MIT.nano

MIT.nano is a world-class, advanced center for nanoscience and nanotechnology, a research facility open to the entire community of faculty, researchers, and students, as well as external academic and industry partners. The 214,000-square-foot facility provides a broad and versatile tool sets for nanoscale advancements—from imaging to synthesis to fabrication and prototyping—entirely within the facility's protective envelope.

After six years of design and construction, occupancy was granted on June 6, 2018, and the facility officially opened on October 4, 2018. The facility will require a few years to be completely outfitted with instruments and tools, with plans to update approximately 5% of the tools every year to keep its capabilities evergreen. When the lab is fully operational, it will support more than 2,000 researchers per year.

Unlike many similar facilities, MIT.nano does not host individual faculty offices, reinforcing its open-access culture. Nanoscale work is inherently interdisciplinary, which is reflected in MIT.nano's broad user base from the multitude of MIT's departments, labs, and centers.

Achievements and Milestones

Official Opening

On October 4, 2018, over 1,000 people attended LAUNCH.nano, a full day of events celebrating the grand opening of MIT.nano. A symposium was held showcasing the broad work of the MIT community, exploring the vast opportunities for new discoveries and ground-breaking technologies enabled by exploration and utilization of nanoscale. The festivities that followed included a ribbon-cutting ceremony, facility tours, exhibitions, a reception, a poster session, and more.

The MIT.nano Grand Opening Ribbon-Cutting Ceremony on Oct. 4, 2014. Dignitaries included (from left) Tim Jamison, associate provost and Robert R. Taylor Professor of Chemistry; Krystyn Van Vliet, associate provost and professor of DMSE and Biological Engineering; Raymond S. Stata '57, chairman and co-founder of Analog Devices; MIT president L. Rafael Reif; Vladimir Bulović, MIT.nano director and Fariborz Maseeh (1990) Professor in Emerging Technologies; Robert Millard, MIT chairman of the Corporation; Provost Martin Schmidt; Vice President for Research Maria Zuber; and Executive Vice President and Treasurer Israel Ruiz.

Since MIT.nano's official opening in October, a significant effort has been underway to prepare the building's facilities to support nanoscale researchers from departments, labs, and centers across the Institute. Progress has included the installation of tools and structuring of systems for user services, developing policies, procedures, training, and other systems to support our community of researchers, establishing research, education, and entrepreneurship programs, and attracting consortium members. Some of the last year's significant achievements include are laid out below.

MIT.nano Consortium

As of June 30, 2019, MIT.nano has 11 founding member companies. Drawn from a variety of industries, the founding members are leaders in the development of systems, materials, and technologies for government, business, and consumers around the world. The financial support of the MIT.nano Consortium funds our operations, purchases equipment, and seeds relevant research directions. As importantly, our industrial colleagues also introduce us to practical problems blocking the path of their own development, and if we overcome the presented challenges, they help deliver our insights and innovations to the market. For our corporate collaborators, joining the potent, problem-solving culture of innovation at MIT energizes their efforts and offers early awareness of the technological advances that will help shape the world of tomorrow. Members could translate this awareness into formal research collaborations with faculty, company-specific seminars, and support for MIT startups, among other opportunities.

Founding members of MIT.nano include Agilent Technologies, Analog Devices, Dow, Draper, DSM, Edwards, IBM Research, Lam Research, NCSOFT, NEC, and Waters.

Support for Research

MIT scientists and engineers are now revealing astonishing new behaviors for elements across the periodic table—and inventing powerful new ways to put them to work. It's a process of discovery and innovation perfectly suited to our interdisciplinary culture and our incomparable record of translating fundamental knowledge in the lab into breakthrough applications out in the world. Our faculty and students see thrilling potential for impact with nanoscale discoveries, and MIT.nano is ready to support their drive for exploration.

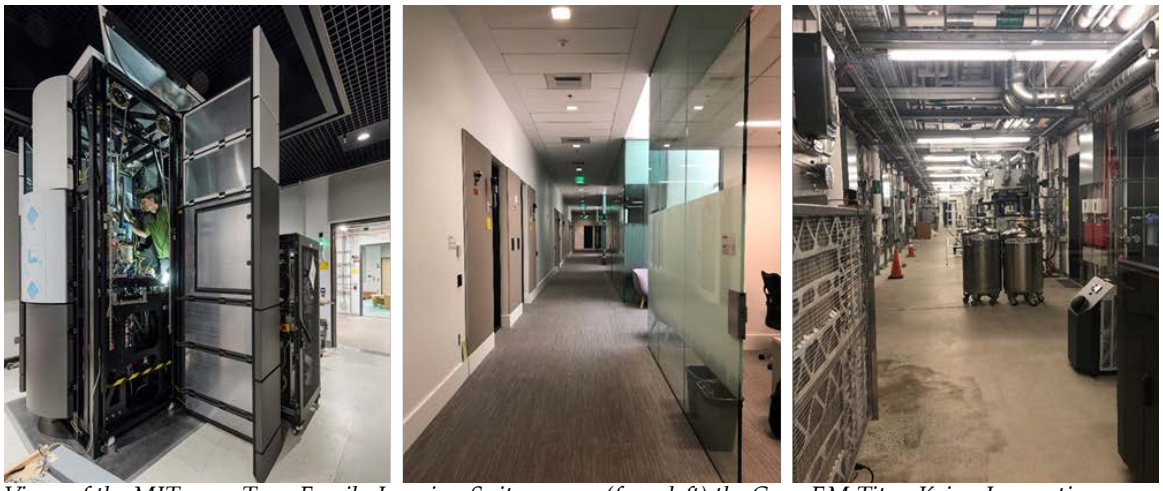
Tool Installation

We established a multistep process for the procurement and installation of tools in MIT.nano with a defined progression and specific timeline. Phase 1 Tool Installation (scheduled to be completed by October 2019) includes over 115 pieces of equipment, including:

- Two cryo-electron microscopes (Cryo-EMs),
- Cryo-focused ion beam scanning electron microscope
- New semiconductor tools
- New tabletop equipment: ovens, hot plate towers, spin rinse drier, and tabletop microscopes
- Operational enhancements: passthrough stations, bottle washer, central vacuum system, and card readers

- Solar Frontiers lab growth/metrology equipment suite
- Lab for Education and Application Prototypes (LEAP) packaging facility
- Exploratory Materials Laboratory, relocated from Microsystems Technology Laboratories (MTL)
- Aberration-corrected scanning transmission electron microscope
- Inert-environment glovebox system (Professor Farnaz Niroui)
- Interference lithography system (Professor Karl Berggren)
- Bulk liquid nitrogen Building 38 distribution upgrade
- FOM sheet-to-sheet coater for large-area thin film deposition

The first tools to be installed in the MIT.nano Tang Family Imagine Suites is a set of two cryo-electron microscopes, which allow structural biologists, such as Professor Thomas Schwartz, to investigate communication across biological membranes, analyze the nanoscale details of large, complex, and flexible biomolecules, and create 3D images of matter at a resolution of 0.3nm or better. (For reference, human DNA is 2nm wide.) Due to the extreme sensitivity of gathering these images, the Cryo-EMs are located in the most environmentally quiet space on campus, a basement level optimized to meet the most stringent nanoscale imaging requirements for low vibration and low electromagnetic interference.



Views of the MIT.nano Tang Family Imaging Suite spaces: (from left) the Cryo-EM Titan Krios; Innovation Alcoves in the south side hallway are designed to encourage spontaneous interactions, sparking ideas that can lead to breakthroughs and new collaborations; Mechanical Alley abutting the back of the 12 state-of-the-art imaging and metrology suites is filled with equipment that supports their operation.

Also located in the Tang Family Imaging Suites:

- Cryo-focused ion beam, which allows the preparation of frozen samples of biological specimens for high-resolution tomographic imaging in the Cryo-EM
- Bio Preparation Room—bio sample preparation for the research that will impact health, biotech, and health care applications

The MIT.nano cleanroom complex, spanning the first and third floor of the facility, encompasses over 40,000 square feet of high-performance research space optimized for energy efficiency, airflow, and future flexibility, is the backbone of the facility. The cleanroom spaces provide tool sets for the design and fabrication of microscale and nanoscale structures, including synthesis, imaging and microscopy, and materials and thin film growth. This January, Professor Farnaz Niroui and her students were the first group of users trained in MIT.nano cleanroom procedures and were approved to begin research in the space. Professor Niroui's group develops hybrid nanofabrication techniques to enable precise yet scalable processing of nanoscale architectures capable of uniquely controlling light-matter interactions, electronic transport, and exciton dynamics to engineer new paradigms of active nanoscale devices. Starting in August 2019, a regular training program will be initiated, preparing over 100 new users over the first month of training.

Immersion Lab

Designed as a two-story, black box theater, the Immersion Lab will be outfitted to provide a space for visualization, augmented reality, and virtual reality, along with the activities supporting those fields. Supported by a four-year, $5 million grant from MIT.nano founding member NCSOFT, the outfitting of the Immersion Lab began in June 2019, utilizing hardware and software tools to create a state-of-the-art immersive environment for visualizing advanced technology concepts, to connect the physical to the digital. The NCSOFT grant also provides for annual seed grants in related technologies.

Prototyping Facility

The fifth floor of MIT.nano houses the Monterrey Tec Prototyping Suites, a unique set of interconnecting labs—the first of its kind at MIT—with capabilities for fabrication, prototyping, and packaging. This is where nano innovations will take the first step toward becoming products, technologies, and solutions that benefit the world. The AIM Photonics Academy LEAP Program moved into one bay of this space in spring 2019. Due to its exceptional flexibility, the prototyping suites have found a purpose as a swing space for one of the newest MIT faculty members, Professor Frances Ross, who needed a temporary home for her research equipment while her permanent lab was being constructed. MIT.nano's ability to support Professor Ross allowed her to continue her research without skipping a beat.

MTL.nano

Starting on July 1, 2018, management of the operation of the Microsystems Technology Laboratories moved to MIT.nano. Both income and liabilities of the MTL tool set became the responsibility of MIT.nano. We successfully closed the first year of MTL.nano management, reaching the expected financial deficit, which was covered by the MIT.nano industry consortium funds.

Operational Model and Financial Sustainability

MIT.nano will host two types of tool sets: centrally managed, which are shared tools and instruments, open to the entire research community; and privately managed, those spaces stewarded for specific projects and capabilities. MIT.nano may accept

faculty secured equipment that is not initially part of the MIT.nano shared tool set, accommodating this equipment for limited durations and dedicated purposes that meet specific criteria. MIT faculty can request to locate such equipment inside MIT.nano by way of an MIT.nano Equipment Support Plan.

MIT.nano operations is financially supported primarily by user fees, and augmented by consortium membership dues, donations, and funding dedicated for support of MIT.nano programs. During the last year, MIT.nano received support from MIT.nano founding member NCSOFT for the Immersion Lab Program, as well as funding to support our equipment purchases from the Lord Foundation and from the Skoltech funds.

The MIT.nano Leadership Council oversees the operation of the facility. The council meets once a month during the academic year and includes the following members:

- Brian Anthony—MIT.nano, Department of Mechanical Engineering (MechE)
- Robert Atkins—MIT Lincoln Laboratory
- Karl Berggren—Nanostructures Laboratory, Department of Electrical Engineering and Computer Science (EECS)
- Vladimir Bulović—MIT.nano
- Jesús del Alamo—MTL.nano, EECS
- Karen Gleason—Department of Chemical Engineering (ChemE)
- Dennis Grimard—MIT.nano
- Pablo Jarillo-Herrero—Department of Physics
- Will Oliver—Research Laboratory of Electronics (RLE), Department of Physics
- Katharina Ribbeck—Department of Biological Engineering
- Thomas Schwartz—Department of Biology
- Carl Thompson—Materials Research Laboratory, Department of Materials Science and Engineering (DMSE)

The MIT.nano Internal Advisory Board (IAB) meets once a year (with the first meeting on Friday, September 13, 2019) and provides strategic advice to the MIT.nano faculty director and to the Vice President for Research on the strategic issues related to MIT.nano. The IAB is an advisory group, not an oversight body, with membership composed of intellectual leaders of the MIT community, reflecting the Institute-wide perspective on the utility of MIT.nano. IAB members are as follows:

- Marc Baldo—Director, RLE; EECS
- Anantha Chandrakasan—Dean, School of Engineering; EECS
- John Deutch—Department of Chemistry
- Elazer Edelman—Director, Institute for Medical Engineering and Science (IMES)
- Paula T. Hammond—Department Head, ChemE

- Susan Hockfield—President Emerita; Department of Brain and Cognitive Sciences
- Joi Ito—Director, Media Lab
- Craig Keast—MIT Lincoln Laboratory
- Chris Schuh—Department Head, DMSE
- Michael Sipser—Dean, School of Science; Department of Math
- Krystyn Van Vliet—Associate Provost, DMSE
- Evelyn Wang—Department Head, MechE

Programs and Initiatives

Over the last year, the MIT.nano team has developed and implemented a variety of programs.

ARTS.nano

ARTS.nano is a platform for exploring, celebrating, and inspiring creativity and artistic collaboration, a hub for connections between artistic practice and the frontiers of advanced materials, computing, virtual reality, artificial intelligence, and other disciplines. On February 26, 2019, MIT.nano launched the ARTS.nano Program with a symposium exploring the intersection of the frontiers of science and technology with artistic practice. Co-organized by MIT.nano and the MIT Center for Art, Science & Technology (CAST), the symposium examined art forms and expressions enabled by the emergence of new materials and by advances in computing paradigms. The program will also fund a diverse set of programmatic elements that support artists and artistic expression, including exhibitions in the MIT.nano galleries.

MIT.nano galleries fill the first and second floor subtending corridors on the south side of the building. They are designed for public exhibitions that highlight the latest, cutting-edge advancements developed at MIT, works of artists from the MIT community, and works produced by visiting artists in collaboration with MIT researchers. The photo features the One.MIT art piece as well as the Digital Gallery wall.

The MIT.nano premiere ARTS.nano exhibition was the *Spider's Canvas / Arachnodrone*, a production of CAST, MIT Music and Theater Arts, and MIT Civil and Environmental Engineering. *Spider's Canvas / Arachnodrone* is a co-creation of composer, CAST faculty director, and Kenan Sahin Distinguished Professor Evan Ziporyn; composer and visual artist Christine Southworth '02; sound artist and lecturer Ian Hattwick; and spider

researcher and doctoral candidate Isabelle Su. It is part of a larger and ongoing artistic research project with CAST visiting artist Tomás Saraceno and Civil and Environmental Engineering head Markus Buehler. Based on research on spiderwebs from MIT's Laboratory for Atomistic and Molecular Mechanics, Su, Buehler, and Ziporyn sonified the threads of a spiderweb and produced an interactive instrument that echoes the parallels of music and materials science. *Spider's Canvas* was installed in the Immersion Lab for viewing for most of the spring 2019 semester, with live performances held during significant MIT.nano events.

SENSE.nano

The first Center of Excellence powered by MIT.nano, SENSE.nano, hosts an annual symposium followed by an external advisory board meeting. The technology space for SENSE.nano includes sensors, new instrumentation, remote sensing, and other measurements solutions. The full-day symposium convenes technical, business, and visionary leaders from MIT, industry, and society, and encompasses invited technical talks, presentations by MIT-launched startups, student-presented posters, and a panel discussion. Co-hosted by MIT's Environmental Solutions Initiative, the Abdul Latif Jameel World Water and Food Security Lab, and MIT.nano, the 2018 SENSE.nano symposium was focused on water, environment, and agriculture systems. The 2019 SENSE.nano symposium, scheduled for September 30, 2019, will provide needs, context, and solution perspectives in the domains of sensing for enhanced realities and advanced manufacturing.

Seminar Series

The MIT.nano Nanotechnology Seminar Series, organized by Professor Farnaz Niroui, was established to offer monthly technology talks from researchers across the spectrum of nanoscience and nanoengineering, starting in fall 2019. To lay the foundation for this series, Niroui organized an introductory set of lectures by experts who have played germinal roles in the progress of our understanding of the nanoscale in each of the key areas over the past decades. Entitled Perspectives in Nanotechnology, the spring 2019 lectures offered insight into current research and future directions by the experts based on their experiences in the field. Speakers included Roger Howe, Stanford University (March 2019); Paul Alivisatos, University of California at Berkeley (April 2019); Eli Yablonovitch, University of California at Berkeley (May 2019); and Robert Langer, MIT (June 2019). The pinnacle of the seminar series will be the annual Mildred S. Dresselhaus Lecture to be held each November honoring the contributions and legacy of one of MIT's most cherished professors.

Tool Talks

MIT.nano Tool Talks are designed to introduce the latest transformative technologies, tools, methods, and even new sciences that are emerging from research innovations. The Tool Talks are technical presentations sponsored by individual tool suppliers, geared toward the entire MIT community but applicable to a generalized scientific audience for broadest impact and to provide educational value for all levels of students, postdocs, staff, faculty, and collaborators. Held approximately once a month, the Tool Talks are flexible in format to enable more learning and cross-pollination through the technical and scientific knowledge-based seminars, as well as discussions, demos, or both. Some of the AY2019 presenters have come from Leika, Refeyn, Tescan, and FEI Thermo Fisher Scientific.

Community Engagements

MIT.nano's design includes features aimed at fostering community connections and supporting campus and public events. Over the last year, numerous collaborative events have been held in the facility, the abutting courtyard, or both. A few of note:

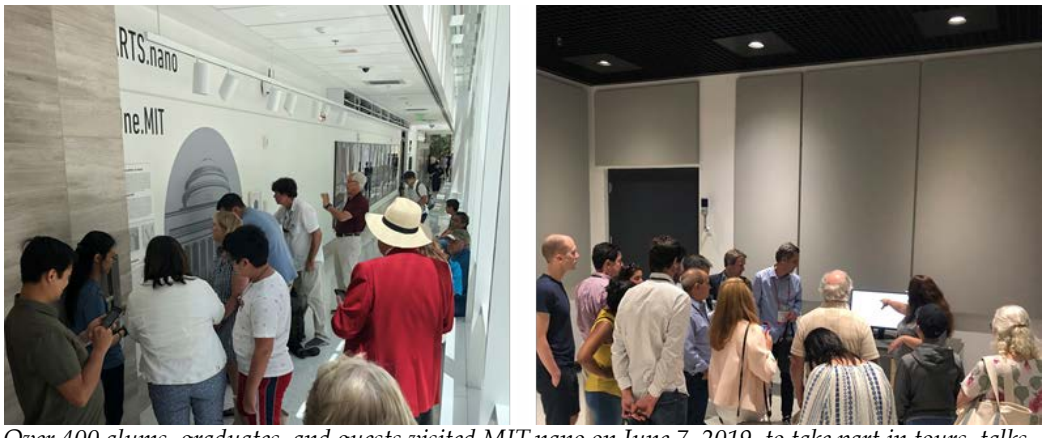
Cambridge Science Festival

MIT.nano welcomed over 500 visitors on the afternoon of April 16, 2019, as part of the Cambridge Science Festival celebration, a 10-day event that offers a variety of activities for children of all ages to help illuminate the richness of scientific inquiry and the excitement of discovery. MIT.nano provided tours, demos, and hands-on activities; a presentation on nanotechnology by Professor Niroui; and access to the MIT.nano galleries and Immersion Lab exhibits.

Visitors to MIT.nano are numerous and plenty curious, and MIT.nano staff are always happy to share with them the wonders of this new research space. These photos captured the April 2019 MIT.nano open house, which was held in celebration of the Cambridge Science Festival. MIT.nano staff provided demos, tours, talks, and behind-the-scenes glimpses of the facility. A highlight was the opportunity for visitors to dress in bunny suits, simulating what researchers would do when working in the MIT.nano cleanrooms.

Alumni Open House

As part of the Alumni Association's annual Tech Reunions Explore MIT Today events, MIT.nano opened its doors on June 7, 2019, to over 400 alumni and their families for an afternoon full of tours and technical exhibitions.



Over 400 alums, graduates, and guests visited MIT.nano on June 7, 2019, to take part in tours, talks, and demonstrations.

Facility Tours

Over the last 12 months, MIT.nano has hosted hundreds of personal tours of the facility. Guests have included MIT students, faculty, and staff; industry titans; foreign dignitaries; and researchers from institutions from around the globe. From a NATO general, to MIT researchers, actor Jaden Smith, and potential donors, to the Sacramento Kings basketball team, each tour is unique and always engaging, delivered by MIT.nano staff, faculty, or a cohort of engaged students.

MIT Collaborations

MIT.nano serves as a resource to the members of the MIT community, providing support and working collaboratively to advance their research objectives. Some of the interdisciplinary engagements in the last year include the following:

- MIT.nano and the MIT Industry Liaison Program (ILP) have partnered to expand the MIT.nano consortium. Through their extensive relationships with industry, ILP is perfectly positioned to connect us to new member prospects.
- Working with MIT Hacking Medicine, a series of hacking nanomedicine workshops was developed. The MIT Nanomedicine Hack 2019 series is a collaboration of IMES, the Marble Center, MIT Hacking Medicine, and MIT.nano.
- The Cambridge Science Festival engagement included the MIT Museum, Office of the Vice President for Research, Environmental Solutions Initiative, Society for Women Engineers, Department of Chemistry, and individual students from various departments, labs, and centers.
- MIT Center for Art, Science & Technology is collaborating on ARTS.nano—developing a structure for a cooperative relationship using the MIT.nano galleries and tool sets as a platform for visiting artists, and planning a joint fundraising activity.
- A new class on environment and engineering and underwater sensors was formed (led by MIT.nano associate director Brian Anthony).
- QI Hardware—Tool Suite (physical backbone of AI supporting the digital overlay of AI)
- MIT chairman of the board Robert Millard provided guidance and support for the Micromosaics exhibit in the MIT.nano upper gallery.

Awards

Samantha Farrell, assistant to the MIT.nano director, received the Infinite Mile Award.

Architectural awards

MIT.nano and the adjoining North Corridor have being recognized with multiple design awards, including the National Recognition Award for exemplary engineering achievement in the American Council of Engineering Companies (May 2019); the American Institute of Architects 2019 Education Facility Design Award of Merit (April

2019); and the 2019 Lab of the Year (May 2019), the 53rd annual Lab of the Year Awards are a joint program of *R&D World*, *Laboratory Design*, and *Laboratory Equipment*, all are publications of Advantage Business Marketing.

Personnel

- Bob Atkins of MIT Lincoln Laboratory joined the MIT.nano Leadership Council.
- Tom Gearty was hired as communications director.
- Anna Osherov was hired as assistant director of User Services, Metrology.
- Jorg Scholvin was hired as assistant director of User Services, FAB.nano.
- Shereece Beckford was hired as administrative assistant II.
- Whitney Hess was promoted from EHS coordinator to MIT.nano manager of Safety Systems and Programs.

Concluding Remarks

The world needs MIT's insights and ingenuity more than ever—and, increasingly, these strengths intersect at the nanoscale. MIT.nano will be at the forefront of the nano revolution, accelerating the pace of research at the Institute, supporting vital research thrusts for decades to come, and helping to define the future of innovation.

Vladimir Bulović
MIT.nano Founding Director
Fariborz Maseeh (1990) Professor in Emerging Technology