Microsystems Technology Laboratories

The mission of MIT's Microsystems Technology Laboratories (MTL) is to foster world-class research and education in microsystems, broadly construed. MTL's activities include research on integrated circuits, systems, electronic and photonic devices, microelectromechanical systems (MEMS), bio-MEMS, molecular devices, nanotechnology, and sensors and actuators. MTL's research program is largely interdisciplinary.

Since October 2013, professor Jesús A. del Alamo has led MTL. Recent additions to MTL's 49 core faculty include Moungi Bawendi of the Department of Chemistry, Vivienne Sze of the Department of Electrical Engineering and Computer Science (EECS), and A. John Hart of the Department of Mechanical Engineering.

MTL maintains service facilities that provide campus-wide access to advanced micro/nano fabrication capabilities as well as to sophisticated computer-aided design (CAD) and information technology infrastructure. During the 2014 academic year, MTL served 750 users; 585 made use of MTL's fabrication facilities and 165 made use of MTL's CAD and information-technology infrastructure. MTL's users are drawn from 18 MIT departments, laboratories, and centers and from 185 faculty research groups.

MTL engages users in a number of technical events. In both fall and spring of each academic year, MTL hosts a regular seminar series that spans diverse technical areas. A committee chaired by professor Tomás Palacios organizes the seminar series, which is open to the public. MTL also hosts one doctoral dissertation seminar each semester that features a recent graduate from MTL's PhD program, as well as occasional distinguished and executive seminars that feature a VIP from one of the companies that belong to MTL's Microsystems Industrial Group (MIG). Most recently, MTL hosted the visit of Jeffrey Marks, vice president at Lam Research.

Every January, MTL holds an annual research conference (MARC) that is run by MTL graduate students. In 2014, students Phillip Nadeau (from Professor Chandrakasan's group) and Farnaz Niroui (from Professor Bulović's group) co-chaired MARC, assisted

Group photo from MARC 2014 (Bretton Woods, NH). Photo by Paul McGrath/MTL.

Director J. A. del Alamo with MARC 2014 Organizing Committee. Photo by Paul McGrath/MTL.

by Professor Luca Daniel as faculty liaison. MARC is broadly attended by industry, faculty, students, and staff; it provides a unique opportunity to learn about research in the diverse areas that MTL encompasses while fostering interactions within the MTL community. The 2014 event was held on January 29–30 at the Omni Mount Washington Resort in Bretton Woods, NH, attracting more than 220 attendees.

Other topical meetings were also held during the year. One example was the Sixth Annual Medical Electronic Device Workshop, hosted by the Institute of Electrical and Electronics Engineers (IEEE) and the MIT Medical Electronic Device Realization Center (MEDRC), which took place at MIT on May 8–9, 2014.

Administrative Update

In October 2013, professor Jesús A. del Alamo was named director of MTL, succeeding professor Vladimir Bulović. On December 21, 2014, an MTL directors' brunch was held to celebrate Professor Bulović's service to MTL and to welcome Professor del Alamo as the new director.

The master of ceremonies for the brunch was Charlie Sodini, with help from Henry Smith, and the guests of honor were all previous MTL directors. It was an impressive lineup, with MIT president Rafael Reif; acting provost (now provost) Martin Schmidt; the School of Engineering's associate dean for innovation, Vladimir Bulović; EECS department head Anantha Chandrakasan; founding MTL director Dimitri Antoniadis and current MTL director Jesús de Alamo.

From left to right: Vladimir Bulović, Anantha Chandrakasan, L. Rafael Reif, Dimitri Antoniadis, Martin A. Schmidt, and Jesús A. del Alamo. Photo, Paul McGrath/MTL.

Bill Holber joined MIT in July 2013 as the first associate director for industrial relations at MTL. His responsibilities include all aspects of interactions with MTL industry partners, maintaining and deepening the strong industry partnerships MTL has benefited from since its founding. Hober received his PhD in applied physics from Columbia University.

Facilities Update

During the past year, as in the recent past, MTL's goals regarding equipment were to replace aging tools, extend the usefulness of existing tools, and acquire new capabilities. To these ends, MTL converted its existing Oxford-100 plasma-enhanced chemical vapor deposition reactive ion etcher to accept gold-contaminated samples. This conversion enables the processing of six-inch wafers of gallium nitride (GaN) and offers a broader range of options for III-V semiconductor samples. The laboratory acquired two Annealsys rapid thermal annealers to replace two very old systems; the new equipment will be used for silicon and III-V samples. The laboratory expanded its metrology capabilities by acquiring a Leica spectroscopic elipsometer and a Nanospec film-thickness measurement tool. Using funds from the service center equipment replacement fund managed by the Office of the Vice President of Research, MTL was able to acquire a critically needed Surface Technology Systems Pegasus deep reactive ion etcher at a deeply discounted price. In addition, Dai-ichi Seitosho Company gave MTL a DAD3240 advanced die saw.

During the past year, MTL finally succeeded, through modest renovations in the second- and fifth-floor laboratories, to generate additional fabrication space without triggering code compliance issues. The space will accommodate MTL's ever-expanding materials base—such as GaN, two-dimensional (2-D) materials, polymers—and support new programs and strategic initiatives that require new tools, such as atomic layer deposition of more materials on more substrates and atomic layer etching.

Industry Interactions

MTL forms partnerships with industry through the MIG consortium. Consortium members support MTL research and operations through membership fees and by making state-of-the-art tools and processes available. MIG members donate major pieces of equipment to MTL and provide access to their industrial integrated circuit chip fabrication services. Members of the MIG's Industrial Advisory Board (IAB) provide significant guidance in shaping the vision of MTL.

Members of the Microsystems Industrial Group Advisory Board together with MIT faculty and staff at MTL IAB meeting on Jan. 31, 2014. Photo, Paul McGrath/MTL.

MTL hosted the annual IAB meeting on Friday, January 31, 2014, with the following IAB members in attendance: Chorn-Ping Chang and Adam Brand (Applied Materials); Susan Feindt (Analog Devices); Yihui Qui (Foxconn); Yuki Kikuchi (Hitachi); Leland Chang (IBM); George Bourianoff (Intel); Brian Brandt and Patrick Coady (Maxim Integrated Products); Michal Danek and Narissa Draeger (Lam Research); David Hansquine (Qualcomm); Dennis Buss (Texas Instruments); Chih Hang Tung (Taiwan Semiconductor Manufacturing Company); Marco DeFazio (ST Microelectronics), and guest Anthony Keen (Edwards Vacuum).

Professor Jesús A. del Alamo began the meeting with the Director's Update. He was followed by professor Vladimir Bulović, who spoke about the new MIT Innovation Initiative and the planned nano-innovation space. Other faculty speakers included professors Scott Manalis, Vivienne Sze, Sang-Gook Kim, Dimitri Antoniadis, and Silvija Gradecak. Dr. Vicky Diadiuk gave an update on the MTL facility.

Four centers affiliated with MTL provide the opportunity for MIG member companies and other companies to supply direct support for focused research initiatives. These are the Center for Integrated Circuits and Systems, the MIT/MTL Gallium Nitride Energy Initiative, the MEDRC, and the MIT/MTL Center for Graphene Devices and 2D Systems.

In 2014 MTL added a new MIG member, Edwards Vacuum, a UK-based company interested in semiconductor capital equipment. This brings the roster of member companies to 15.

One of the benefits that member companies receive is the opportunity to have a staff scientist or engineer participate in the research activities of an MTL-affiliated faculty member or research center. There are currently eight visitors from MTL member companies.

Recent examples of interactions with MTL's industry partners include:

- Visits to member companies by MTL faculty and students:
    - February 13, 2014: 11 students spent the day at Maxim Integrated Products in San Jose, CA.
    - February 12, 2014: professor Jesús A. del Alamo visited NEC in Japan.
    - February 28, 2014: professor Nicholas Fang visited IBM in Yorktown Heights, NY, and gave a presentation, "Sculpting Light and Acoustic Fields with Metamaterials." His host was Dr. Siyuan Lu.
    - December 19, 2013: professor Jesús A. del Alamo visited Taiwan Semiconductor Manufacturing Company. His host was Bing Sheu.
    - December 17, 2013: David Perreault visited Texas Instruments (TI) in Santa Clara, CA, and made a presentation, "In Search of Powerful Circuits: Developments in Very High Frequency Power Conversion."
    - November 30, 2013: professor Karl Berggren visited Taiwan Semiconductor, where he gave a presentation, "Next-Generation Lithography by Physical Templating of Block Copolymers: Posts, Patterns, and Possibilities." His host was Jack Chen.

  - November 21, 2013: Eight students and two faculty members attended MTL Day at IBM in Yorktown Heights.
  - November 1, 2013: professor Jesús A. del Alamo gave a two-hour online presentation to Lam Research, "InGaAs MOSFETs for CMOS: Recent Advances in Process Technology."
  - October 31, 2013: Sang-Gook Kim gave a presentation at Analog Devices (Wilmington, DE), "Piezoelectric Micro Ultrasonic Transducer."

- Visits to MTL by staff of member companies:
  - April 22, 2014: Rob Gilmore and Eladio Arvelo from Qualcomm visited MTL for a full day of meetings with faculty.
  - April 9, 2014: Stefan Wolff and Dave Johnson from Intel visited MTL.
  - March 26, 2014: Venu Menon from TI visited MIT for a day of meetings with students and faculty.
  - March 5, 2014: Maxim Integrated Products' chief executive officer (CEO), Tunç Doluca, visited as a recruiter. His visit included laboratory tours with students and faculty and a presentation about Maxim Integrated.
  - February 26, 2014: Joyce Kwong from TI gave a seminar, "Ultra-High Speed Digital Design."
  - February 26, 2014: Brett Miwa from Maxim Integrated Products presented a seminar, "Opportunities and Challenges in Mobile Power Management."
  - February 20, 2014: Four visitors from Applied Materials (Ludovic Godet, Srinivas Nemani, Lou Steen, and Chris Hatem) met with professor Jesús A. del Alamo while at MIT; their host was the Industrial Liaison Program.
  - January 28, 2014: Lam Research held a recruiting session at MIT.
  - November 14, 2013: Jeffrey Marks, vice president of Lam Research, presented an MTL executive seminar, "Future Challenges of Semiconductor fabrication and Atomic Scale Processing."
  - November 12, 2013: Dennis Buss from TI presented an MTL seminar, "Microelectronics: An Industry in Transition."
  - November 6, 2013: 12 Maxim employees attended the Center for Intelligent Control Systems review.
  - November 5, 2013: John Memishian (Analog Devices Inc.) presented an MTL seminar, "Fun with Micromachines: Measuring Zeptofarads and Picometers for Under a Buck."
  - November 1, 2013: Alex Yoon from Lam Research attended the Center for Graphene Devices and 2D Systems review.
  - October 31, 2013: Rob Gilmore from Qualcomm visited MTL.
  - October 24, 2013: Qualcomm held a recruiting session at MIT.

- October 8, 2013: Yuri Vlasov of IBM gave a presentation at an MTL seminar, "IBM Silicon Nanophotonics Technology for Datacenters and Computer Systems."
- September 25-26, 2013: Maxim Integrated Products held a recruiting session at MIT, led by CEO Tunç Doluca.

MTL Outreach and Educational Activities

To support MTL's mission to provide access to advanced fabrication technologies, MTL makes its facilities available to industry users through the Fabrication Facilities Access program and to users from academia and government agencies through the Outreach Program.

MTL supports MIT's educational mission through courses held at the laboratory. These include 6.152J Micro/Nano Processing Technology, which introduces the theory and technology of micro/nano fabrication; 3.042 Materials Project Laboratory, which gives student project teams the capabilities to design and fabricate a working prototype using materials processing technologies; and 6.07J Projects in Microscale Engineering for the Life Sciences, which teaches a project-based introduction to manipulating and characterizing cells and biological molecules using microfabricated tools.

MTL also supports two EECS initiatives: the Women's Technology Program and the Advanced Undergraduate Research Program (Super UROP).

Women's Technology Program

The Women's Technology Program (WTP) was created in 2002 to encourage young women with strong mathematics, science, and analytical skills and abilities to pursue studies in engineering and computer science. The program provides young women with positive female role models, college-level computing and engineering experience, and an understanding of what engineers and computer scientists do and how they work.

Participants in WTP have an opportunity during the summer for a hands-on experience in MTL's microfabrication facilities. The WTP group of 40 young women is divided into four subgroups of 10. Participants then enter the fabrication facility, don gowns and masks, and go through the fabrication steps needed to transfer a photograph onto a

The 2013 WTP participants, properly attired In clean room garments, pose before entering the MTL clean rooms. Photo, EECS.

Each WTP participant received her own etched silicon wafer. Photo, EECS.

silicon wafer; they observe the development of a "picture wafer" that carries their own group's image being developed. Each student receives a wafer. Feedback from students has been very positive, and the "picture wafers" are a great reminder of their summer at MIT.

Super UROP

SuperUROP, initiated by EECS in the fall of 2012, engages students in a year-long research experience through participation in a course titled "Preparation for Undergraduate Research." SuperUROP promotes direct interaction with faculty and industry sponsors, cultivates student creativity and professional development, and encourages students to consider the ethical and entrepreneurial aspects of their work. In academic year 2014, there were 17 students in the program working in MTL, six of whom were qualified to work in the fabrication unit as part of their SuperUROP project.

MTL has been proud to be a partner with EECS in the SuperUROP program, providing $3,000 of subsidized access for each student whose project makes use of MTL computational or fabrication facilities.

SuperUROP graduates pose with MIT President Reif, center right, and professor Anantha Chandrakasan, center left, as they finished the year-long program for undergraduate research in EECS. Photo, Neal Hamberg/EECS.

Research Highlights

MOS Transistor Compact Model Parameter Extraction Using Bayesian Inference

In this work, the group developed a novel metal–oxide–semiconductor field-effect transistor (MOSFET) parameter extraction method to enable early technology evaluation. The distinguishing feature of the new method is that it enables the extraction of an entire set of MOSFET model parameters using limited and incomplete current-voltage characteristic curve measurements from on-chip monitor circuits. An important step in this method is the use of maximum a posteriori probability estimation, in which past measurements of transistors from various technologies are used to learn a prior distribution and its uncertainty matrix for the parameters of the target technology. The framework then uses Bayesian inference to facilitate extraction using a very small set of additional measurements. The new method is validated using various past technologies and post-silicon measurements for a commercial 28 nm process. The proposed extraction method can also be used to characterize the statistical variations of MOSFETs, with the significant benefit that some constraints required by previous approaches, such as the backward propagation of variance method, are relaxed. Professors Duane Boning and Dmitri Antoniadis carried out this research with graduate student Li Yu.

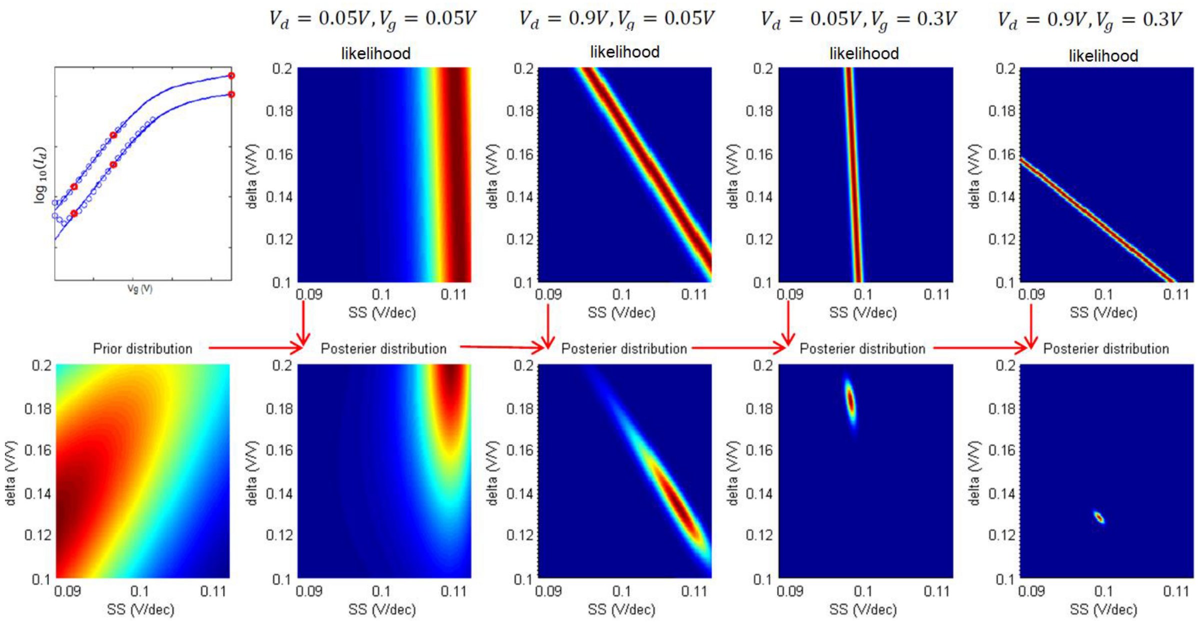


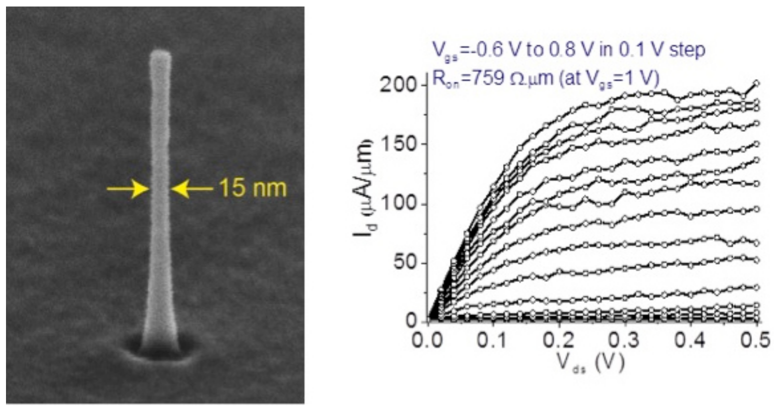
Illustration of sequential Bayesian learning of two parameters in the MIT virtual source MOSFET model using priors and I-V measurements. The two parameters shown are the sub-threshold swing factor, SS, and the drain-induced barrier-lowering term, delta. The red color represents estimates with high likelihood while the blue color represents estimates with low likelihood. As more measurements are added (left to right), the maximum a posteriori probability parameter estimates become more accurate.

Nanoscale InGaAs Nanowire Transistors

Silicon-based nanoelectronics is reaching fundamental limits. This suggests the coming suspension of Moore's Law, something that could have profound implications for human society. The group headed by professor Jesús del Alamo of MTL is committed to finding technological paths that will allow Moore's Law to operate into the future by exploiting the unique physics of III-V compound semiconductors.

In particular, del Alamo's group is investigating the ternary compound indium gallium arsenide (InGaAs) as an alternative material for future transistors because of its outstanding electron transport properties. The group is fabricating planar, Trigate, and nanowire MOSFETs based on InGaAs. The nanowire geometry is especially attractive—it allows footprint scaling, and therefore density scaling, which is the very essence of Moore's Law; and it does so without gate length scaling, which is required in all other families of transistors. This potentially enables extremely high transistor density while keeping short-channel effects acceptable.

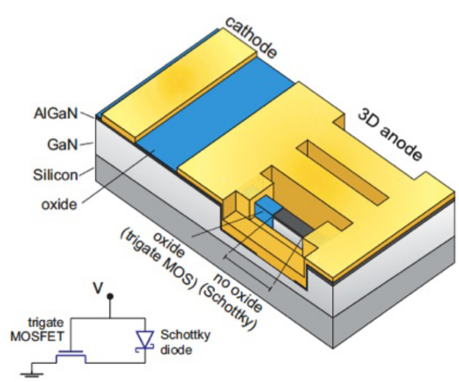
The group has fabricated vertical nanowire InGaAs MOSFETs through a new top-down approach. In the literature, every vertical III-V nanowire transistor to date has been implemented through bottom-up techniques that are harder to manufacture. The group has developed new reactive-ion etching technology that allows them to implement high-aspect ratio nanowires with smooth vertical sidewalls, as shown in the figure to the left. Using this technology, the group has fabricated transistors with final nanowire diameters between 30 nm and 50 nm. The figure to the right shows the output characteristics of a 30 nm diameter single-nanowire transistor. The group's electrical results are as good as those demonstrated in the literature using bottom-up techniques. This suggests the great potential of the group's novel approach for future nanoscale InGaAs nanowire transistors.



Left: 15 nm diameter InGaAs nanowire fabricated by reactive ion etching and digital etch. Right: output current-voltage characteristics of single-nanowire transistor with 30 nm diameter.

GaN Nanowires to Increase the Performance of Transistors and Diodes

Top-down GaN nanowires have been fabricated to demonstrate radio frequency (RF) and high-voltage transistors and diodes with state-of-the-art performance. The nanowire structure allows a much better confinement of the channel electrons in these devices, which significantly reduces the leakage current under high reverse bias conditions. At the same time, the use of a nanowire structure under the gate of a GaN transistor increases the current capability of the device, which helps to improve the linearity of the transistors. This work, which in 2012 received the IEEE George Smith Award for the best paper published in *IEEE Electron Device Letters*, has resulted in several invention disclosures and patent applications. The technology is in the process of being licensed to a start-up company in Cambridge, MA.



Schematic of a GaN-based diode with nanowire structures in the anode. An equivalent circuit model of the novel device is also shown.

Professor Palacios carried out the research with postdoctoral associates Mohamed Azize and Elison Matioli and graduate students Bin Lu and Dong Seup Lee. The Office of Naval Research, the Defense Advanced Research Projects Agency (DARPA), the Department of Energy, and the National Science Foundation funded the work.

Quantum Photonics Laboratory

Professor Dirk Englund leads the Quantum Photonics Laboratory, focusing on semiconductor quantum technologies for controlling quantum states in photons and spins to address problems in communication, computation, and metrology. Over the past 12 months, the Englund group developed new types of high-efficiency, chip-integrated photodetectors based on graphene; precision biochemical sensors based on polymer nanocavities; and diamond nanocrystals for precision sensing using optically addressable spins.

There has been increasing interest in developing opto-electronic devices based on graphene, whose tunable optical and electronic properties make it applicable to both high-speed and broadband modulators and photodetectors. The Englund group and its collaborators demonstrated that when graphene is draped over silicon waveguides, the material’s intrinsically low optical absorption can be increased nearly to unity over a broad wavelength range. Using this waveguide-integrated architecture, the team demonstrated graphene-based, high-responsivity, ultrafast photodetectors in the silicon photonics platform. This work was featured on the National Public Radio program, “Marketplace,” broadcast on November 21, 2013.

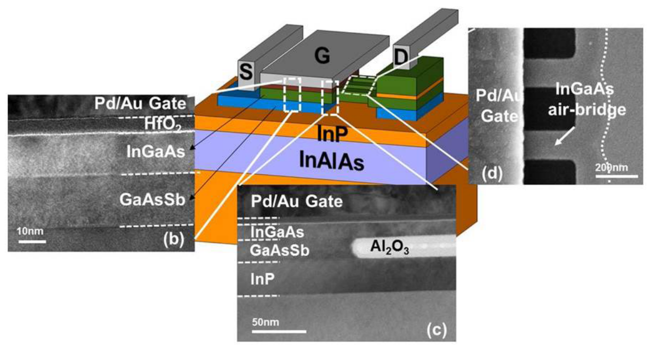
The team previously also demonstrated high-contrast electro-optic modulation using graphene-integrated photonic crystal cavities. This work indicates that the integration of low-dimensional materials into photonic circuits promises a new route for ultrafast and broadband on-chip optical interconnects, nonlinear optics, on-chip light sources, and other functionalities.

Molecular and Cell Separation and Sorting Technologies

Professor Jongyoon Han’s group focuses on molecular and cell separation and sorting technologies, as well as on the novel use of various types of ion selective membranes. As reported in a recent publication [Sarkar *et al.*, *Nature Communications*, 5, 3421 (2014)], Professor Han and the micro/nanofluidic bioMEMS group is introducing a novel microfluidic device that enables unique molecular analysis of single cells without disrupting their cellular context. This research team, in collaboration with professor Douglas Lauffenburger’s group from the Department of Biological Engineering, has developed a multiplexed microfluidic probe for single-cell analysis directly from the standard adherent cell culture; they also demonstrated that the study of cellular heterogeneity, a concept of intense, current research interest, would now be possible. Many physiological and pathophysiological processes are driven by a minority cell group contained in a given tissue or culture, and more specific measurements of molecular signatures of these cells may lead to better understanding and treatment of cancer and other diseases.

Quantum-Well Tunnel-FETs Demonstrated

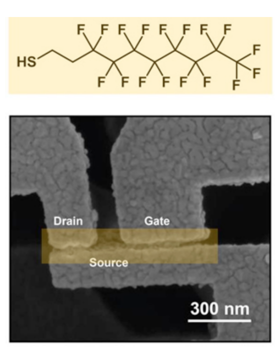
Professor Judy Hoyt's group is studying the device physics of futuristic transistors based upon quantum mechanical tunneling. Such tunnel field effect transistors (FETs) hold theoretical promise for very low-voltage, low-power operation. In recent work, gate control of the tunneling between two quantum well layers was experimentally demonstrated in the indium gallium arsenide/gallium arsenide antimonide (InGaAs/GaAsSb) system. The devices were fabricated at MTL's facilities and include seven levels of electron-beam lithography (EBL), the highest number of aligned EBL levels fabricated in a structure at MIT. Graduate students Tao Yu and James T. Teherani, whose work was funded by the National Science Foundation, published the work in *IEEE Electron Device Letters* (December 2013).



Schematic illustration of the device structure (center) as well as images of a fabricated tunnel field-effect transistor: (a) cross-section transmission electron microscopy (TEM) under the gate, (b) cross-section TEM near the air-bridge, (c) top view scanning electron microscopy of the air-bridge area of the device, which serves to prevent unwanted tunneling paths near the drain.

Nanoelectromechanical Switch

A team of graduate students and postdoctoral associates, under the supervision of professors Vladimir Bulović, Timothy Swager, and Jeffrey Lang, is developing a nanoelectromechanical switch that operates with an organic molecular monolayer between its contacts. A micrograph of the switch is shown below; the switch terminals are labeled following their functionality in a MOSFET. Closing the relay is effected with electrostatic gate-source actuation (typically below 1V). When closed, the relay conducts from drain to source via tunneling through the molecular monolayer; when open, its

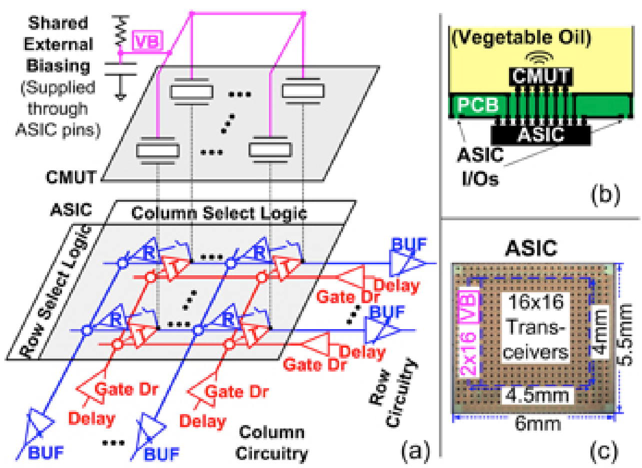


Micrograph of the switch (below) and chemical structure of the molecular monolayer (above); the functional location of the monolayer is high-lighted in the micrograph.

conduction is reduced by a factor of 105 or more. The molecular monolayer is also shown, and its location in the switch is highlighted in the micrograph. The importance of the molecular monolayer is that it prevents contact sticking, thereby eliminating a major roadblock to using the relay for digital logic and RF switching. Current work focuses on reducing the actuation voltage and simultaneously increasing the ratio of on-state to off-state conduction.

Column-Row-Parallel Architecture

In Professor Sodini's work, a 2-D NxN ultrasound transducer array was used to acquire 3-D volumetric data. A column-row-parallel architecture a*pplication-specific integrated circuit* (ASIC), which achieves much more 3-D beam-formation functionality and better tradeoff for complexity and speed than other reported architectures was designed and characterized. A 16x16 capacitive micromachined ultrasonic transducer (CMUT) was biased at 20–40 volts. Each CMUT element and its transceiver (a transmit pulser and a low noise amplifier) have the same size, 250x250 µm2, and are co-packaged vertically through an interposer printed circuit board. At the ASIC perimeter, 16-column and 16-row pulser gate drivers and buffer amplifiers interface to the transceiver array. Their inputs/outputs (I/Os) are multiplexed to share 16 input and 16 output ports reducing ASIC I/Os to N. In the figure below, (c) shows the ASIC die photo in a 0.18µm high-voltage complementary metal–oxide–semiconductor (CMOS) process. Although CMUT was used here, this ASIC architecture is equally applicable to other 2-D transducers.



Column-Row-Parallel architecture and the system assembly.

Video Compression Architectures

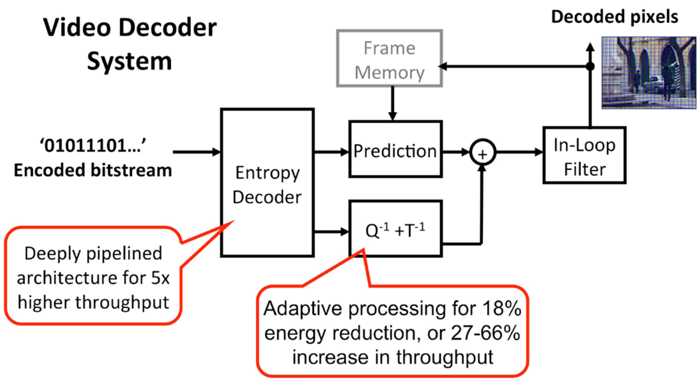
Professor Vivienne Sze's group has developed video compression and decompression hardware to support the next generation of video applications that require high throughput for high resolutions and frame rates, or low energy consumption for battery-operated devices. Specifically, the group designed two key modules for the latest video coding standard, high-efficiency video coding:

1. A high-throughput entropy decoding engine known as context-adaptive binary arithmetic coding. The group's design achieves a throughput five times higher

than previous state-of-the-art engines, which enables the video decoder to deliver real-time processing of high-resolution videos up to 8K Ultra HD at 120 feet per second;

2. An energy-efficient inverse transform that supports large transforms up to 32x32 with minimal hardware cost, and can adapt energy consumption based on video content (for an 18% energy reduction, or 27%–66% increase in throughput).

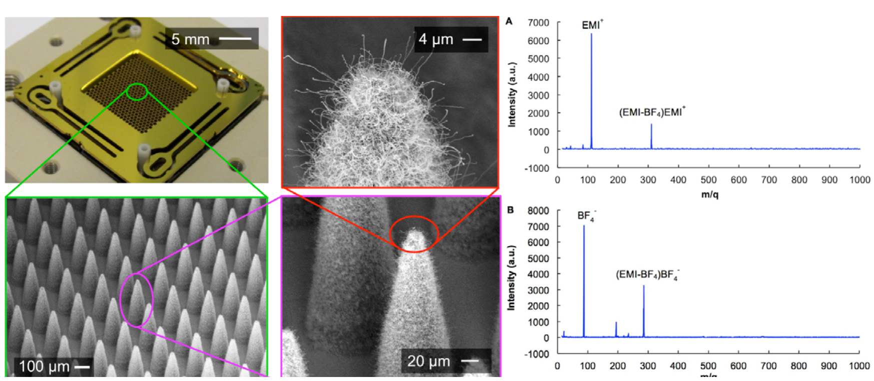
Professor Anantha Chandrakasan was co-principal investigator.



The video decoder system explained.

High-Throughput Ionic Liquid Ion Sources

One MTL group recently demonstrated advanced planar arrays of miniaturized externally fed electrospray emitters with integrated extractor grid and carbon nanotube flow control structures for low-voltage and high-throughput electrospray of the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate (EMI-BF4) in vacuum. Microfabricated arrays with as many as 1,900 emitters in 1 cm^2 were fabricated and tested (this is four times the largest emitter array size and emitter density reported in the literature). Per-emitter currents as high as 5 µA in both polarities were measured (a five times larger ion current emission than the best results in the literature), with start-up bias voltages as low as 470V and extractor grid transmission as high as 90%. A conformal carbon nanotube forest grown on the surface of the emitters acts as a wicking structure that transports liquid to the emitter tips, providing hydraulic impedance to regulate and make uniform the emission across the array. Mass spectrometry of the electrospray

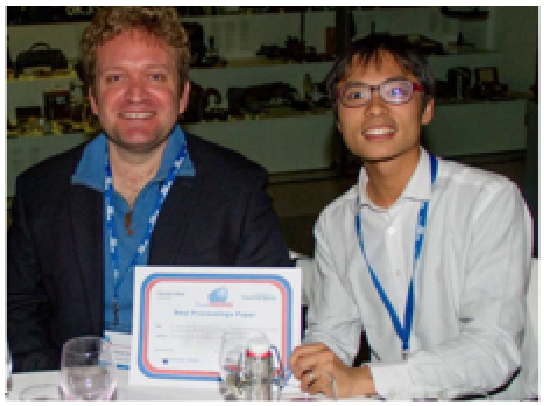


Left, center: array of 1,900 electrospray emitters in 1 cm^2 with close-up of the emitter array, emitter, and emitter tip. Right: mass spectrometry of the emission in the positive (A) and negative (B) polarity, demonstrating that the emission is purely ionic.

beam confirms that emission in both polarities is composed of solvated ions, and nanoscale etching of the silicon collector electrode is observed. Collector imprints and per-emitter current-voltage characteristics for different emitter array sizes spanning three orders of magnitude show excellent emission uniformity across the array. These groundbreaking results are of great importance to novel applications such as nanosatellite propulsion and high-throughput nanomanufacturing. Dr. Luis Velásquez-García carried out the research with F. A. Hill, E. V. Heubel, and P. Ponce de Leon. DARPA funded the work.

Awards and Honors for Faculty, Students, and Staff[1*]

S. Cheng (L. Velásquez-García): "A Compact X-ray Generator using a Nanostructured Field-Emission Cathode and a Microstructured Transmission Anode," Best Proceedings Paper Award, 13th International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS 2013), London, England, December 2013.



Left to right: Luis Velasquez-García and Samuel Cheng

H. Wang (T. Palacios): "Large-Scale 2D Electronics Based Single-Layer MoS2 Grown by Chemical Vapor Deposition," *International Electron Devices Meeting* (*IEDM*) 2012, Roger A. Haken Best Student Paper Award (given at IEDM 2013).

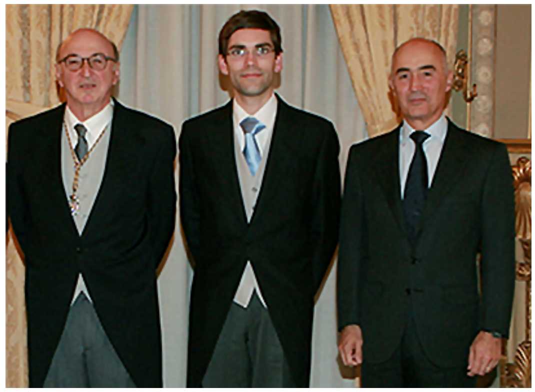
B. Lu, E. Matioli and T. Palacios: "Tri-Gate Normally-Off GaN Power MISFET," IEEE Electron Device Letters, 2012 George Smith Award (given at *IEDM 2013)*.

From left to right: Bin Lu, Elison Matioli, Tomás Palacios, and Han Wang.

1 * Parentheses denote the names of advisers.

On April 14, 2014, an MIT student team, P. Nadeau (A. Chandrakasan) and M. Mimee (Timothy Lu) won the Qualcomm Innovation Fellowship ($100,000 for the team). The title of their innovation was "BacMOS: Electronic Bio-Sensors Using Synthetic Biological Transducers." There were 137 proposals submitted nationwide; nine teams were chosen.

T. Palacios won the 2013 Betancourt Award, given by the Spanish Royal Academy of Engineering.



Left to right: Elias Fereres, President of the Spanish Royal Academy of Engineering; Tomás Palacios, and Rafael del Pino, member of the MIT Corporation and CEO of Ferrovial

W. Tisdale won the 2014 3M Non-Tenured Faculty Award.

Will Tisdale, winner of the Non-Tenured Faculty Award. Photo, Curt Schulz/MTL

W. Chern (J. Hoyt) was awarded the Ernst A. Guillemin SM Thesis Prize for Electrical Engineering, fall 2013.

K. Chen (C. G. Sodini) won the 2013 Chinese Government Award for Outstanding Self-Financed Students Abroad.

Z. Mahmood, B. Guérin, B. Keil, E. Adalsteinsson, and L. L. Wald (L. Daniel) received the Magna cum Laude Merit Award at the International Society for Magnetic Resonance in Medicine (ISMRM) 2014 Annual Meeting, Milan, Italy (May 2014) for their paper, "Design of a Robust Decoupling Matrix for High Field Parallel Transmit Arrays."

J. Fernandez Villena, A. G. Polimeridis, B. Guerin, Y. Eryaman, L. L. Wald, E. Adalsteinsson (J. K. White and L. Daniel) received the Summa cum Laude Merit Award at the ISMRM 2014 Annual Meeting, Milan, Italy (May 2014) for their paper, "Fast Electromagnetic Analysis of Transmit RF Coils based on Accelerated Integral Equation Methods."

V. Sze won the Jonathan Allen Junior Faculty Award (December, 2013). The award is given by MIT's Research Laboratory of Electronics.

V. Sze now holds the Emanuel E. Landsman (1958) Career Development Chair.

D. Hodges-Pabon, MTL's human resources officer, was awarded the 2013–2014 Young Men's Christian Association (YMCA) Achievers Community Service Award by the YMCA of Greater Boston, the largest provider of social services in Massachusetts.
V. Diadiuk won the 2014 School of Engineering Ellen J. Mandigo Award for Outstanding Service.

Debroah Hodges-Pabon, winner of the YMCA Achievers Community Service Award

P. McGrath won the 2014 School of Engineering Infinite Mile Award for Excellence.

Left to Right: Jesús A. del Alamo (MTL Director); Vicky Diadiuk (Mandigo award recipient); Paul McGrath (Infinite Mile Award for Excellence recipient): Ian Waitz (Dean of Engineering): and Vladimir Bulović (Associate Dean for Innovation).

Jesús A. del Alamo
Director
Donner Professor of Electrical Engineering