MTL MICRONOTES

the annual news magazine of the Microsystems Technology Laboratories

fall 2008

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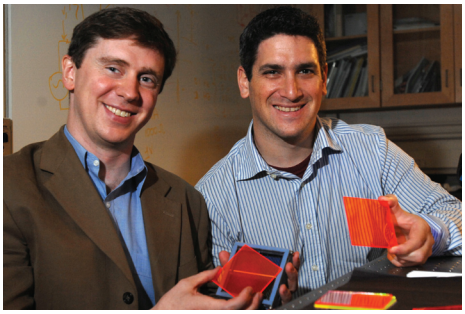

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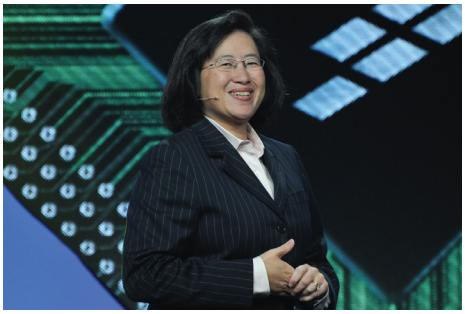

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ON THE COVER:

Graduate student Ivan Nausieda at work in the Dawson/Sodini group laboratory's EM-free workroom (Photo, Tony Rinaldo Photography).

Notes from the Director

Welcome to the 2008 edition of the Microsystems Technology Laboratories (MTL) magazine, MTL Micronotes. The purpose of this annual magazine is to keep MTL alumni, members, industrial consortium and friends up-to-date with news from MTL.

During the past year, our 32 core faculty members engaged in a broad range of exciting research initiatives, including device fabrication, integrated circuits and systems, photonics, MEMS, and molecular- and nano-electronics. In addition, more than 80 affiliate faculty members at MIT benefited directly from the fabrication and/or CAD infrastructure provided by MTL. More than 550 researchers conducted research at MTL. Several faculty, staff members and students received significant awards.

MTL hosted a number of exciting technical events and seminars this year. In February 2008, we were honored to co-host (along with ILP) an MTL Distinguished Seminar led by Dr. Craig Barrett, Chairman of the Board of Intel Corporation. The MTL faculty and students had an opportunity to interact with Dr. Barrett on emerging directions in the semiconductor industry. A video of his presentation can be found at: http://mitworld.mit.edu/video/552/.

MTL's Annual Research Conference (MARC 2008) was a great success as always. The event featured over 75 posters covering various technical areas and two exciting keynote presentations. The event, organized by our graduate students and a faculty steering committee chaired by Professor Joel Voldman, drew more than 220 attendees. The students appreciated the technical interactions with the industrial attendees from our Microsystems Industrial Group (MIG) companies. MARC is a unique opportunity to learn about research in the diverse areas encompassed by MTL, and helps encourage interaction among the MTL community.

We continue to feature exciting presentations in our regular MTL Seminar Series organized by the MTL Seminar Committee chaired by Prof. Joel Dawson (seminar videos are available to the MIT community and MIG members through the MTL website).

The MTL community greatly benefits from the generous financial support of the MIG. The MIG funding provides subsidy for device and circuit research. In addition, the MIG members donated equipment, contributed directed fellowships and provided fabrication access to state-of-the-art technologies. I would like to welcome three new companies to the MIG: TSMC, STMicroelectronics and Qualcomm. Our Industrial Advisory Board (www-mtl.mit.edu/mig/iab.html) provides significant assistance in shaping the vision of MTL (e.g., helping define new opportunities in emerging medical electronics systems). We continued our successful MTL visit days to Intel, ADI, and Hewlett-Packard. The students benefit greatly from the opportunity to give detailed presentations to industry experts. These visits have resulted in increased collaborations between MTL and the MIG companies.

We are eager to hear from our alumni. Please register at the web site (www-mtl.mit.edu) to receive future MTL publications. We hosted a successful alumni event at ISSCC 2008. More than 100 people attended the event. You may contact Debroah Hodges-Pabon for information about any future alumni events. Please contact me if you have suggestions for ways to improve MTL. I am eager to hear from you.

Sincerely,

ANANTHA P. CHANDRAKASAN
Director
Microsystems Technology Laboratories

Photo, Tony Rinaldo

Anantha P. Chandrakasan

Director, Microsystems Technology Laboratories

MTL Welcomes New Members Qualcomm,

Above, from left to right: Walid Hamdy, Eladio Arvelo, Jeremy Lin, Rob Gilmore, Rajesh Pankaj, Ali Tassoudji, and Carlos Labrada. (Photo/Qualcomm)

Qualcomm

A visionary technology leader in wireless technology since 1985, Qualcomm's products have been changing the world by improving the way we communicate, work and live. Qualcomm's business model has always been built on the strength of collaboration, and it was that collaborative spirit that led them to join forces with MTL. "We are excited to join MTL's Microsystems Industrial Group and look forward to building a strong partnership," said Rob Gilmore, Vice President of Technology in Qualcomm's Corporate Research and Development. "We look forward to collaboration on innovative architectures, processes and nanotechnology with emphasis on wireless, healthcare and the environment."

Qualcomm stands out in the industry for its commitment to research and development. In 2007, the company invested 21% of their gross revenue, or $1.83 billion, in R&D—an investment that has increased every year since 2000. This large financial commitment has been central to Qualcomm's strategy for staying on the leading edge of wireless technologies that create opportunity for more partnerships.

Qualcomm has enjoyed strong ties with MIT since its founding in 1985. Both of the founders, Dr. Irwin Jacobs and Dr. Andrew Viterbi, were MIT graduates. In 2007, Joan and Irwin Jacobs provided a $30M gift to MIT to support on an annual basis at least 15 graduate fellows in the Department of Electrical Engineering and Computer Science. "The generosity and engagement of the Jacobs and Qualcomm are incredibly important to MIT, EECS, and MTL so we can carry out our education and research mission," said Duane Boning, Professor and Associate Department Head for EECS. He added "Qualcomm is a key member of the EECS VI-A Industrial Masters Thesis internship program, and we are delighted that Qualcomm has joined the MIG." Today Qualcomm has over 125 MIT graduates on staff.

– Professor Joel Dawson, MIT

About Qualcomm

QUALCOMM®

Qualcomm is a global leader in developing and delivering innovative digital wireless communications products and services based on CDMA and other advanced technologies. Ranked on FORTUNE Magazine's list of the "100 Best Companies to Work For," Qualcomm employs more than 15,000 individuals around the world. Headquartered in San Diego, California, Qualcomm innovates new ways to communicate and plays a central role in the rapid adoption and growth of 3G and next-generation wireless. Qualcomm's current intellectual property portfolio includes more than 7,200 United States patents for wireless technologies, with more than 145 telecommunications equipment manufacturers licensing them worldwide. To learn more about Qualcomm please visit http://www.qualcomm.com.

STMicroelectronics

Collaborates with MTL on Ultra Low Power Microcontroller development

STMicroelectronics, among the world's largest semiconductor companies and a leading supplier of embedded System-on-Chip ICs for use in consumer, communications, automotive and computer peripheral markets, recently joined the Microsystems Technology Laboratories' (MTL) industry consortium: the Microsystems Industrial Group (MIG).

"We are thrilled to have STMicroelectronics join the Microsystems Industrial Group as the first European company in the consortium. We are looking forward to an active collaboration in a number of important areas including ultra-low-power electronics, sensor systems and medical electronics," said Anantha Chandrakasan, MTL director and MIT professor of electrical engineering and computer science.

"STMicroelectronics is a leader in the development of low-power technologies that can reduce power dissipation in embedded System-on-Chip solutions, while maintaining the same level of performance in cutting-edge industrial and portable consumer products," said Alessandro Cremonesi, Strategy and System Technology Group Vice President and Advanced System Technology General Manager, STMicroelectronics. "By inviting ST to play a key role in developing the next-generation of power-efficient microcontrollers, the Microsystems Industrial Group is recognizing the expertise that we offer in this field. ST looks forward to contributing and expanding its expertise in ultra-low-power technology."

"By joining MTL, ST will be able to push its research efforts to fully exploit 'near-threshold' technology and reach far below the actual power consumption limits of energy-efficient System-on-Chip solutions," said Elio Guidetti, Director for Ultra Low Power Platforms, Advanced System Technology, STMicroelectronics. "This technology can enable the development of an entirely new generation of microcontrollers for wireless sensors and portable medical devices."

STMicroelectronics is engaged in a wide range of research programs conducted with leading universities and research institutes around the world.

– Francesco Pappalardo, STMicroelectronics

About STMicroelectronics

STMicroelectronics is a global leader in developing and delivering semiconductor solutions across the spectrum of microelectronics applications. An unrivalled combination of silicon and system expertise, manufacturing strength, Intellectual Property (IP) portfolio and strategic partners positions the Company at the forefront of System-on-Chip (SoC) technology and its products play a key role in enabling today's convergence markets. The Company's shares are traded on the New York Stock Exchange, on Euronext Paris and on the Milan Stock Exchange. In 2007, the Company's net revenues were $10 billion. Further information on ST can be found at http://www.st.com.

Above: Visiting Scientist Dr. Francesco Pappalardo from STMicroelectronics in his office at MIT. (Photo/Paul McGrath)

ST Microelectronics, TSMC to MIG

TSMC

The world's largest dedicated independent semiconductor foundry, Taiwan Semiconductor Manufacturing Company, Limited, (TSMC) recently rejoined the Microsystems Technology Laboratories' (MTL) industry consortium.

With its headquarters and main operations in Taiwan, TSMC created the semiconductor-dedicated foundry industry when it was founded in 1987. In the 1990s, TSMC was the first Taiwanese company to join the MTL's Microsystems Industrial Group (MIG), a consortium of 14 industry and technology leaders.

MIG was formed in the 1980s to support MTL infrastructure and research by working with faculty members on directing the labs' research and educational objectives.

TSMC rejoined the group this year after a multi-year hiatus. Over the past year, TSMC participated in meetings and a joint workshop, TSMC Day at MTL.

"We are very excited with TSMC joining the MIG," said Anantha Chandrakasan, MTL director and MIT Professor of Electrical Engineering and Computer Science. "TSMC is the first company from Taiwan to join the industrial consortium. The MTL faculty and students are eager to collaborate with TSMC in a number of areas, including device optimization, statistical metrology and advanced circuit design. We are happy with our ongoing joint research and greatly appreciate access to advanced CMOS (complementary metal–oxide–semiconductor) integrated circuit fabrication through the University Shuttle Program." In addition to TSMC's MIG membership, the company provides access to its advanced semiconductor manufacturing technologies for MIT and other university faculty.

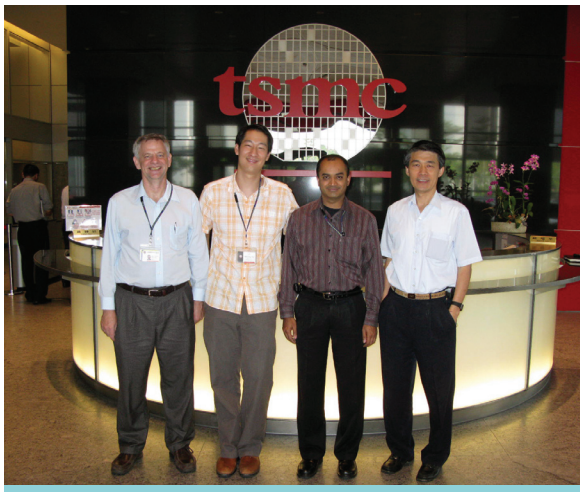
"TSMC is eagerly collaborating with the MTL's outstanding faculty and students in a range of projects supporting our research into advanced technology nodes," said Dr. Jack Sun, TSMC's Vice President of Research and Development. "At the same time, we are just as pleased to support university research with our world-class manufacturing capabilites through the Unversity Shuttle program."

TSMC has participated in collaborative research at MIT in the past under the leadership of TSMC's chairman, Dr. Morris Chang, a 1952 MIT alumnus, life member emeritus of the MIT Corporation and advocate of industry-academic collaborations.

– Rachel Oberai-Soltz, Associate Director, and Charles Hsu, Senior Industrial Liaison Officer; MIT Industrial Liaison Program

About TSMC

TSMC is the world's largest dedicated semiconductor foundry, providing the industry's leading process technology and the foundry's largest portfolio of process-proven libraries, IP, design tools and reference flows. The Company's total managed capacity in 2008 is to exceed nine million (8-inch equivalent) wafers, including capacity from two advanced 12-inch Gigafabs, four eight-inch fabs, one six-inch fab, as well as TSMC's wholly owned subsidiaries, WaferTech and TSMC (Shanghai), and its joint venture fab, SSMC. TSMC is the first foundry to provide 40nm production capabilities. Its corporate headquarters are in Hsinchu, Taiwan. For more information about TSMC please see http://www.tsmc.com.



Above, from left to right: David Scott, Mark Peng, Sreedhar Natarajan, Douglas Yu. (Photo/TSMC)

MIG Annual Meeting
January 31, 2008

Clockwise, from top: Attendees listen to the meeting in progress. MIG company industrial advisory board members and representatives are seen in the first row. From left: Sreedhar Natarajan, TSMC; Elio Giudetti, STMicroelectronics; Dennis Buss, Texas Instruments; Paul Benning, Hewlett-Packard; Takemitsu Kunio,NEC. ***Middle right:*** Peter Holloway, National Semiconductor; Brad Scharf, Analog Devices; Ghavam Shahidi, IBM. ***Bottom:*** John Kelly, Novellus; William Bowhill, Intel. (Photos/Paul McGrath)

MTL Day at Intel

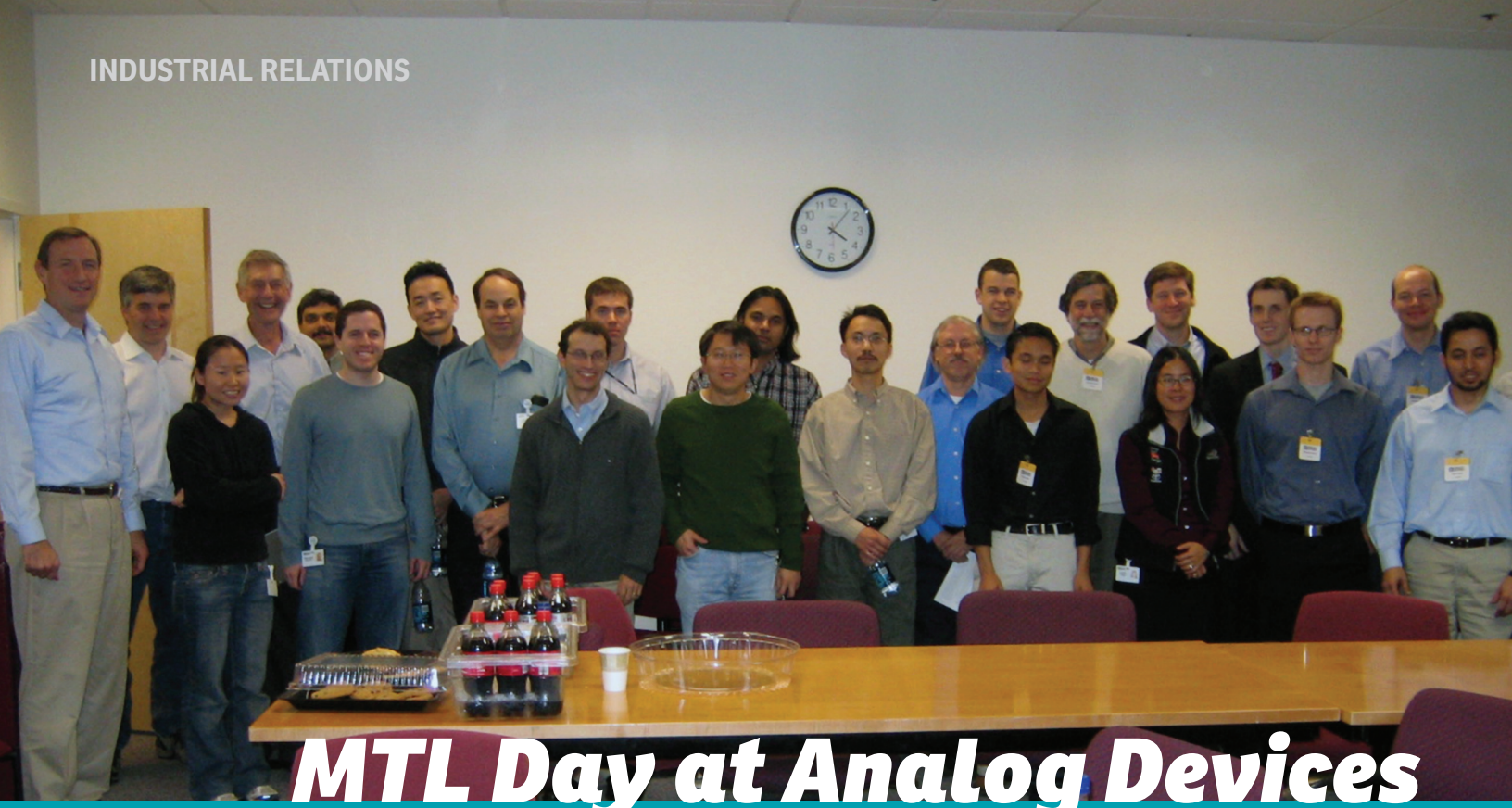
May 27, 2008

Above, from left to right: Kimberly Sills, Intel; Gilbert Nessim, MIT; George Bourianoff, Intel; Jason Orcutt, MIT; Jesus del Alamo, MIT; Lane Brooks, MIT; Joyce Kwong, MIT; Nigel Drego, MIT; Johnna Powell, MIT; Osama Nayfeh, MIT; Leo Gomez, MIT; Niamh Waldron, MIT; Byungsub Kim, MIT. (photographer unknown)

Schedule of Events

8:00am	Arrival in RA3, introductions
8:30am	Mark Bohr, Ian Young -Intel Overview
9:00 am	Prof. Jesus del Alamo - MTL/CICS Overview
9:30 am	Niamh Waldron - III-V FETs for logic
10:00 am	Nigel Drego - Electrical variations in IC manufacturing
10:30 am	Osama Nayfeh - Nanodot memories
11:00 am	Gilbert Nessim - Carbon nanotube in scaffolds
11:30 am	Leonardo Gomez - P-channel strained SiGe FETs
12:00pm	Lunch
12:30pm	Tours of fab and testing labs (Bohr, Young)
1:30 pm	Joyce Kwong - Ultra-low voltage digital circuits
2:00 pm	Johnna Powell - Millimeter-wave circuits
2:30 pm	Lane Brooks - Zero-crossing based A/D converter
3:00 pm	Byungsub Kim - On-chip equalized interconnects
3:30 pm	Jason Orcutt - CMOS Photonics
4:30pm	Mike Mayberry - Future Intel Directions
5:00pm	Break
6:30pm	Dinner

MTL Days at MIG member companies continued in 2008 with a spring visit to the Intel campus in Hillsboro, OR . Ten graduate students accompanied by Prof. Jesus del Alamo viewed the facility along with Intel representatives Kimberly Sills and Dr. George Bourianoff. Students gave half-hour presentations on their work and also had an opportunity to discuss the future of Intel's research.



MTL Day at Analog Devices

November 18, 2007

Above: The MIT delegation mingles with Analog employees for a group photo during a break in the day. (photographer unknown)

This event was organized by Brad Scharf (IAB member, Analog Devices) and Charles Sodini (Faculty Liaison). Presentations were made by MIT students and ADI. Prof. Judy Hoyt also participated in this event.

Schedule of Events

9:10-9:30	M.K. Kim, "Epitaxial Ge on Si"
9:35-9:55	B. O'Mara, "Optical Device Development at ADI"
10:00-10:20	A.C. Weber, "Power MEMS Relay"
10:25-10:45	Break
10:45-11:05	M. Judy, "ADI MEMS"
11:10-11:30	P. Godoy, "Nested Chopper Stabilization in CMOS Analog Multiplier"
11:35-11:55	D. Daly, "Integrated Pulsed UWB Transceiver"
12:00-1:00	Lunch
12:00-12:20	C. Sodini, "MTL Overview"
12:25-12:45	Martin, "ADI Overview"
1:00-1:20	B.M. Helal, "1.6GHz Multiplying DLL"
1:25-1:45	B. Moss; "8b, High-Efficiency Low-Area Successive Approx. ADC"
1:50-2:10	Kapusta, "Digital Still Camera AFE"
2:15-2:35	M. Guyton, "Low-V Comparator-Based Switched Cap D-S ADC"
2:40-3:00	Break
3:00-3:20	M. Straayer, "12b, 10MHz Contin.-Time S-D ADC"
3:25-3:45	A. Shabra, "RF Systems"

Above: Front row, left to right: Laura King, Hewlett-Packard; Jennifer Yu, MIT; Liang-Yu Chen, MIT; Bryan Cord, MIT; Brian Taft, MIT; Hayden Taylor, MIT. Back row, left to right: Karl Berggren, MIT; Martin Schmidt, MIT; Paul Benning, Hewlett-Packard; Salil Desai, MIT; Kyeong-Jae Lee, MIT; Tim Weber, Hewlett-Packard. (photographer unknown)

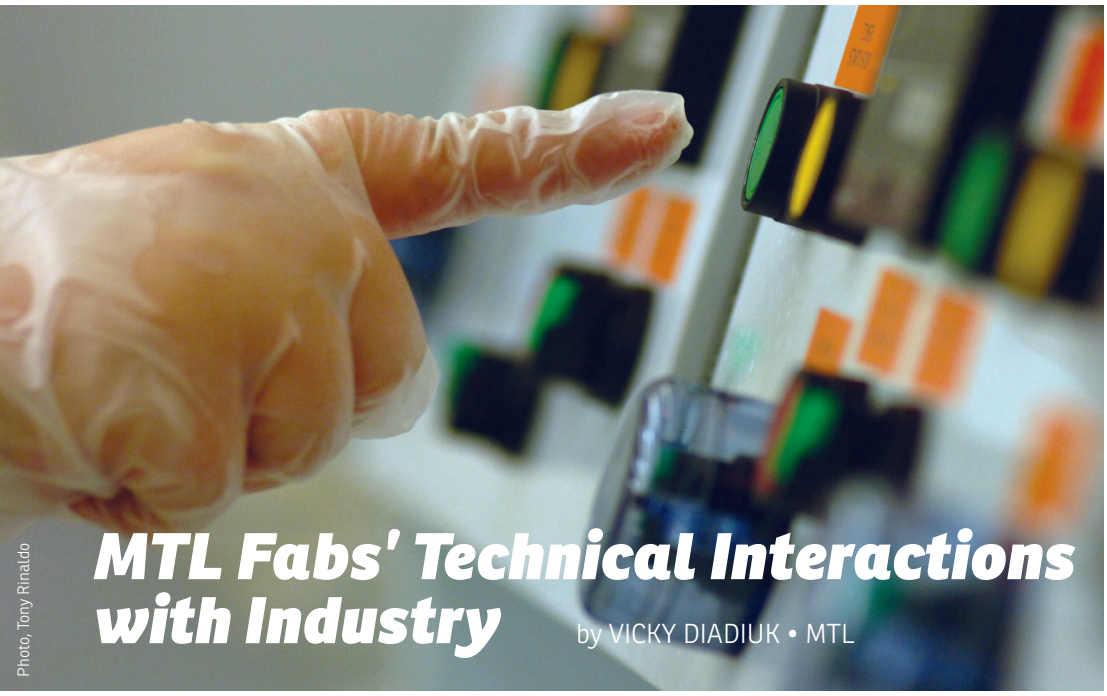
MTL Day at Hewlett-Packard

November 5, 2007

MTL Day at Hewlett-Packard took place in November 5, 2007. Chaperoned by Professors Martin Schmidt and Karl Berggren, the trip took everyone to Corvallis, OR to meet with HP execs.

Schedule of Events

9:00am	Tim Weber, Intro to the HP & TDOE.
9:45am	Bryan Cord, "Charged-particle lithography at the sub-10-nm length scale"
	Liang-Yu Chen, "Micro Ionizer: Double-gated Vertically Aligned Carbon Nanofiber (VACNF) Arrays"
	Jennifer Yu, "Patterning and printing nanostructured thin films"
10:50am	Break
11:00am	Brian Taff, "Dielectrophoretically Active Microfluidic Weir Geometries for Patterned Single-cell Assays"
	Hayden Taylor, "Modeling pattern dependencies in MEMS fabrication processes"
	Kyeong-Jae Lee: Low-Power Carbon Nanotube Sensor System
	Salil Desai, "Dielectrophoresis and Cell Health"
12:35pm	Lunch Panel discussion: Transition from University to Industry.
1:45pm	Pavel Kornilovich, John Bamber, Jim Przybyla, and Jeremy Donaldson, Projects in HP
2:45pm	Break
3:00pm	Laura King, Neal Meyer, Paul Benning, Jim Stasiak; NFL tour and discussions (Faculty)
3:00pm	Henry Lewis, Lorraine Wang, Michelle Pangborn, "Working at HP (Students)"
4:00pm	Laura King,Opportunities at HP Meet with hiring Managers/Engineers (Students)
5:00pm	Fab/Plant tour (Students & Faculty)
6:30pm	Dinner



Photo, Tony Rinaldo

MTL Fabs' Technical Interactions with Industry

by VICKY DIADIUK • MTL

The three nano & microfabrication facilities (fabs) that MTL maintains in Building 39 - the Integrated Circuits Laboratory (ICL), Technology Research Laboratory (TRL) & Exploratory Materials Laboratory (EML) - provide MIT students with access to a wide array of technologies for designing and fabricating semiconductor devices for ULSI, MEMS and many other applications. In addition, MTL's fabs can be accessed by external users via the MTL Outreach Program - for users from other academic institutions and government agencies, and the Fabrication Facilities Access Program (FFA) - for engineers from local industry.

Thus, MTL's fabs welcome scientists and engineers from industry both from MTL's sponsoring companies (MIG) as well as from start-ups and other companies through the FFA. The former tend to be high-level and somewhat infrequent interactions, that take place mostly when a MIG member company requires a non-standard process that would be difficult to implement in their production facilities. In this case, MTL serves as an advanced development lab, where cutting-edge approaches can be safely and rapidly tested. An example of this was the development by ADI of Ge photodetectors; these devices have now been transferred into ADI mainstream fabrication facilities.

The FFA companies, by contrast, do their main device and process development at MTL, where the flexibility offered by MTL's tools and its research approach, allow them to experiment with materials and processes until they have optimized their device fabrication flow. At that point, if warranted, they can proceed to use commercial foundries for their production runs. Developing the processes at foundries would be cost- and time-prohibitive, as would, in most instances, setting up a company fab. Thus MTL allows local (for the most part, though some geographically-distant companies have participated in the FFA), industry to spend their limited resources on development, not facility installation. Since its inception in 2004, the FFA program at MTL has had about 16 member companies, many companies have been members until their products matured into production-worthy devices, and many have returned for a second round of development. Examples of devices developed through the FFA program are time-controlled drug delivery systems, optical waveguides, IR detectors and many others.

MTL is proud of its many successful technical interactions with industry, and of its role in enabling industry's successful development.

Former MTL Lab Director appointed Associate Provost

Above: Professor Martin Schmidt (Photo/Tony Rinaldo)

Professor Martin Schmidt of the Department of Electrical Engineering and Computer Science has been appointed Associate Provost, Provost L. Rafael Reif announced in June 2008.

Schmidt has succeeded Lorna Gibson, the Matoula S. Salapatas Professor of Materials Science and Engineering, who planned a return to her research in the Department of Materials Science and Engineering after taking a sabbatical for the 2008-2009 academic year.

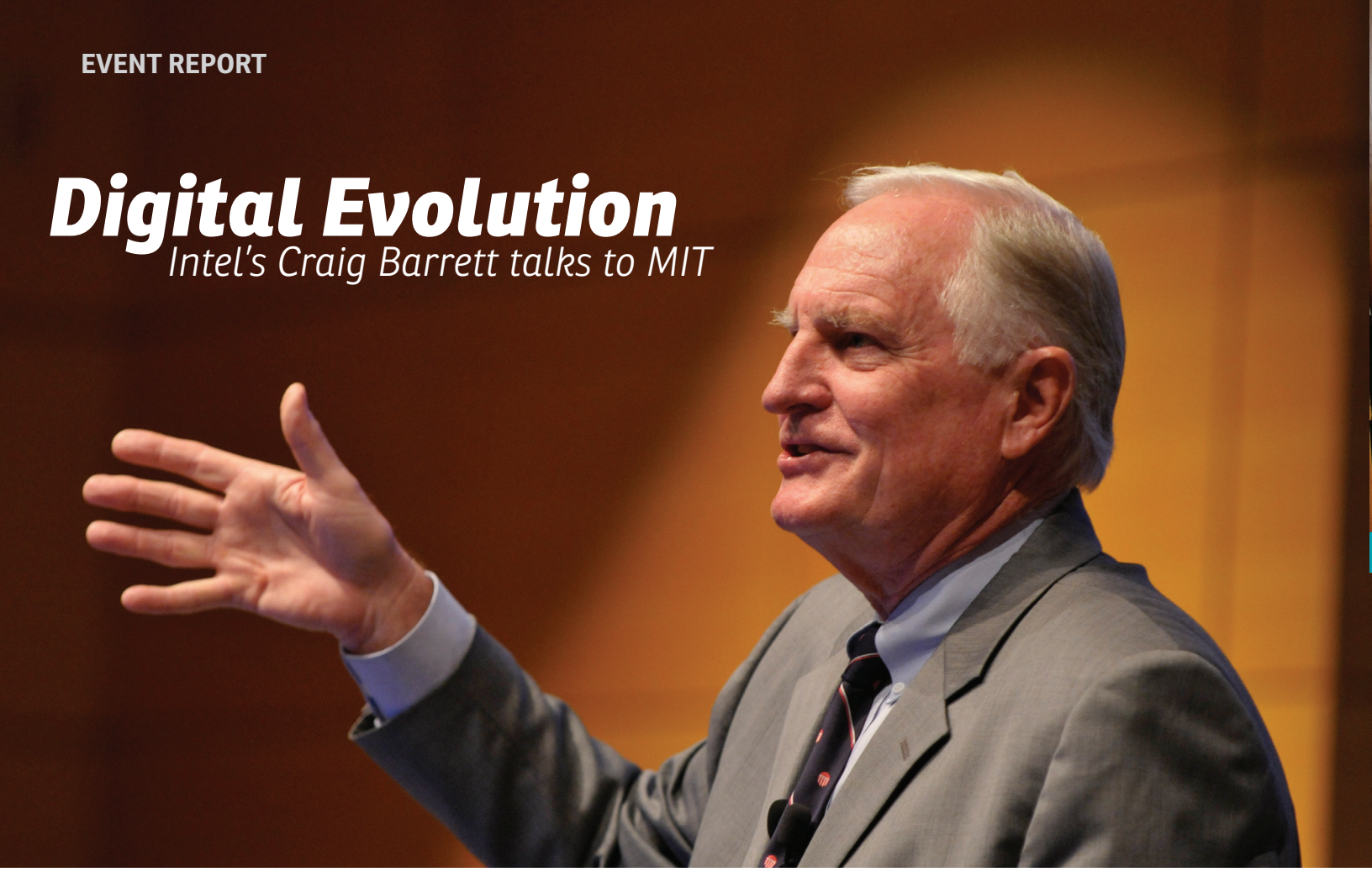
"Professor Gibson brought a depth of experience, sound and thoughtful judgment, and a strategic perspective to this position, and I am deeply grateful for her service," Reif said. "I look forward to working with Professor Schmidt to build on the strong foundation she helped establish."

Professor Schmidt SM '83, PhD '88 has been a faculty member since 1988. From 1999 to 2006 he served as the director of the Microsystems Technology Laboratories (MTL) at MIT. His teaching and research is in the areas of micro and nanofabrication of sensors, actuators, and electronic devices, microelectromechanical systems (MEMS), design of micromechanical sensors and actuators, and micro/nanofabrication technology. He is the co-author of more than 60 archival journal publications and 110 peer-reviewed conference proceedings. His appointment commenced on July 1.

The Associate Provost chairs the Committee for the Review of Space Planning (CRSP), with oversight for space planning, allocation and renovations across the Institute. The position also includes responsibility for managing faculty affairs, including faculty development, renewal, and grievance policies and procedures.

Digital Evolution

Intel's Craig Barrett talks to MIT



"Invest in good people with good ideas... Don't be afraid to change the rules (Intel has one of the most recognizable brands in spite of the fact that we don't sell to the end user)."
– Craig Barrett

Americans today are living longer than ever before (life expectancy in this country is about 78 years). The aging "Baby Boomer" population, in particular, is on everyone's mind, especially when it comes to health care needs for the group. According to a June 15-19, 2008, USA Today/Gallup Poll, 80% of adults nationwide stated that a candidates' position on health care was extremely important in influencing their vote for president.[1]

During his February 20, 2008 talk, "Digital Evolution," Intel Corporation's chairman, Craig Barrett, urged the Wong Auditorium audience to pay close attention to the political debate going on and find a candidate who "talks about taking the cost out of healthcare instead of adding to the cost of healthcare."

What should we be doing about health care? According to Barrett, we need to focus on the elderly and chronically ill. He suggests that by empowering the individual to take care of their own health, the system can work better. One way Barrett says health care can be personalized is by shifting care from the hospital to the home.

"Health care is like the mainframe computer industry of 20 or 30 years ago," Barrett said. "What we don't have in the health care industry is health care that is personalized and diversified, allowing you to put input into the system on a remote basis."

Barrett and Intel would like to change that. Take, for instance, Intel's home assessment device for Parkinson's patients.

1 Source: http://www.pollingreport.com/prioriti.htm.

1 From left to right: Abdul Jarrar (Intel), Kimberly Sills (Intel), Eugene Meieran (Intel), Prof. Anantha Chandrakasan (MIT), Will Swope (Intel), Craig Barrett (Intel), Dean Subra Suresh (MIT), Ian Young (Intel), Lawrence Chen (Intel). **2** Craig Barrett presents a wafer with Intel chips to the audience. **3** Talking about high-K metal gate dielectrics. **4** Various Intel products and devices presented during the seminar. (Photos / Tony Rinaldo).

The personal health device developed by Intel's Digital Health Group, allows physicians to monitor Parkinson's patients' tremors remotely. It is just one of several devices the Group currently is working on.

Besides health care, Barrett also discussed Intel's role in global development and offered a few observations: "Invest in good people with good ideas… Don't be afraid to change the rules (Intel has one of the most recognizable brands in spite of the fact that we don't sell to the end user)… Change before the environment makes you change…[and] It's fun to take risks, but take informed risks."

Craig R. Barrett became Chairman of the Board of Intel Corporation on May 18, 2005. Barrett began his tenure at Intel as a Technology Development manager in 1974. Prior to joining Intel, Dr. Barrett was an Associate Professor at Stanford University in the Department of Materials Science and Engineering.

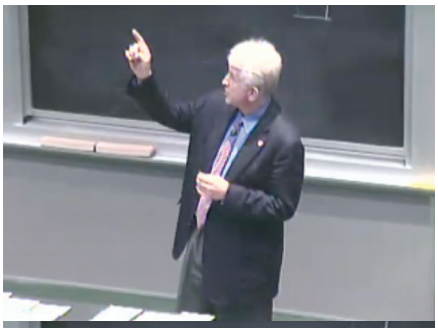
Barrett's talk can be viewed at
http://mitworld.mit.edu/video/552/

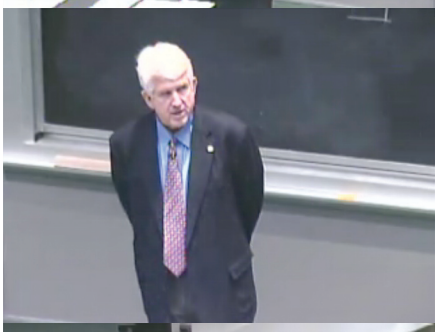
– Rhonda Maynard • Correspondent

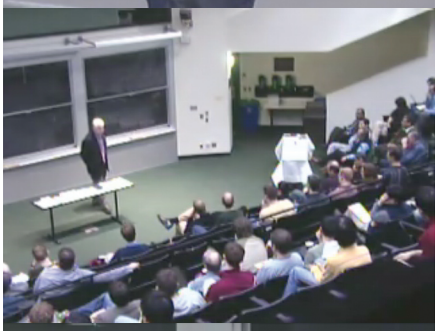
THE ENERNET

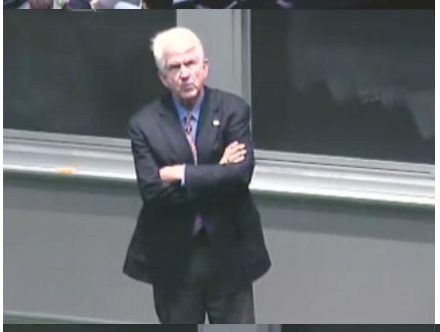
Bob Metcalfe • March 4, 2008

by DEBORAH HALBER • Correspondent









Just as the Internet created unexpected yet valuable connections over the past four decades, a future network may do the same for green technology, according to venture capitalist Bob Metcalfe.

On March 4th, Metcalfe came to MIT to give a highly anticipated talk for the MTL Seminar Series. Metcalfe, who received a bachelor's degree from MIT in 1969, is known the world over as the inventor of the Ethernet, the founder of the billion-dollar company 3Com Corporation, and as an immensely popular Internet pundit and columnist for InfoWorld.

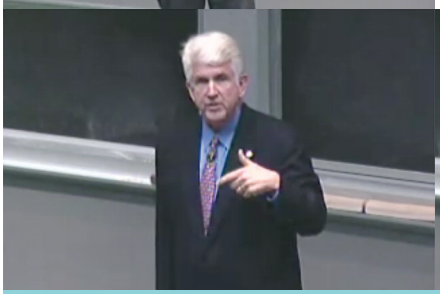
The "Enernet" is what we are building to meet the world's need for cheap and clean energy, Metcalfe says. It will not happen overnight, and it will be hard to predict how the various technologies will play out over time. Metcalfe spoke about what we can learn from the arc of the Internet boom to anticipate how the energy business landscape will evolve. He drew insightful parallels between the two types of businesses, drawing on the parallels between the need for cheap, widely available digital processing power during the Internet boom and the current need for cheap, widely available and renewable energy. Among other things, the Enernet, he said, can explore how best to standardize fuels of the future.

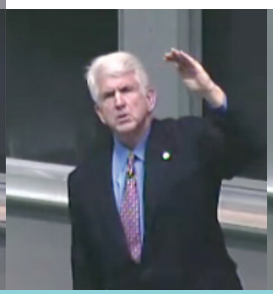
"We try to satisfy a lot of different audiences with the Seminar Series," said MTL Seminar Series committee chair Prof. Joel Dawson. "We like to have senior technologists and academics who can provide a broad perspective of their fields, and we also like to give more junior scholars an opportunity to share their vision and build a name for themselves. But every once in a while, we try for a truly high-wattage pioneer who is of interest to everyone at the Institute, and it doesn't get any more high-wattage than Bob Metcalfe." Metcalfe is now a partner at venture capital firm Polaris Ventures in Waltham, MA.

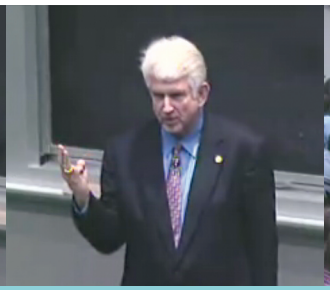
Suffused throughout the talk was Metcalfe's unbridled faith in, and enthusiasm for, the creativity and inventiveness of the technological community. When asked about the problem of disposing of nuclear waste, his answer was that it shouldn't be a barrier to using this otherwise very promising technology. We should commit ourselves to the problem over the next few decades, he reasoned. If we do so, there is no reason to think that we will not find a means of disposal well before the quantities of nuclear waste overwhelm our capacity to store it.

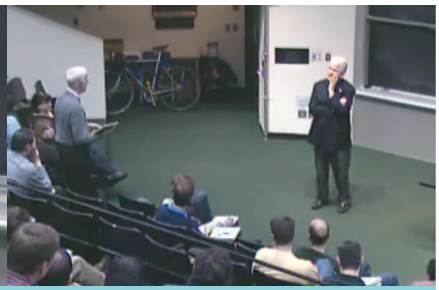
Metcalfe's presentation was an enjoyable experience for all involved. More information about the MTL Seminar Series can be found at http:/mtlweb.mit.edu/news/seminars/index.html.

– Professor Joel Dawson contributed to this report.









The video for this event can be found at http://mitworld.mit.edu/video/559.

MARC 2008

Waterville Valley Conference & Event Center • January 29-30, 2008

by RHONDA MAYNARD • Correspondent

Each January, MTL brings together students, staff, faculty, and industry partners to promote interaction and foster new discussions, new collaborations, and new research ideas. We call it MARC – the Microsystems Technology Laboratories Annual Research Conference.

MARC 2008 Co-Chairs Tania Khanna and John Hennessy led the student-run Technical Program Committee, under the guidance of Steering Committee Chair, Prof. Joel Voldman.

The conference comprised a record 77 presentations from the MEMS & BioMEMS, Circuits & Systems, Photonics, Electronic Devices & Emerging Technologies, and Molecular & Nanotechnology areas. In addition, William R. Rodriguez, M.D., Partners AIDS Research Center, Massachusetts General Hospital and Harvard Medical School gave a talk on Tuesday evening, while Sass Somekh, Chair, Technical Advisory Board, Novellus Systems and Chair of the Plug-in Hybrid Electrical Vehicle Early Demonstration and Adoption Initiative, Silicon Valley Leadership Group, provided the Keynote Talk, "Combatting Oil Dependence & Global Warming Through Leadership and Action."

Once again, Texas Instruments generously sponsored MARC's Presentation Awards. Industry attendees evaluated student oral presentations based on relevance of the technical contribution and how well the student motivated the audience.

MARC 2008 award winners include:

- Christopher Rohde, "Microfluidic System for High-Throughput On-Chip Whole-Animal Screening"
- David Kong, "Integrated Gene and Protein Synthesis in Microfluidic Device"
- Joseph Kovac, "Intuitive, Image-based Sorting of Mammalian Cells Using OPTO-FLUCS (OPTO-FLUidic Cell Sorting)"
- Melissa Read, "Design and Fabrication of Standard Coupons for the Testing of MEMS Scale Electrical Contacts"
- Patrick Mercier, "Fully Integrated Pulsed-UWB Transceivers for Small Lightweight Flying Vehicles"
- Vivienne Sze, "Algorithms and Architectures for Ultra-Low-Power Video Compression"
- M. Scott Bradley, "Inkjet-Printed J Aggregates for Integrated Optical Devices"
- Jonathan Mapel, "High Flux Gain in Luminescent Solar Concentrators"
- Niamh Waldron, "A 90-nm Self-Aligned InGaAs HEMT for Future Logic Applications"
- Daniel Nezich, "In-situ Sample Rotation as a Tool to Understand CVD Growth of Long Aligned Carbon Nanotubes"

Above: Steering Committee chair Joel Voldman (right) and Keynote Speaker Sass Somekh. (Photo / Paul McGrath, MTL)

Above: Technical Program Committee Chairs Tania Khanna (left) and John Hennessey. (Photo / Paul McGrath, MTL)

Above: Joel Voldman (left) and guest speaker William R. Rodriguez. (Photo / Paul McGrath, MTL)

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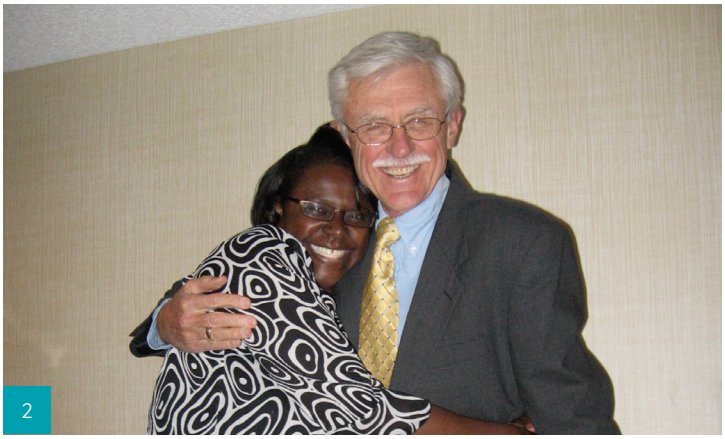

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ISSCC 2008

MTL alumni and friends get together for fun at ISSCC

Around one hundred people turned out for the first MIT/MTL Alumni and Friends reception at the International Solid State Circuits Conference (ISCCC) in San Francisco.

On February 4, 2008, Professors Anantha Chandrakasan and Charles Sodini hosted the event in the Sierra Room located at the San Francisco Marriott from 5:30 PM- 7:30 PM. Attendees included alumni, MTL faculty and students, as well as friends.

Professor David Wentzloff (University of Michigan), an MTL alumni and former student of Professor Chandrakasan said, "I'm glad we're having the reception this year. We've been talking about it for a while."

Among the attendees were Professor Rajeev Ram (Massachusetts Institute of Technology) and MIT student Jason Orcutt.

Alice Wang from Texas Instruments sponsored three iPods as raffle prizes. The winners were Sandro Herrera, Benjamin Walker, and Josie Ammer-Bolotski, all employed with Analog Devices.

Susan (Dacy) Luschas, MTL alumna and former student of Professor Hae-Sung Lee called the event an "awesome shindig!"

– Deborah Halber and Debroah Hodges-Pabon

5

1 Anantha Chandrakasan and Charles Sodini (MIT). **2** Debroah Hodges-Pabon (MIT) with Dennis Buss (Texas Instruments). **3 Foreground, left to right:** Sandro Herrera (Analog Devices), Benjamin Walker (Analog Devices), Alice Wang (Texas Instruments), Uming Ko (Texas Instruments), Anantha Chandrakasan (MIT), and Josie Ammer-Bolotski (Nextwave). **4** Benjamin Walker, Rikki Mueller, Iliana Chen, Jennifer Lloyd, Pablo Acosta-Serafini, and Kimo Tam. **5** The crowd enjoys wine and appetizers. (Photos / Debroah Hodges-Pabon)

MIT gas sensor is tiny, quick

Energy-efficient device could quickly detect hazardous chemicals

by ANNE TRAFTON • MIT News Office

Engineers at MIT are developing a tiny sensor that could be used to detect minute quantities of hazardous gases, including toxic industrial chemicals and chemical warfare agents, much more quickly than current devices.

The researchers have taken the common techniques of gas chromatography and mass spectrometry and shrunk them to fit in a device the size of a computer mouse. Eventually, the team, led by MIT Professor Akintunde Ibitayo Akinwande, plans to build a detector about the size of a matchbox.

"Everything we're doing has been done on a macro scale. We are just scaling it down," said Akinwande, a professor of electrical engineering and computer science and member of MIT's Microsystems Technology Laboratories (MTL).

Akinwande and MIT research scientist Luis Velasquez-Garcia presented their work at the Micro Electro Mechanical Systems (MEMS) 2008 conference in January 2008. In December 2007, they presented at the International Electronic Devices Meeting.

Scaling down gas detectors makes them much easier to use in a real-world environment, where they could be dispersed in a building or outdoor area. Making the devices small also reduces the amount of power they consume and enhances their sensitivity to trace amounts of gases, Akinwande said.

He is leading an international team that includes scientists from the University of Cambridge, the University of Texas at Dallas, Clean Earth Technology and Raytheon, as well as MIT.

Their detector uses gas chromatography and mass spectrometry (GC-MS) to identify gas molecules by their telltale electronic signatures. Current versions of portable GC-MS machines, which take about 15 minutes to produce results, are around 40,000 cubic centimeters, about the size of a full paper grocery bag, and use 10,000 joules of energy.

The new, smaller version consumes about four joules and produces results in about four seconds.

The device, which the researchers plan to have completed within two years, could be used to help protect water supplies or for medical diagnostics, as well as to detect hazardous gases in the air.

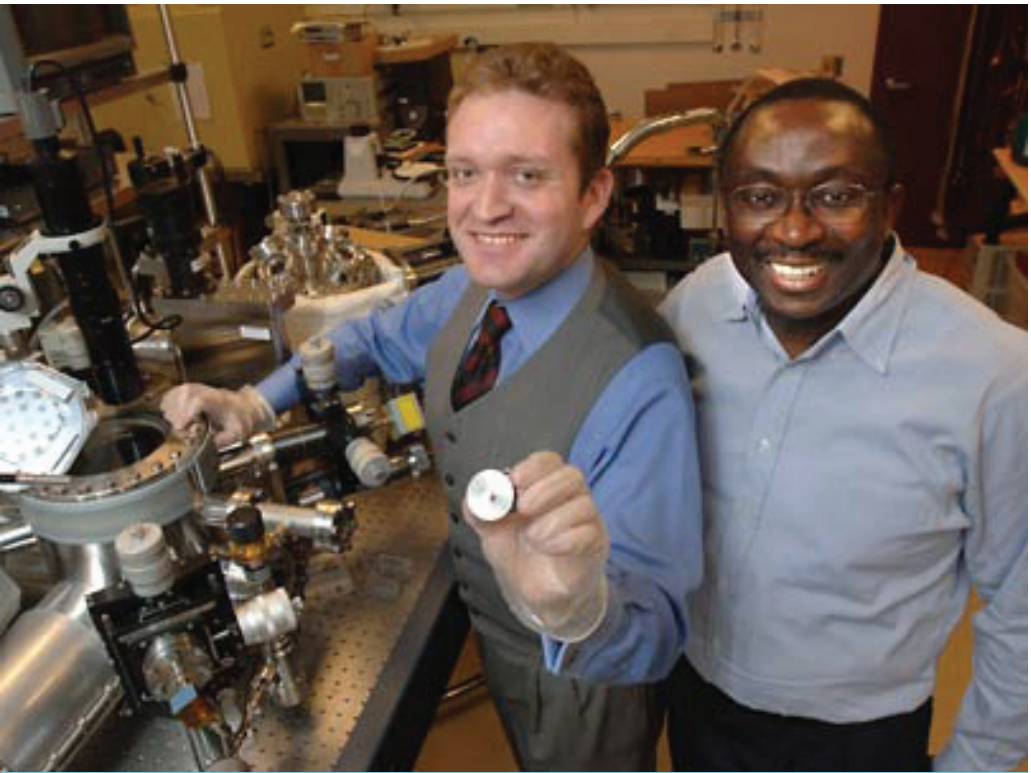
The analyzer works by breaking gas molecules into ionized fragments, which can be detected by their specific charge (ratio of charge to molecular weight).

Gas molecules are broken apart either by stripping electrons off the molecules, or by bombarding them with electrons stripped from carbon nanotubes. The fragments are then sent through a long, narrow electric field. At the end of the field, the ions' charges are converted to voltage and measured by an electrometer, yielding the molecules' distinctive electronic signature.

Shrinking the device greatly reduces the energy needed to power it, in part because much of the energy is dedicated to creating a vacuum in the chamber where the electric field is located.

Another advantage of the small size is that smaller systems can be precisely built using microfabrication. Also, batch-fabrication will allow the detectors to be produced inexpensively.

The research, which started three years ago, is funded by the Defense Advanced Research Projects Agency and the U.S. Army Soldier Systems Center in Natick, Mass.

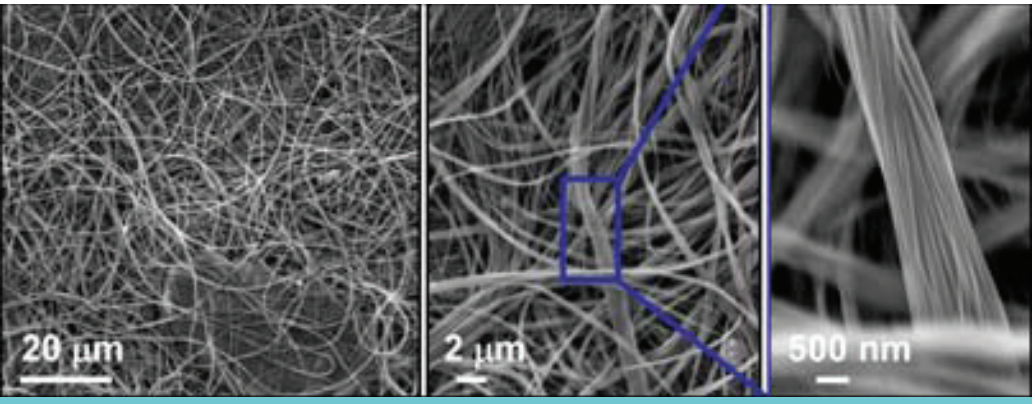


Above: MIT research scientist Luis Velasquez-Garcia, left, and Akintunde Ibitayo Akinwande, professor of electrical engineering and computer science, are developing a tiny sensor that can detect hazardous gases, including biochemical warfare agents (Photo / Donna Coveney, MIT News Office).

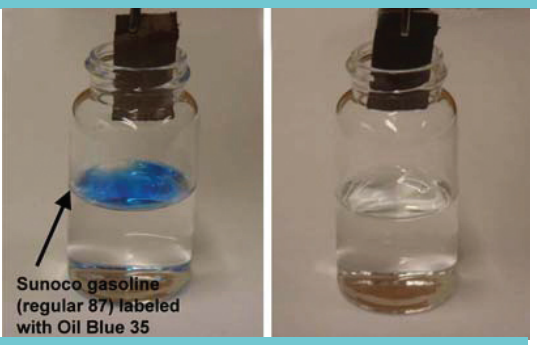
MIT develops a 'paper towel' for oil spills

Nanowire mesh can absorb up to 20 times its weight in oil

by ELIZABETH A. THOMSON • MIT News Office



Above: The mesh of nanowires behind MIT's new material for absorbing oil and other organic pollutants, here shown at increasing magnifications (left to right). (Image/Francesco Stellacci, MIT, and *Nature Nanotechnology*)



Above: The material is used to remove a layer of gasoline (dyed blue) from a vial of water. (Image/Francesco Stellacci, MIT, and *Nature Nanotechnology*)

Above: A swatch of MIT's new oil-absorbing nanowire mesh next to a pen for scale. (Image/Francesco Stellacci, MIT, and *Nature Nanotechnology*).

A mat of nanowires with the touch and feel of paper could be an important new tool in the cleanup of oil and other organic pollutants, MIT researchers and colleagues report in the May 30 online issue of *Nature Nanotechnology*.

The scientists say they have created a membrane that can absorb up to 20 times its weight in oil, and can be recycled many times for future use. The oil itself can also be recovered. Some 200,000 tons of oil have already been spilled at sea since the start of the decade.

"What we found is that we can make 'paper' from an interwoven mesh of nanowires that is able to selectively absorb hydrophobic liquids--oil-like liquids--from water," said Francesco Stellacci, an associate professor in the Department of Materials Science and Engineering and leader of the work.

In addition to its environmental applications, the nanowire paper could also impact filtering and the purification of water, said Jing Kong, an assistant professor of electrical engineering in the Department of Electrical Engineering and Computer Science and one of Stellacci's colleagues on the work. She noted that it could also be inexpensive to produce because the nanowires of which it is composed can be fabricated in larger quantities than other nanomaterials.

Stellacci explained that there are other materials that can absorb oils from water, "but their selectivity is not as high as ours." In other words, conventional materials still absorb some water, making them less efficient at capturing the contaminant.

The new material appears to be completely impervious to water. "Our material can be left in water a month or two, and when you take it out it's still dry," Stellacci said. "But at the same time, if that water contains some hydrophobic contaminants, they will get absorbed."

Made of potassium manganese oxide, the nanowires are stable at high temperatures. As a result, oil within a loaded membrane can be removed by heating above the boiling point of oil. The oil evaporates, and can be condensed back into a liquid. The membrane--and oil--can be used again.

Two key properties make the system work. First, the nanowires form a spaghetti-like mat with many tiny pores that make for good capillarity, or the ability to absorb liquids. Second, a water-repelling coating keeps water from penetrating into the membrane. Oil, however, isn't affected, and seeps into the membrane.

The membrane is created by the same general technique as its low-tech cousin, paper. "We make a suspension of nanowires, like a suspension of cellulose [the key component of paper], dry it on a non-sticking plate, and we get pretty much the same results," Stellacci said.

In a commentary accompanying the Nature Nanotechnology paper, Joerg Lahann of the University of Michigan concluded: "Stellacci and co-workers have provided an example of a nanomaterial that has been rationally designed to address a major environmental challenge."

In addition to Stellacci and Kong (who is also affiliated with MIT's Microsystems Technology Laboratory and Research Laboratory of Electronics, or RLE), other authors are Jikang Yuan, a postdoctoral associate in MIT's Department of Electrical Engineering and Computer Science (EECS) and RLE; Xiaogang Liu, now at the National University of Singapore; Ozge Akbulut of the Department of Materials Science and Engineering; Junqing Hu of the National Institute for Materials Science in Japan; and Steven L. Suib of the University of Connecticut, Storrs.

This work was primarily funded by the Deshpande Center for Technological Innovation at MIT.

MIT aims to optimize chip designs

Model could reduce fabrication costs

by ANNE TRAFTON • MIT News Office

The computer chips inside high-speed communication devices have become so small that tiny variations that appear during chip fabrication can make a big difference in performance.

Those variations can cause fluctuations in circuit speed and power so the chips don't meet their original design specifications, says MIT Professor Duane Boning, whose research team is working to predict the variation in circuit performance and maximize the number of chips working within the specifications.

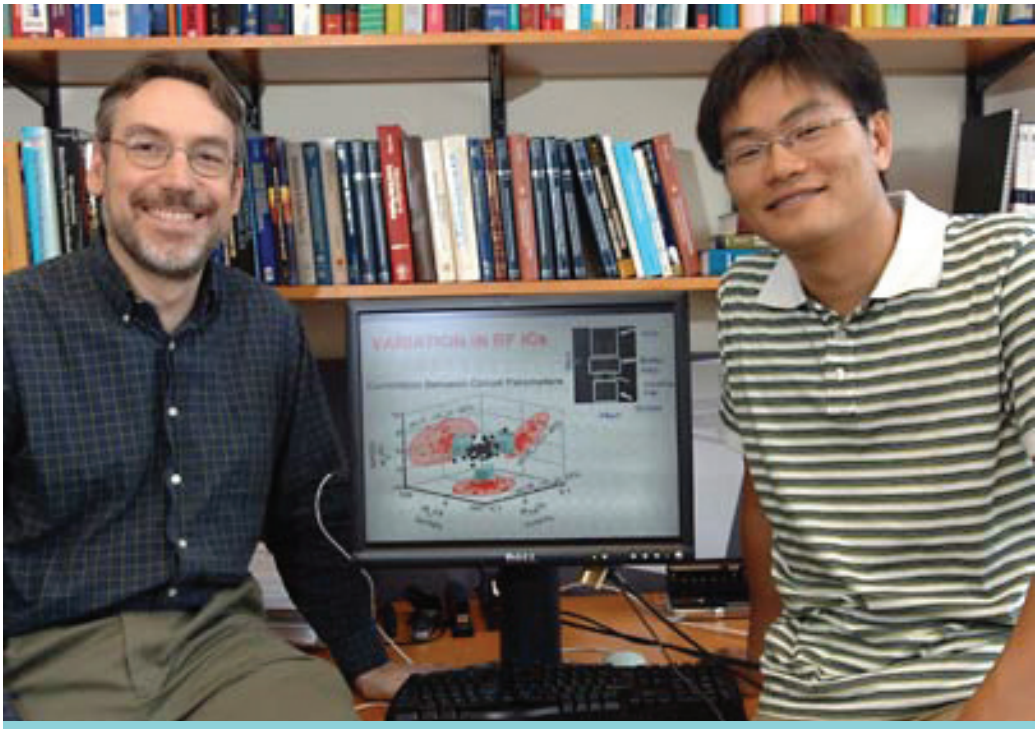
The researchers have recently developed a model to characterize the variation in one kind of chip. The model could be used to estimate the ability to manufacture a circuit early in the development stages, helping to optimize chip designs and reduce costs.

"We're getting closer and closer to some of the limits on size, and variations are increasing in importance," says Boning, a professor of electrical engineering and computer science (EECS) and associate head of the department. "It's becoming much more difficult to reduce variation in the manufacturing process, so we need to be able to deal with variation and compensate for it or correct it in the design."

Boning and EECS graduate student Daihyun Lim's model characterizes variation in radio frequency integrated circuits (RFICs), which are used in devices that transfer large amounts of data very rapidly, such as high-definition TV receivers.

The researchers published their results in two papers in February and June 2007. They also presented a paper on the modeling of variation in integrated circuits at this year's International Symposium on Quality Electronic Design.

RFIC chips are essential in many of today's high-speed communication and imaging devices. Shrinking the size of a chip's transistors to extremely small dimensions (65 nanometers, or billionths of a meter), improves the speed and power consumption of the RFIC chips, but the small size also makes them more sensitive to small and inevitable variations produced during manufacturing.



MIT Professor Duane Boning, left, and graduate student Daihyun Lim are working toward increasing the performance of computer chips. [Photo / Donna Coveney, MIT News Office]

"The extremely high speeds of these circuits make them very sensitive to both device and interconnect parameters," said Boning, who is also affiliated with MIT's Microsystems Technology Laboratories. "The circuit may still work, but with the nanometer-scale deviations in geometry, capacitance or other material properties of the interconnect, these carefully tuned circuits don't operate together at the speed they're supposed to achieve."

Every step of chip manufacturing can be a source of variation in performance, said Lim. One source that has become more pronounced as chips have shrunk is the length of transistor channels, which are imprinted on chips using lithography.

"Lithography of very small devices has its optical limitation in terms of resolution, so the variation of transistor channel length is inevitable in nano-scale lithography," said Lim.

The researchers' model looks at how variation affects three different properties of circuits--capacitance, resistance and transistor turn-on voltage. Those variations cannot be measured directly, so Lim took an indirect approach: He measured the speed of the chip's circuits under different amounts of applied current and then used a mathematical model to estimate the electrical parameters of the circuits.

To the researchers' surprise, they found correlations between some of the variations in each of the three properties, but not in others. For example, when capacitance was high, resistance was low. However, the transistor threshold voltage was nearly independent of the parasitic capacitance and resistance. The different degrees of correlation should be considered in the statistical simulation of the circuit performance during design for more accurate prediction of manufacturing yield, said Lim.

The research was funded by the MARCO/DARPA Focus Center Research Program's Interconnect Focus Center and Center for Circuits and Systems Solutions, and by IBM, National Semiconductor and Samsung Electronics.

Team develops energy-efficient microchip

Could lead to longer-lasting, self-charging cell phones, more

by DAVID CHANDLER • MIT News Office

Researchers at MIT and Texas Instruments have unveiled a new chip design for portable electronics that can be up to 10 times more energy-efficient than present technology. The design could lead to cell phones, implantable medical devices and sensors that last far longer when running from a battery.

The innovative design was presented Feb. 5, 2008 at the International Solid-State Circuits Conference in San Francisco by Joyce Kwong, a graduate student in MIT's Department of Electrical Engineering and Computer Science (EECS).

Kwong carried out the project with MIT colleagues Anantha Chandrakasan, the Joseph F. and Nancy P. Keithley Professor of Electrical Engineering, and EECS graduate students Yogesh Ramadass and Naveen Verma. Their Texas Instruments (TI) collaborators are Markus Koesler, Korbinian Huber and Hans Moormann. The team demonstrated the ultra-low-power design techniques on TI's MSP430, a widely used microcontroller. The work was conducted at the MIT Microsystems Technology Laboratories, which Chandrakasan directs.

The key to the improvement in energy efficiency was to find ways of making the circuits on the chip work at a voltage level much lower than usual, Chandrakasan explains. While most current chips operate at around one volt, the new design works at just 0.3 volts.

Reducing the operating voltage, however, is not as simple as it might sound, because existing microchips have been optimized for many years to operate at the higher standard-voltage level. "Memory and logic circuits have to be redesigned to operate at very low power supply voltages," Chandrakasan says.

Above, from left: Electrical engineering graduate students Yogesh Ramadass, Naveen Verma and Joyce Kwong, along with Professor Anantha Chandrakasan. This team has developed a microchip that can be up to 10 times more energy-efficient than present technology. (Photo / Donna Coveney, MIT News Office).

One key to the new design, he says, was to build a high-efficiency DC-to-DC converter--which reduces the voltage to the lower level--right on the same chip, reducing the number of separate components. The redesigned memory and logic, along with the DC-to-DC converter, are all integrated to realize a complete system-on-a-chip solution.

One of the biggest problems the team had to overcome was the variability that occurs in typical chip manufacturing. At lower voltage levels, variations and imperfections in the silicon chip become more problematic. "Designing the chip to minimize its vulnerability to such variations is a big part of our strategy," Chandrakasan says.

So far the new chip is a proof of concept. Commercial applications could become available "in five years, maybe even sooner, in a number of exciting areas," Chandrakasan says. For example, portable and implantable medical devices, portable communications devices and networking devices could be based on such chips, and thus have greatly increased operating times. There may also be a variety of military applications in the production of tiny, self-contained sensor networks that could be dispersed in a battlefield.

In some applications, such as implantable medical devices, the goal is to make the power requirements so low that they could be powered by "ambient energy," Chandrakasan says--using the body's own heat or movement to provide all the needed power. In addition, the technology could be suitable for body area networks or wirelessly enabled body sensor networks.

"Together, TI and MIT have pioneered many advances that lower power in electronic devices, and we are proud to be part of this revolutionary, world-class university research," said Dr. Dennis Buss, chief scientist at Texas Instruments. "These design techniques show great potential for TI's future low-power integrated circuit products and applications including wireless terminals, battery-operated instrumentation, sensor networks and medical electronics."

The research was funded in part by a grant from the U.S. Defense Advanced Research Projects Agency.

A New Window on Solar Energy

Cost effective devices expected on market soon

by ELIZABETH THOMSON • MIT News Office

Imagine windows that not only provide a clear view and illuminate rooms, but also use sunlight to efficiently help power the building they are part of. MIT engineers report a new approach to harnessing the sun's energy that could allow just that.

The work, to be reported in the July 11 issue of Science, involves the creation of a novel "solar concentrator." "Light is collected over a large area [like a window] and gathered, or concentrated, at the edges," explains Marc A. Baldo, leader of the work and the Esther and Harold E. Edgerton Career Development Associate Professor of Electrical Engineering.

As a result, rather than covering a roof with expensive solar cells (the semiconductor devices that transform sunlight into electricity), the cells only need to be around the edges of a flat glass panel. In addition, the focused light increases the electrical power obtained from each solar cell "by a factor of over 40," Baldo says.

Because the system is simple to manufacture, the team believes that it could be implemented within three years—even added onto existing solar-panel systems to increase their efficiency by 50 percent for minimal additional cost. That, in turn, would substantially reduce the cost of solar electricity.

In addition to Baldo, the researchers involved are Michael Currie, Jon Mapel, and Timothy Heidel, all graduate students in the Department of Electrical Engineering and Computer Science, and Shalom Goffri, a postdoctoral associate in MIT's Research Laboratory of Electronics.

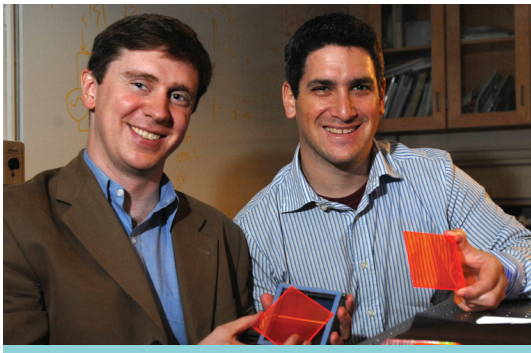
"Professor Baldo's project utilizes innovative design to achieve superior solar conversion without optical tracking," says Dr. Aravinda Kini, program manager in the Office of Basic Energy Sciences in the U.S. Department of Energy's Office of Science, a sponsor of the work. "This accomplishment demonstrates the critical importance of innovative basic research in bringing about revolutionary advances in solar energy utilization in a cost-effective manner."

Solar concentrators in use today "track the sun to generate high optical intensities, often by using large mobile mirrors that are expensive to deploy and maintain," Baldo and colleagues write in Science. Further, "solar cells at the focal point of the mirrors must be cooled, and the entire assembly wastes space around the perimeter to avoid shadowing neighboring concentrators."

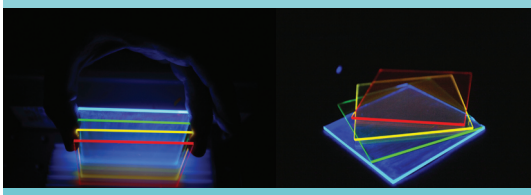
The MIT solar concentrator involves a mixture of two or more dyes that is essentially painted onto a pane of glass or plastic. The dyes work together to absorb light across a range of wavelengths, which is then re-emitted at a different wavelength and transported across the pane to waiting solar cells at the edges.

In the 1970s, similar solar concentrators were developed by impregnating dyes in plastic. But the idea was abandoned because, among other things, not enough of the collected light could reach the edges of the concentrator. Much of it was lost en route.

The MIT engineers, experts in optical techniques developed for lasers and organic light-emitting diodes, realized that perhaps those same advances could be applied to solar concentrators. The result? A mixture of dyes in specific ratios, applied only to the surface of the glass, that allows some level of control over light absorption and emission. "We made it so the light can travel a much longer distance," Mapel says. "We were able to substantially reduce light transport losses, resulting in a tenfold increase in the amount of power converted by the solar cells."



ABOVE: Marc Baldo, associate professor of electrical engineering and computer science (left) and Shalom Goffri, postdoc in MIT's Research Laboratory of Electronics (right) hold examples of organic solar concentratorss. (Photo / Donna Coveney, MIT News Office)



ABOVE: Organic solar concentrators collect and focus different colors of sunlight. Solar cells can be attached to the edges of the plates. By collecting light over their full surface and concentrating it at their edges, these devices reduce the required area of solar cells and consequently, the cost of solar power. Stacking multiple concentrators allows the optimization of solar cells at each wavelength, increasing the overall power output. (Photo / Donna Coveney).

This work was also supported by the National Science Foundation. Baldo is also affiliated with MIT's Research Laboratory of Electronics, Microsystems Technology Laboratories, and Institute for Soldier Nanotechnologies.

Mapel, Currie and Goffri are starting a company, Covalent Solar, to develop and commercialize the new technology. Earlier this year Covalent Solar won two prizes in the MIT $100K Entrepreneurship Competition. The company placed first in the Energy category ($20,000) and won the Audience Judging Award ($10,000), voted on by all who attended the awards.

Supporting Roles

The staff makes it all happen at MTL

By Deborah Halber • Correspondent

Bill Maloney remembers the case of the missing poster. Each year, the Microsystems Technology Laboratories (MTL) showcase the research that makes the facility an international leader in microsystems. Up to 80 posters depicting research results are typically on display during its annual two-day conference, which is attended by students, faculty members and industry partners.

Maloney, MTL systems manager since 2001, is one of many MTL staffers who help prepare for the conference. He produces dozens of posters with the help of a large-scale graphics printer for display at the conference center in Waterville Valley, NH.

"One year, one of the posters didn't get printed," Maloney recalls. "The conference was about to start, so going back to the labs wasn't an option."

The poster was projected from a laptop onto a wall. A little unconventional, but it worked. "Other working environments that I have been a part of would not have shrugged this off so easily," he says. "We all pull together and it comes out pretty well in the end."

The poster incident is small, but it demonstrates a key feature of the MTL's day-to-day working atmosphere. The MTL is a community where employees at all levels have each other's backs.

Staying power

"MTL staff are pretty highly valued by the faculty and the students," says Mara E. Karapetian, MTL media specialist, who started out as an administrative assistant 9 years ago and now maintains the labs' web site and produces its annual publication, Micronotes. "Students maintain fond and friendly relationships with researchers and even administrators at MTL, sometimes long after graduation."

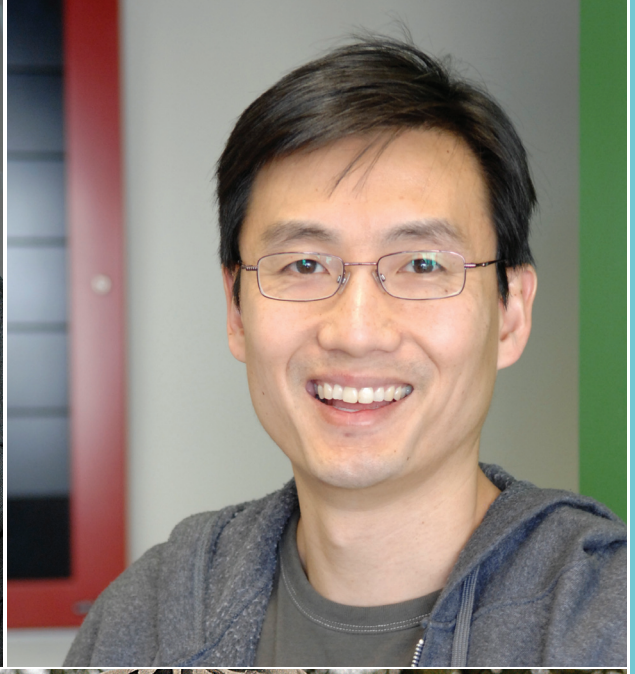
This is possible because MTL staff members tend to stick around. On average, professional staff stay at the MTL for 12.5 years, according to figures compiled by Sam Crooks, Associate Director of Finance and Administration.

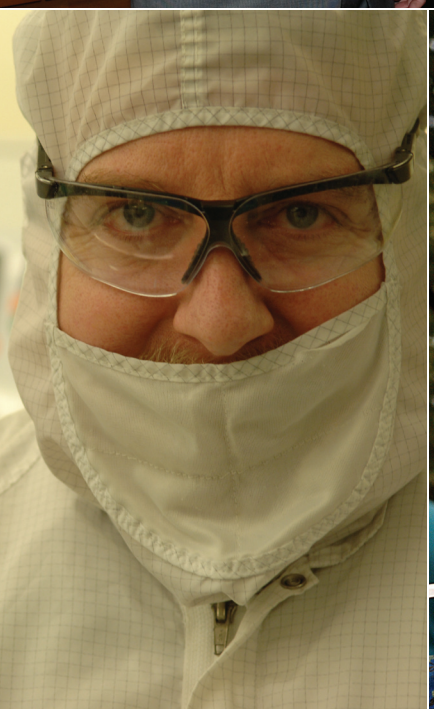
This page: Top, former MTL Administrative Assistant Michele Hudak, now of the Office of Sponsored Programs. Middle, Administrative Assistant Elizabeth Kubicki. Bottom, Associate Director of Finance and Sponsor Relations Sam Crooks. Above: Administrative Assistant Valerie Dinardo. (Photos / Tony Rinaldo).

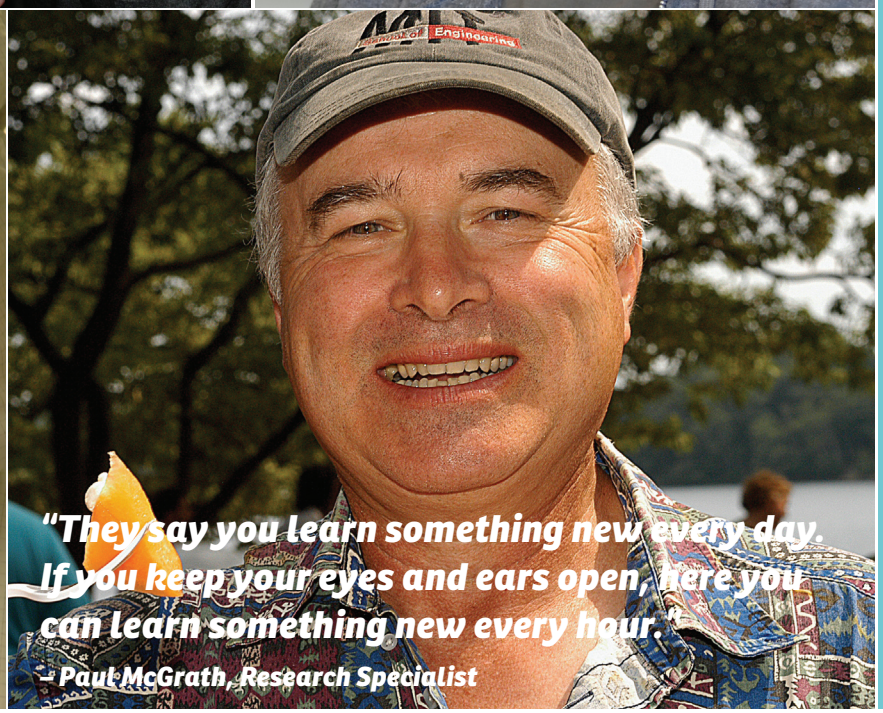
Research specialist Paul McGrath started with MTL when it was little more than a clean room in Building 13 in the mid-1980s. "It was a little tiny lab," he recalls. "The whole thing could have fit into two bays of the current lab." McGrath, who lives in Milton, was hired to take care of the labs' equipment, which at the time centered mostly with semiconductor design aimed at making integrated circuits smaller and faster.

After years of training, McGrath has expanded his repertoire to different kinds of machinery as the labs themselves have expanded.

In addition to maintaining ancillary equipment such as air handlers and the clean rooms'







Left: Top left: MTL's Personnel and Operations Administrator Debroah Hodges-Pabon (center) poses with Intel's Craig Barrett (left). **Top right:** Research Specialist Eric Lim. (Photos/Tony Rinaldo)

Bottom left: research specialist Paul Tierney, gowned up for training in ICL, 2005. (Photo/Tony Rinaldo) **Bottom right:** Research Specialist Paul McGrath in a photo taken at the annual staff summer barbecue in 2005 (Photo/Gary Riggott).

extraordinarily high level of functionality—they filter out everything down to the size of a polio virus—McGrath does everyday tasks such as changing locks. He also would be involved if MTL builds a new semiconductor facility from scratch. The variety has kept him coming back to MIT for 20-plus years. "It's very, very interesting," he says. "They say you learn something new every day. If you keep your eyes and ears open, here you can learn something new every hour."

Feeling welcome

MTL opened for business in 1984. A premier university microfabrication facility, the multidisciplinary MTL carry out research activities in the fabrication of extremely small-scale structures and their applications for integrated systems, including X-ray lenses, VLSI circuits and micro-gas turbine engines. These artificial microstructures in micron, submicron and nanometer scales are at the heart of the information revolution and used for increasing numbers of applications for state-of-the-art microsensors and actuators.

Each year, 550 staff members and students conduct $40 million of sponsored research in circuits and systems, microelectromechnical systems (MEMS), electronic and photonic devices, molecular-scale technology and nanotechnology.

Bonnie Lam, one of 39 MIT Energy Fellows, chose MTL over other programs because she was won over by the labs' working atmosphere. This inaugural, multidisciplinary group of doctoral students, sponsored by the MIT Energy Initiative (MITEI) member companies, shares an interest in addressing the science, technology, and policy required to meet the global energy challenge and associated environmental issues. Lam, who is interested in low-power circuits, knew she wanted to continue her academic career outside her hometown of Vancouver after graduating from the University of British Columbia. Both Stanford and MIT appealed to her, but it was an exploratory visit to MIT that won her over. She liked the fact that the Master's/PhD program incorporated a lot of research with the coursework.

"Everyone in the group was really friendly and MIT seemed like a nice place to be," she said. "It will all be a fresh experience for

me, especially since my background is not in traditional electrical engineering. It will be a very new experience—moving into a new field and a new place."

Comfortable, casual and fun

Staffers describe MTL's atmosphere as comfortable, even casual. While the MIT work ethic prevails, staff and faculty are offered a degree of flexibility they might not encounter in industry.

Research specialist Kurt A. Broderick is a long-time employee who trains students, repairs equipment and consults on lab processes in the Exploratory Materials Laboratory (EML). He describes MTL's atmosphere as being like a "fun house" where researchers have a lot of freedom and enjoy being a part of a dynamic facility conducting innovative research. "This place is especially cool because you learn as people approach you with unique scenarios, and you can cooperatively learn how to get solutions together, so you're constantly learning," Broderick says.

Maloney agrees. "I've worked here at MTL for a little over seven years. Before that, I worked for privately owned companies, a publicly traded company, and a startup that was purchased by a publicly traded company. As an IT professional, many of the same issues present themselves from place to place, but I think the main difference here is that people here seem to be more friendly and flexible. For the most part, people are willing to work together to get things done rather than dig their heels in to get their way," he says.

Chandrakasan is credited by Debroah Hodges-Pabon, personnel and operations administrator, with setting the tone that infuses every level of the MTL. Chandraksan won an instant following when, during his first year as director, he hand-delivered an American Express gift card to each staff member as a token of appreciation. "Let me tell you something, people appreciate that," said Debroah Hodges-Pabon. "Everybody works hard, but all our work is truly appreciated," she says. The gift cards and the annual appreciation party for faculty and staff, held for the past few years at upscale local hotels—are two ways that message is delivered. "It makes a difference when you have the leader at the helm walk with everyone," Hodges-Pabon says.

Defining community

MTL's three divisions, in addition to administrative and computation divisions, include a fabrication facility.

The fabrication facility has users—students, faculty members and other researchers—from within MIT, while external users include researchers and students from universities and government research labs who are part of an outreach program; industrial engineers from the Fabrication Facilities Access (FFA) program, and members of the Microsystems Industrial Group (MIG).

While the MTL community fluctuates, Hodges-Pabon works to build it into one solid entity. "I pride myself on building community," she says. "I think that we have a strong foundation of community, and each member feels like a valued contributor. I think that makes a difference in a work environment.

"Why do people stay here? My gut is that people generally like what they do. Our researchers could make a helluva lot more in industry, but when you add flexibility and a family-friendly environment, MTL is a community," she says. "It's not just a job."

Above: Akintunde Akinwande, Hae-Sung Lee, and Carolyn Collins (Photo/Tony Rinaldo)

Carolyn Collins

Over twenty years in service at MTL yields stories and experiences galore

In 1985, Carolyn Collins was thinking she didn't have much room to grow in the human services organization where she worked in Central Square when she happened to hear about an opening in the Microsystems Technology Laboratories (MTL), part of the Department of Electrical Engineering and Computer Science (EECS) at MIT.

Collins was hired as secretary to L. Rafael Reif, now MIT's provost and then an EECS faculty member in the MTL, and Charles G. Sodini, currently the Clarence J. LeBel Professor of Electrical Engineering and Computer Science in the MTL. It was a pivotal time for the MTL, which became an independent entity, moved into Building 39 and started to evolve into an Institute-wide interdepartmental laboratory supporting research and education in micro- and nanosystems.

It was also a pivotal time for Collins. "That's when I became a fixture here," she says. Collins worked for both professors until Reif became director in 1990. After five more years with Reif, Collins "moved upstairs" to stay in MTL as assistant to Akintunde "Tayo" Akinwande and Hae-Seung "Harry" Lee, professors of electrical engineering and computer science, when Reif went on to become associate head of EECS. Because Akinwande and Lee attract graduate students from their native countries—Nigeria and Korea, respectively—"there's a lot of diversity and international presence right in our office," Collins says. "I appreciate the diversity and ethnicity because we can learn so much from each other's cultures."

Collins, who lives in Malden with her husband, Billy, has never really stopped using her business major and psychology minor from Aquinas College. As a member of the Working Group on Support Staff Issues and finance director for one of its subcommittees, Artists Beyond the Desk (ABD), Collins once played the Big Bad Wolf in a play for the MIT day care center. ("My costume was so hot I couldn't walk in it, and I got so nervous I couldn't remember my lines," she recalls.) Collins is the point person for virtually everyone who comes into contact with Akinwande and Lee. Her skills include intuitively picking up who needs what, when they need it, and how to get it to them.

"With the same amazing energy and efficiency and the best MIT spirit, Carolyn makes the interests of her professors and the graduate and undergraduate students her highest priority," says the citation for the School of Engineering Infinite Mile Award for Sustained Excellence Collins received in 2005.

Big Bad Wolf and all, Collins appreciates the opportunities MIT has afforded her over the years. "MIT allows me to grow my wings into whatever I want," she says.

Lisa Su

Senior Vice President and CTO of Freescale Semiconductor

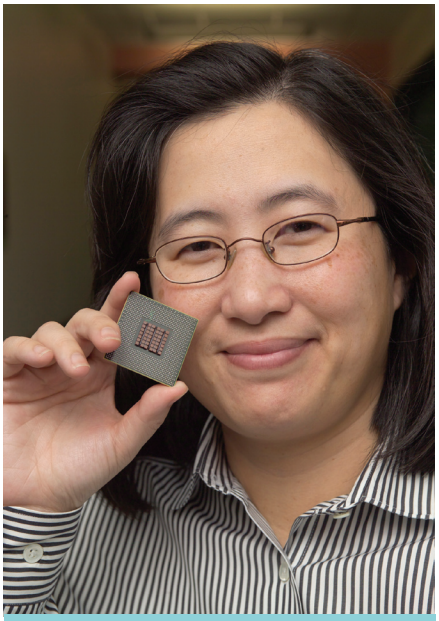
by JUDY L. HOYT • Professor, Department of Electrical Engineering & Computer Science, MIT

image: Lisa Su in 2008, Senior Vice President and Chief Technology Officer, Freescale. (Photo / Freescale)

Lisa Su is an MTL alumna who is quite familiar with being in the spotlight. After graduation, she rose quickly in the semiconductor industry, in positions which enabled her to lead technology innovation, manage global strategic alliances, and launch new products. She obtained all three degrees (BS, MS and Ph.D) in EECS at MIT, and her thesis advisors were Prof. Dimitri Antoniadis and Prof. James Chung. Lisa speaks very strongly about the importance of the experiences and education she received at MIT.

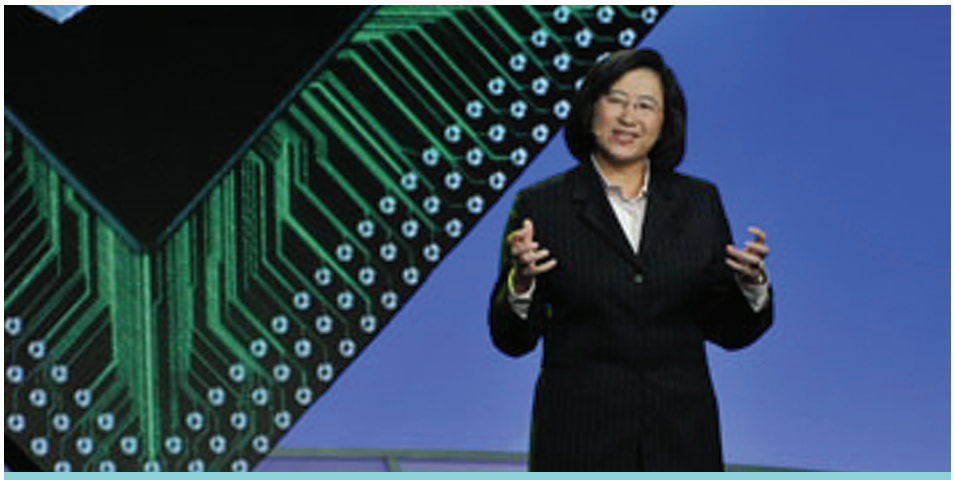
From Bronx High School of Science to MIT: Lisa was born in Taiwan and immigrated to the US when her dad attended graduate school at Columbia University. Her family lived in Queens and she attended the Bronx High School of Science, where she received a heavy dose of math and science, and enjoyed being on the Math Team. Her father was a math major and her mother started her own business when Lisa was a teenager. Both of those factors have had a strong influence on Lisa's career. "My mother is still running her own business, and it was very inspiring to see that grow from a one-person show to a multi million dollar business," Lisa said.

Lisa's interest in semiconductors was nucleated as an MIT Freshman, through a UROP (Undergraduate Research Opportunities Program) position in Prof. Hank Smith's lab. This was her first exposure to "hands-on doing and making things in the lab" and she loved it. The UROP experience cemented Lisa's concentration in semiconductor devices. She did her undergraduate work in Course 6, participating in the 6A program, which enables industrial internships for EECS undergraduates. "The internships at Analog Devices were a great opportunity, with a chance to get a dose of the real world of engineering," she recalls.



Above right: Lisa Su in 2005, holding an IBM Cell processor. The Cell processor is used in Sony's Playstation 3 gaming console. (Photo / IBM)

"The first wave of products was PCs/ laptops and personal communication devices. A much larger wave is coming, which is also dependent on semiconductor technology, with embedded devices in everything you touch."
-Lisa Su



Above: Lisa Su gives her keynote talk during the General Session at the Freescale Technology Forum Americas in June 2008. (Photo / Freescale)

Graduate school and MTL: Lisa remembers being very impatient to finish her Masters and get out of school. At first, she didn't think she wanted a Ph.D. but her parents thought it was a good idea. In hindsight, she says "staying on at MIT for the Ph.D. was one of the best decisions I ever made. Everyone says your graduate school days are the best times of your life, and it's absolutely true." Some of her graduate student peers are still extremely good colleagues and friends. "Another thing that's amazing about that time of your life is the amount of freedom you have," she remarked (something that current graduate students, in a hurry to get finished, as she was, may be overlooking). "MIT has a fantastic graduate school program with a strong research focus," she adds. Lisa won the IEEE IEDM Best Student Paper Award, a highly competitive prize, in 1992, for her work on SOI self-heating effects. Presenting papers at IEDM was a key experience for her, building confidence and providing the opportunity to interact with many people from the semiconductor industry.

IBM and Freescale: As Lisa was finishing her Ph.D. in 1994, she started to think about academia vs. industry, and the practical side of her drew Lisa to industry. At IBM TJ Watson Research Center, she worked on CMOS development, specifically 0.22 um device design. She was the first person to join the project and participated in every aspect of the development leading to the launch of the first copper microprocessor in the industry. It was her first taste of what she found she really enjoys: mobilizing a team of people to make a technical project successful, including getting products out the door and making money. Prof. Antoniadis recalls that "I saw Lisa's natural leadership talent as soon as she joined my research group. With time she proved to be a great mentor to the more junior students of the group and the go-to person." At IBM she had the opportunity to learn about the business side of things as well as technology including working on the Sony "Cell" microprocessor introduction. Lisa held executive positions including Director of PowerPC Products and Vice President of the Semiconductor Research and Development Center.

In June, 2007, Lisa joined Freescale Semiconductor as senior vice president and chief technology officer. Joining Freescale was an opportunity to be on a senior leadership team and influence the direction of a leading semiconductor company at a critical time in the industry. Interestingly, as CTO, Lisa spends just as much time on business direction as technology decisions as Freescale is transforming its global R&D operations.

Lisa is very optimistic about the future of the semiconductor business, at a time when there is a lot being said about the industry being very mature. "It's harder because we don't know what will come after the 22 nm node, but looking at the broader opportunities shows a lot of growth in the industry," she says. "The first wave of products was PCs/laptops and personal communication devices. A much larger wave is coming, which is also dependent on semiconductor technology, with embedded devices in everything you touch. Thousands of chips will control everything in the home, cars, and industrial applications all based upon technology, systems integration, packaging, and software," she explains.

Through out her career, Lisa has maintained ties to MTL. She spoke at the MARC meeting several years back, even though the event was just a few days before her wedding. As for advice for current graduate students, she says "It's important to appreciate how much grad school will help shape who you are. MTL is a great place. It is not about job training... it is really about teaching you to think and solve problems. Few experiences will give you that type of opportunity."

In her spare time, Lisa likes to play golf, which she took up about ten years ago. It's good for pleasure and for your health, and she adds "it's good for business."

Alumni Updates

Micronotes *Special Correspondent Ted Equi talks with six MTL alumni about their jobs, lives, and MTL.*

Roxann Broughton-Blanchard

Ph.D., 1999 As a senior RF circuit designer at Analog Devices, Roxann says "the work is challenging and interesting, with great opportunities to learn from some of the most talented designers in the industry. The learning requires precious time and focus, but like many professionals with young children, my biggest challenge is balancing work and life." Through her research in MTL she found, "The most important product of the Ph.D. is the process. In the end, a successful Ph.D. experience should teach one to be self-directed, resourceful, persistent and creative while figuring out what are the important questions to ask. Finding the right answer is often not difficult once you've figured out the right question and the right way to ask it!" While juggling the many demands on her time, she says she still finds time to sing and play keyboards in a couple of garage bands with her husband, play a little tennis, and enjoy cooking.

Words of wisdom for the MTL community:
"I recently met a woman who has reached the Senior Management level in her career, and she shared something with me that I really appreciated: You can have it all... you just can't have it all at the same time."

Valencia Joyner M.Eng., 1999

"I am constantly thinking about what new technologies will transform our world and how my scientific contributions will contribute to this transformation." says Valencia Joyner, an Assistant Professor at Tufts University in the Department of Electrical Engineering and Computer Engineering. Prior to joining the faculty, Valencia continued her studies and research, as a Marshall scholar, at the University of Cambridge completing her PhD degree 2003. She comments "it was an honor to be involved in the early stages of a technology that will continue to have broad-reaching impact for many years to come," which she experienced as part of Professor Tayo Akinwande's research team. Her time in MTL was also transformational in that it helped her chose a career as an academic professor. "The collaborative community at MTL changed my perceptions of what academic life is really like and provided a window for me to be able to see the many areas of life impacted by VLSI technology." Valencia has a passion for traveling and working with community outreach organizations to excite young people about science and technology, helping to foster the curiosity that will fuel future generations of innovative minds.

Words of wisdom for the MTL community:
"Be inspired to get involved in humanitarian projects to use technology to bring hope and healing to populations around the globe."

Steven Nagle Ph.D., 2000

Since founding the Nanofabrication Center at Veeco Metrology in Santa Barbara, CA, Steven Nagle, Director of Nanoprobe Development, says, "Presently the most interesting aspects of my role are in business development. The work requires keen intuition from the team in order to spend limited resources to buy the latest equipment only where necessary. I have never forgotten how well the MTL provided this experience." Commenting on his time in MTL, "Perhaps the one experience I remember the most was a conversation with Professor Stephen Senturia. He said, 'The best way to solve a problem is to already know the answer.' This struck me as not only the MTL way, but also the MIT way. It speaks to the sound intuition of an MTL student, and to the fundamental worth of a good literature search." Outside his technical pursuits Steven's passions include: flying, restoring antique fighter planes, and singing Baritone in the Santa Barbara Choral Society.

Words of Wisdom for the MTL community:
"A bit of wisdom that seems timely in today's workplace and market: persevere. If your intuition tells you something is a good idea, you've run the numbers, and it stands up to trusted but critical peers, then stay with it through discouragement and problems. Don't give up."

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

Susanne Paul Ph.D., 1999 "Working on brand new and disruptive technology is both the most challenging and the most interesting part of my job," says Susanne Paul, Chief Technologist at Black Sand Technologies. After receiving her Ph.D. from Professor Hae-Seung Lee's group at MIT, she went to work for Silicon Labs, where she won a number of awards for her work, including the 2004 EDN awards for 'Innovator of the Year' and 'Analog Product of the Year'. Although Susanne left Silicon Labs with the intention of being a full-time stay-at-home mom with her three children, she says, "Black Sand was a chance to build a semiconductor company from the ground up and to apply my technical vision to develop never-been-done-before technology." Of her MTL experience: "The Center for Integrated Circuits and Systems (CICS) reviews were particularly impactful for me because they allowed me to meet many new people from industry, and they exposed me to the work of other students."

Words of Wisdom for the MTL community:
"I would offer the advice to female engineers that it is possible to have both a successful career and a fulfilling family life with kids. No doubt there are times when it is challenging to juggle both, but I find myself comfortable with the lifestyle and enjoy the diversity that having both brings to my life."

Krishna Shenoy Ph.D., 1995 "We conduct highly interdisciplinary research, ranging from machine learning and statistical signal processing on the engineering end of the spectrum through neurosurgery and electrophysiology on the neuroscience end of the spectrum. This interdisciplinary range is both extremely exciting and rather challenging," says Krishna Shenoy, an Associate Professor at Stanford University where he has a dual appointment with the Department of Electrical Engineering and Bioengineering and Neurosciences Program. He was an early pioneer in working at the interface between fields, which has now become a more standard practice at universities. After receiving his EECS PhD working with Professor Fonstad, he retrained as a neurobiologist. He then initiated research on "neural prostheses." While following a non-traditional path, Krishna developed the perfect blend of backgrounds to fit the emerging field of bioengineering. While at MTL, an impactful experience was: "Appreciating the interdependencies among the various levels of a system, be it from materials, through devices and circuits, up to full systems in electronics or from molecules, through cells and circuits, up to full organisms in neuroscience."

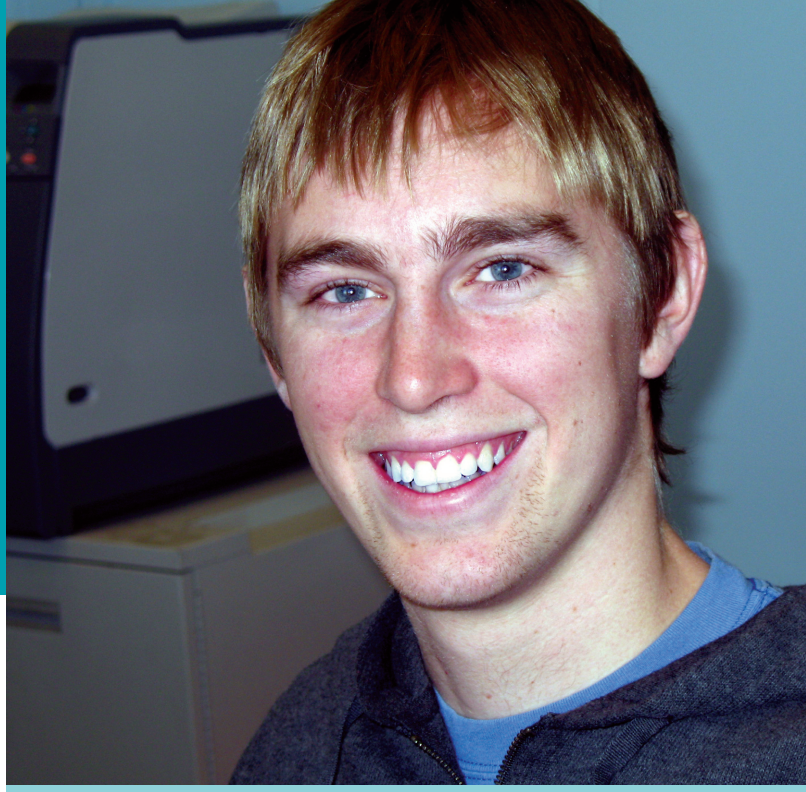
Word of Wisdom for the MTL community:
"Interdisciplinary is a tricky word. Multidisciplinary is more appropriate as you have to work in both fields. How does one educate one-self in multidisciplinary fields? Formal training can never suffice; continuous learning is required."

Brian Stine Ph.D., 1998 Since joining PDF Solutions after graduation, Brian Stine has seen the staff expand from 7 to ~400 now operating in 9 countries. As the president of the Japan subsidiary Brian says "The most interesting part of my role is dealing with other people in the industry and across cultures. My interest in different areas of technology has waxed and waned over the years, but it is the people that keep me coming back." He felt MTL provided some unique opportunities: "I felt it was a unique and rewarding experience at the time to work with industrial partners so closely. I felt very privileged to experience it." When not driving the PDF technology forward, Brian enjoys fishing: "once or twice/year I get a chance to go for really big catches off the coast of California or Hawaii."

Words of wisdom for MTL community:
"Strive to be a generalist. Use the time to take courses in other areas and disciplines. This will give you the ability to understand broader areas that you may encounter in your future career...Try to involve your research with industrial partners. For some researches, this might not make much sense, but as much as possible, I recommend it."

Geek Pride
John Gardner '08

John Gardner '08, an analog circuit designer, may have received his MEng from MIT, but one of his favorite experiences while a student at MIT may have been his role in season 4 of the CW reality TV show *"Beauty and the Geek."* The show from the producers of *"Punk'd"* pitted Gardner and his partner Natalie, a waitress and promotional model for Hooters, against nine other teams of hot girls and geeky guys. Unfortunately, Gardner's team was eliminated in Episode 8, but the juggler and MTL grad had a blast nevertheless. Gardner sat down with Micronotes correspondent Rhonda Maynard in March 2008 to discuss the reality show.



Above: John Gardner. (Photo / Rhonda Maynard)

Tell me about your role in EECS. You're a VI-A student, right? Where did you do your internship?
Yes. I already did my six-month stay at Linear Technologies, so this is the last semester I'll be here. I'm writing my thesis and finishing up my classes.

Now I heard that you were scheduled to go to Linear when you got the call from Beauty and the Geek. It must have been a tough choice. Tell me a little about that.
Filming was the majority of July and so I was scheduled to start at Linear mid-June, but I wanted to do the show, so I talked to them about it, and the agreement we came to was that I could make up the time by working through IAP. It was awesome that Linear was so flexible. It helped that I had worked with them the previous summer, and it turned out that I had the same supervisor, so they didn't think I was a total flake.

What do you plan to do after graduation?
I plan to go back and work for Linear after graduation. I'll be back out in California working for them as a design engineer in the power converter group.

Why did you decide to audition for Beauty and the Geek?
One of my friends, Matt, was on season 3, and he encouraged me to audition. He had a good experience and he thought I would be what they were looking for.

Was there a local casting call?
There were several rounds of auditions. The first two parts were here in Boston.

Did you think you would get on the show right away?
I thought my initial interview went well, and they asked me to come back for the next day, so that seemed to be a pretty good indication. They asked me to bring in my "toys."

What did you take?
I brought in the magnetic levitator I made in 6.302, and I needed a 16V supply to run it, so I used the power supply we made in 6.101 where we take a transformer so you can the rectify the power coming from the wall to get a 16V supply. They were a little weary of that. They were asking if it was going to explode. [laughs]

So what was the next step in the audition process?
You have to make a home video. I ran around in some of the labs and had my friends film me there. I showed a little bit of campus. I put some juggling in there too. I got the call that I was a finalist on the same day as graduation day. I think I was still in my gown. [laughs]

So what was the experience like? I heard they made contestants look geekier than they really are? Did they do that?
It's hard to say. Initially they are concerned about how things look, but that fades pretty fast.

When you watched the show later, did you notice that they edited a lot to make it more interesting?
A lot happens, and they can only show so much. They definitely choose things that look intense and I think things were intense. It was sort of like watching a Harry Potter movie after reading the book. They have to cut so much out, and you wonder, "Where did that go? What about that?" Things that you thought were really cool and exciting they didn't have time to show.

It sort of looked like contestants targeted your team early on – they definitely thought you were the team to beat. Was that true?
I think that what happened was that certain teams seem like they are strong so they are targeted. After Will and Rebecca were gone, Natalie and I were kind of viewed as the strongest team. We were good at answering questions. I think how it looks is kinda how it happened. We were tough competitors.

You seemed to get along very well with Natalie.
We got along great. One of the things that really was good with our team was that we wanted to do well, but it wasn't the driving force behind everything. You're there and you know that it's going to be shown on TV and you don't want to look foolish. You already put a lot of stress on yourself and if your partner puts a lot of stress on you as well it gets bad quickly. We both realized that wasn't the way we wanted it to go. We decided that early on.

So you live in this house until you are eliminated...then what?
That's one thing I wondered about, too. When they say you are eliminated and you walk out the front door and are gone, you really are gone.

Where do you go?
You go home. You have to say your goodbyes before you go. I was wondering if that is true, and it is.

What else can you tell us about the show that others might not know?
One of the weird things I noticed from watching shows was that the people would get really close and really into it really fast, and so you think, "Why are they crying? They've only known each other a couple of weeks." It's crazy! But after being on the show and going through the experience, I know how that can happen. It's kind of strange, but I think the reason is is that having the cameras on you all the time and being asked to do things that are weird and crazy is very stressful, and the only people you have with you are people that are going through the same thing. We all felt pretty close. It's sad to see people go because you are so immersed in the environment.

How much are you aware of what's going on in the outside world while you're on the show? You don't have access to TV or internet or anything, right?
We don't know what's going on because we're so busy doing what you have to do.

Have you maintained contact with others in the show?
I have seen the other contestants from Boston, and I have kept in email contact with Natalie.

Would you do it again?
Yeah. Definitely.

How has your life changed because of the show?
I guess there's kind of superficial changes, like I'm wearing jeans right now and I never wore jeans before the show. On a larger scale I would like to think that I'm more laid-back and relaxed now.

How do you feel about being labeled a geek? Are you offended at all?
I am not offended at all. Who knows exactly what that means? I feel like the definitions can vary a lot. I feel that the engineering/academic interest I have is what I enjoy. Maybe others don't enjoy that. I think that's fine. Maybe people think geeks are socially awkward, or not as social as other people, but I'm happy with the friends I have and how social I am. I think it's ok to be a geek. If you were offended by it, you wouldn't try out for the show.

– interview by Rhonda Maynard • Correspondent

Graduation

June 6, 2008

MTL honored its graduates with a reception held in the Grier Room on Friday, June 6, 2008. Hosted by Debroah Hodges-Pabon, this event brought students together with family, friends, and faculty to say their goodbyes and embark on new beginnings. (Photos/Paul McGrath)

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MTL

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- Hear recent research results from projects throughout the MTL Community encompassing Circuits & Systems, Electronic Devices, Emerging Technologies, MEMS, BioMEMS, Photonics, and Nanotechnologies
- Interact with MTL students, faculty, and other industry partners
- Student presentations and posters
- Morning keynote and evening dinner speakers
- Skiing and other activities at Waterville Valley

for more information:
mtlweb.mit.edu/marc2009

MTL microsystems technology laboratories

Annual Research Report

September 2008

Here is your complimentary copy of MTL's annual research report spanning the academic year from 2007-2008!

To view the PDFs contained on this disc, you will need Adobe Reader version 7 or greater.

View online at **http://mtlweb.mit.edu/research/ar2008**

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