him busy, he loves to spend time with his family and enjoys rock climbing, amateur radio, and traveling.

Words of Wisdom for the MTL community: "It is an honor and a pleasure to be affiliated with MTL, with remarkable people and amazing technology. What more could you ask for?"

ARAVIND PADMANABHAN • Ph.D. 1996 "I found the environment at MIT to be very entrepreneurial. Developing a deep knowledge of technology was only part of the journey. Determining the applications of the technology for successful business execution was equally challenging." After receiving his Ph.D. in EECS focused on microelectromechanical systems (MEMS) with a minor in management from MIT, Aravind Padmanabhan joined Honeywell in 1997 as a Principal Scientist. His research work at Honeywell has involved the development and commercialization of MEMS-based sensors/actuators and highly integrated microsystems. Aravind shares that Professor Marty Schmidt created an environment for his students to be independent thinkers and problem solvers: "I use these skills even more in leadership roles than I did as a new research scientist. Not only was there incredible talent in the MTL community, there was also a humility and collegial nature that fostered learning." He currently serves as Director of Honeywell's Automation and Control Solutions (ACS) Sensors & Wireless Global Labs. His lab is responsible for establishing and driving the technology research strategic plan for the ACS businesses in the area of sensors and wireless technologies.

Words of Wisdom for the MTL community: "You need to keep the big picture or the 'so what?' in the forefront of your mind while doing a research project in order to keep the work fresh and relevant. Breadth is equally as important as depth to become an effective technology leader. Complex problems need multiple minds for effective solutions."

FRONT ROW: Joy Johnson, Prof. Carol Livermore, Courtney Schmitt, Sheila Nabanja, Johnna Powell, Eric Lam (behind), Tyrone Hill, Kerry Cheung, Polina Anikeeva. **SECOND ROW:** Nigel Drego, Yogesh Ramadass, Naveen Verma, Denis Daly, David He, Salil Desai, Daniel Finchelstein, Hyun Hu Boo (in front), John Ho, Osama Nayfeh, Kailiang Chen, Zhipeng Li, and Daniel Ku.

Polina Anikeeva (left) and Osama Nayfeh (right).

Johnna Powell

Sarah Zhang (left) and Denis Daly (right).

Graduation *June 5, 2009*

The annual reception for MTL graduates was held in the Grier Room on Friday, June 5, 2009. Hosted by Debroah Hodges-Pabon, this event brought students together with family, friends, and faculty to say their good-byes and embark on new beginnings. (All photos / Paul McGrath, MTL)

Yogesh Ramadass (second from right) with his family and advisor Anantha Chandrakasan (middle).

From left: Tayo Akinwande, Luis Velásquez-García, Liang-Yu Chen, Kerry Cheung, Annie Wang, and Melissa Read.

Prof. Joel Dawson

Same name, new venue.

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