MIT.nano

MIT.nano's mission is to build a better world by fostering education, innovation, and research on nanoscale phenomena, materials, devices, and systems.

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

MIT.nano is a shared resource for the entire MIT campus. Located in the heart of MIT's Cambridge campus, we are an open-access, service-oriented facility. Any faculty member, researcher, student, or qualified partner may bring a project or unsolved problem to our specialized environments and conduct their work supported by highly qualified technical staff.

Our primary user community is MIT researchers. Individuals from other academic institutions, industry collaborators, MIT.nano consortium member companies, and other external organizations are also welcome. Every step of the way, our staff is here to enable researchers and educators to get their work done with as few barriers to progress as possible.

Sharing resources through MIT.nano enables the MIT community to acquire the state-of-the-art equipment that would be challenging for individual labs or departments to afford or maintain on their own. The ample size of our research facility also allows us to look beyond the present state-of-the-art by seeding dedicated lab spaces where new nanoscience and nanotechnology tools, instruments, processes, and techniques can be reinvented.

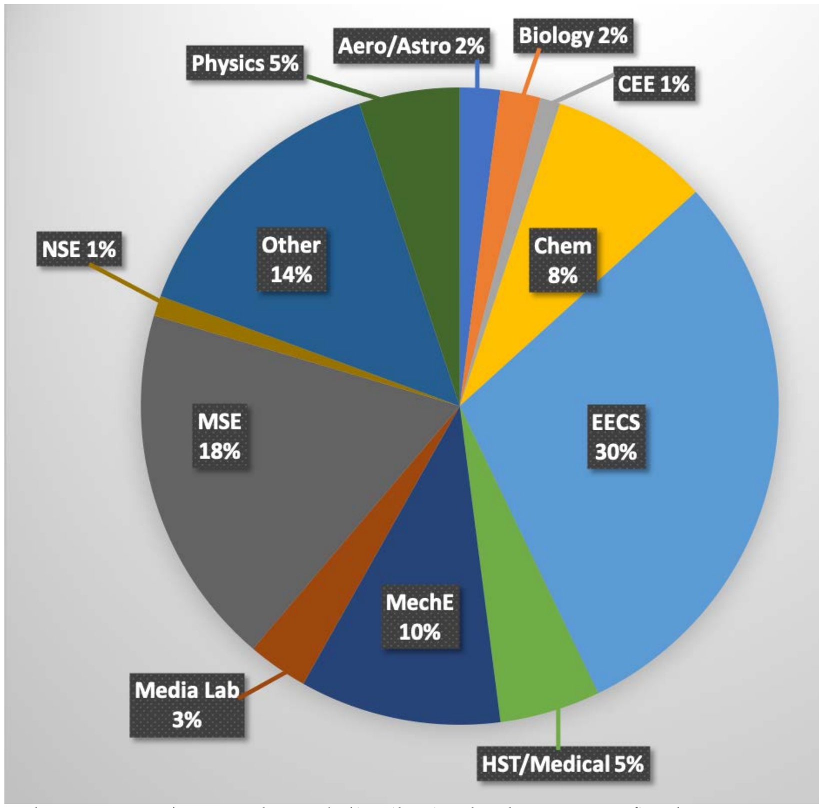
The operation of MIT.nano was impacted by the COVID-19 pandemic. The facility was shut down from mid-March to mid-June 2020, but the technical team efficiently and rapidly developed policies and processes for safely reopening and managing the facility under the new COVID-19 pandemic mandated restrictions. At the end of June, researchers were welcomed back to MIT.nano and trainings resumed with modified virtual formats and small in-person groups to accommodate physical distancing and COVID-19 pandemic protocols. During fiscal year 2021 (FY2021), MIT.nano has supported:

- Departments, labs, and centers: 37
- Faculty research groups: 127
- Researchers: 431—accessing more than 140 tools for more than 20,000 tool uses

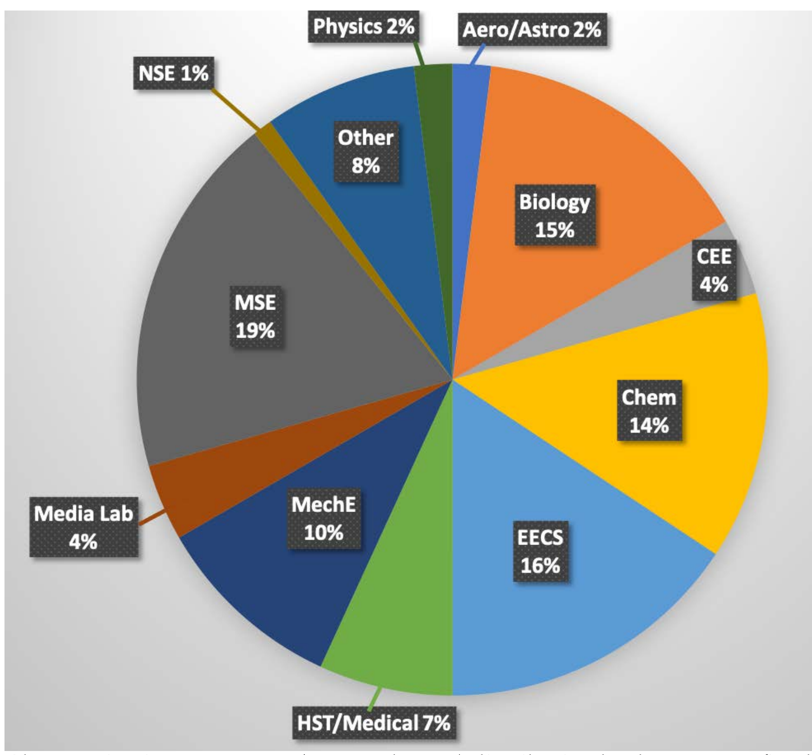
With its central location and with the breadth of curated instruments, MIT.nano is continuing to be a natural convening place for interdisciplinary research.

Supporting Intellectual Communities and Education

There were 310 Fab.nano users and 167 Characterization.nano users for a total of 431 users in FY2021.



Fab.nano users (310 total users) distribution by department, fiscal year 2021.



Characterization.nano users (167 total users) distribution by department, fiscal year 2021.

MIT.nano activities are designed to support intellectual communities and education activities:

Key Activities

- Core: Provide user access to a curated set of shared tools and instruments
- New Equipment: Bring in new tools and instruments
- User Subsidy: Bring in funds to subsidize use of tools and instruments

Other Activities

- Bring in funds to support starting faculty, new users, undergrad users
- Bring in funds for programs that need MIT.nano tools and instruments
- Use MIT.nano as a leverage to bring other programs to MIT
- Develop and support new intellectual communities
- Support new education activities that utilize MIT.nano facilities
- Develop cross-cutting education and outreach programs
- Serve as a repository and convener of technology-futures studies
- Serve as a bridge between academia, industry, and national labs
- Support regional startup activity

Laboratory Spaces

MIT.nano provides high-performance, state-of-the-art research space equipped with an extensive assembly of toolsets and instruments.

Cleanroom Complex

The cleanroom complex, spanning the first and third floor of the facility, encompasses over 40,000 square feet of Class 100/1,000/10,000 cleanroom space for controlled processing of nanoscale structures. Inside the cleanrooms, one will find toolsets for the design and fabrication of micro- and nano-scale structures including synthesis, imaging and microscopy, materials and thin film growth. The cleanrooms are optimized for energy efficiency, airflow, and future flexibility.

Tang Family Imaging and Characterization Suites

Housed in the basement of MIT.nano—the so-called quietest place in the building and perhaps all of New England—are 11,000 square feet designated for metrology and characterization research including 12 highly sophisticated suites for nanoscale observation with low vibration and minimal electromagnetic interference.

Tecnológico de Monterrey Prototyping Suites

Located on the fifth floor of MIT.nano, these suites are a unique set of interconnecting labs—the first of its kind at MIT—with capabilities for fabrication, prototyping, and packaging. The Prototyping Suites currently house the Lab for Education and Application Prototypes (LEAP) which includes a collection of electrical and optical packaging and interconnect tools.

Immersion Lab

The Immersion Lab is a two-story black-box theater, a state-of-the-art immersive environment for visualizing advanced technology concepts, to connect the physical to the digital. The lab provides a space for motion tracking, visualization, augmented reality, and virtual reality, along with the activities supporting those fields.

Advancements and Milestones

Throughout the FY2021, the MIT.nano team continued to develop facilities in Building 12 and maintain the facilities in Buildings 39 and 24 to support nanoscale researchers from departments, labs, and centers (DLCs) across the campus. Progress included the installation of additional new tools in Building 12, relocation of the majority of tools from Building 39 into Building 12 and the structuring of systems for user services; updating 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 are described below.

MIT.nano Focus Facilities

The 100,000 square feet of cleanroom and laboratory spaces in MIT.nano accommodate a variety of technical thrusts, each supported by one or more MIT.nano Focus Facilities. Nearly all focus facilities house shared tools and instruments, and we refer to these as the Shared Experimental Facilities (SEFs). A few focus facilities house privately managed tools and instruments which are stewarded by an MIT faculty on behalf of MIT.nano.

The present MIT.nano focus facilities are listed below:

- Aberration Corrected Scanning Transmission Electron Microscope (STEM) SEF—ultra-high-resolution scanning transmission electron microscope. Funding for this toolset originated from the Department of Materials Science and Engineering (DMSE) faculty, with installation costs provided by MIT.nano.
- Characterization.nano SEF—consists of general metrology and characterization tools in the basement of MIT.nano. Funding for these toolsets is brought in by MIT.nano.
- Cryo-Electron Microscope (EM) SEF—for atomic-scale investigation of complex nanostructures, with particular focus on bio-material studies. Funding for this toolset originated from the Biology Department faculty, with installation costs provided by MIT.nano. Biology Department also provides funds that support salaries of the technical staff that run the facility.

- Immersion Lab SEF—consists of tools for visualizing large data sets through the use of augmented reality (AR) and virtual reality (VR) environments and new computational toolsets. Funding for this toolsets and the technical staff that operate the facility originated from the NCSOFT-sponsored grant program brought in by MIT.nano.

- Integrated Circuits Laboratory (ICL), Technology Research Laboratory (TRL), and Electron Beam Lithography Laboratory (EBL) SEFs—these legacy SEFs located in Buildings 39 and 24, accommodate hundreds of users, and are sunsetting their operation. ICL, TRL, and EBL legacy toolsets have been obtained by Microsystems Technology Laboratories (MTL) and Research Laboratory of Electronics over the course of their operation of more than 30 years. Many of the ICL and TRL tools are being relocated to the Building 12 Fab.nano shared fabrication facility over the course of the next year. Tools in EBL will remain in Building 24.

- LEAP SEF—consists of a collection of electrical and optical packaging and interconnect tools. Funding for this toolset originated from the AMP Photonics Center, with installation costs provided by MIT.nano. Technical support for the facility operation is in part provided by AMP Photonics staff.

- Microfluidic Assembly and Testing SEF—This toolset was developed by MIT.nano in response to user demand and academic class needs.

- Nano-Materials SEF—relocated from the Materials Research Laboratory (MRL) in Building 13 and enhanced with new toolsets for large-area coating deposition, and solar technology development and testing. Majority of the funding for this toolset originated from the MIT Energy Initiative Solar Frontiers Center, with installation costs provided by MIT.nano.

- Thin-film Processing SEF—The Exploratory Materials Lab (EML), formerly located in the MTL on the 5th floor of Building 39, has been relocated and integrated into the Fab.nano toolset in Building 12 of MIT.nano. The lab provides thin-film processing and lithography for a wide range of materials.

- Focus Facilities with Private Tools are limited spaces within MIT.nano that are stewarded by MIT faculty on behalf of MIT.nano and contain privately managed tools and instruments. The Equipment Support Program (ESP) defines the responsibilities of the faculty steward and defines the costs incurred by MIT.nano in support of these stewarded spaces. Prior to awarding an ESP, MIT.nano discusses the space needs with the Committee for Renovation and Space Planning (CRSP). The stewarding responsibilities for each space are further described in the memorandum of understanding between MIT.nano and the steward, which would include information such as:

    - The initial agreement on stewarded space use for private tools will be at most seven years in duration but could be extended with a follow-on agreement.

    - MIT.nano will be compensated to offset incurred costs for installation and maintenance of private tools.

- In addition, MIT.nano digital gallery and physical exhibit spaces, the contents of which we hope will broadly represent activities of the MIT research community. Galleries and exhibit spaces are curated by MIT.nano and have engaged scholars and researchers from the Schools of Architecture and Planning, Engineering, Science, and Humanities, Arts, and Social Sciences.

Access to Off-Campus Partner Facilities Through MIT.nano

MIT.nano's close connection to MIT Lincoln Laboratory allowed us to develop a program that provides access to MIT Lincoln Laboratory's 200mm Prototyping Facility, known as the Microelectronics Laboratory (ML). ML is equipped with commercial-class cassette-to-cassette fabrication equipment and is professionally staffed 24 hours a day and five days a week. It can be utilized as a work-for-hire 90 nm-class facility, resulting in high yield processing of complex 200mm structures. ML operates full-flow fabrication across a broad range of integrated circuit technologies, including Fully Depleted Silicon On Insulator, complementary metal-oxide semiconductor (CMOS), charge-coupled device (CCD) imagers, superconducting electronics, photonics, micro-electromechanical systems (MEMs), and microfluidics. Through MIT.nano as an intermediary our users can receive access to ML capabilities, augmenting the present MIT.nano processing capabilities.

User Services

MIT.nano offers a new user training program comprised of Fab.nano Orientation, Emergency Preparedness, and a hands-on Quick Start class for familiarization with fabrication processes. From July 2020 to June 2021, 346 new MIT.nano users from 32 DLCs were trained across more than 100 training sessions which included:

- MIT.nano Emergency Preparedness (Zoom class): 27 offerings
- Fab.nano Orientation (Zoom class): 27 offerings
- Fab.nano Quick Start for new users (in-person class): 38 offerings
- Fab.nano Wet Chemical Processing (Zoom class): 22 offerings

Additional Zoom and in-person training sessions were delivered for each of the more than 140 tools that are presently in MIT.nano.

Trained users have access to the cleanroom complex and the prototyping and packaging facility.

MIT's trained users come from 37 DLCs: Departments of Aeronautics and Astronautics; Architecture; Biology; Brain and Cognitive Sciences; Biological Engineering (BE); Chemistry; Chemical Engineering (ChemE); Civil and Environmental Engineering; Comparative Media Studies/Writing;; Earth, Atmospheric, and Planetary Sciences; DMSE; Electrical Engineering and Computer Science (EECS); Mechanical Engineering (MechE); Nuclear Science and Engineering; Physics; Urban Studies and Planning; Center for Global Change Science; Computational and Systems Biology: Computer Science and Artificial Intelligence Laboratory; Harvard-MIT Program in Health Sciences and Technology; Institute for Data, Systems, and Society; Institute for Soldier

Nanotechnologies; Kavli Institute for Astrophysics and Space Research; The Koch Institute for Integrative Cancer Research; The McGovern Institute for Brain Research; MIT Environmental Solutions Initiative; MIT Media Lab; MIT Sea Grant College Program; MRL; MTL; Plasma Science and Fusion Center; Quantum Engineering; Quantum Photonics Laboratory; RLE; System Design and Management Program; Lincoln Laboratory (LL).

During FY2021, a total of 42 users came from 20 external companies, universities, and organizations.

Classes in MIT.nano

MIT.nano hosts a number of classes through the academic year and contributes many hours of pro-bono staff time to support the MIT community. For example, from February to May, MIT.nano staff provided 290 hours—an average of 16 hours per week—of class instruction time at no additional charge to the community.

Students in the spring 2021 undergraduate class, 3.155J/6.152J Micro/Nano Processing Technology.

Classes included:

- 3.155J/6.152J Micro/Nano Processing Technology—students used MIT.nano to fabricate and test silicon solar cells; build and test microfluidic devices in the soft-lithography cleanroom space on the third floor; used corrosive wet-benches on the first floor of the cleanroom to etch cantilever beams; and employed the LEAP facility on the fifth floor for electrical and photonic packaging.
- 3.001 Introduction to Materials Science and Engineering
- 20.051 Introduction to NEET: Living Machines—The New Engineering Education Transformation (NEET) Living Machines thread used the soft lithography room and the MLA-150 tool for creating microfluidic channels.

Independent Activities Period

The Independent Activities Period (IAP) provides members of the MIT community—students, faculty, staff, and alums—with a unique opportunity to organize, sponsor, and participate in a wide variety of activities, including how-to sessions, forums, athletic endeavors, lecture series, films, tours, recitals, and contests. In response to the pandemic, MIT.nano offered five virtual IAP courses this January:

Explore MIT.nano Live

Explore MIT.nano with live Zoom tours—a three-part series took attendees behind the scenes of the fabrication, characterization, and supporting infrastructure of MIT.nano. Topics included: What it takes to build and see on the atomic scale; How to create a dust-free environment, and why people in Building 12 fabrication facilities wear "bunny suits"; How 5 million pounds of concrete help us look at atoms; What a 1.5-Megawatt backup generator looks like; and What it takes to filter and air condition 250,000 cubic feet of fresh air every minute. The technical team walked through the space live with a camera, ran small demos, and gave everyone the chance to ask questions as they went along.

Hands-on Fabrication on Zoom

Attendees learned about micro-fabrication techniques and joined a live fabrication demo via Zoom inside the MIT.nano cleanrooms. Instruction included: thin-film deposition; lithography and etching processes at the micro- and nano-scale; and how to combine these techniques to build a semiconductor device, such as you might find in your computers or phones.

Biomechanics in Everyday Life

In this course, participants saw how motion capture, photogrammetry, electromyography, and VR can be applied to understand more deeply how we achieve seemingly intuitive and easy tasks, and how these tools can be used in research, education, art, and athletic improvement.

nanoStories: Workshop on Science Communication at the Nanoscale

Guided by instructors and invited guest speakers, students explored a new topic in each two-hour class, jointly developing an instructional narrative told in text, video, and/or interactive multimedia.

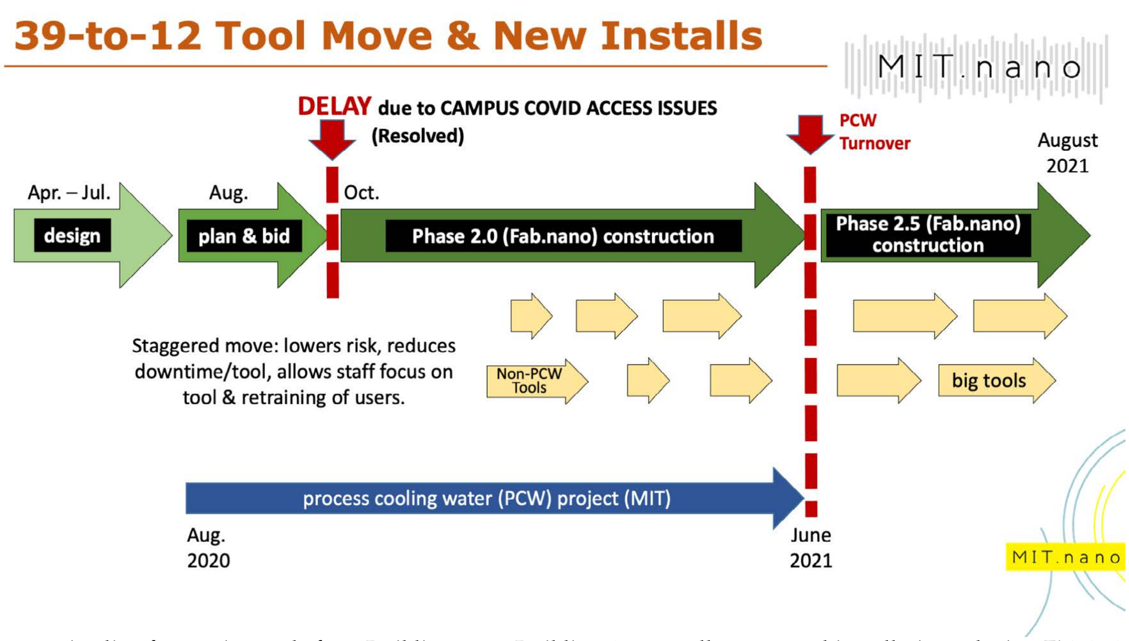
Creating, Editing, and Distributing 360 Photography

This class provided a thorough introduction to the art and technology behind 360-degree immersive photography and how to integrate photographic and graphically produced content into finished VR applications and experiences.

Tool Installations

This year we continued to follow our established multi-step process for the procurement and installation of tools in MIT.nano. Our methodology defines the critical checkpoints, operational modes, schedule and estimated costs required to operate and install equipment in MIT.nano. To enable financial benefits from the economy of scale and to leverage professional resources, we aggregate groups of tools into "Phases."

During FY2021, the MIT.nano technical team continued to focus on the completion of the Phase 2 of tool installation and facilitation process, as they also ramped up preparations for Phase 3 and beyond. MIT.nano and an outside engineering firm were able to work through the COVID-19 pandemic induced shutdown and maintain their schedule, initiating weekly design review meetings and leveraging the on-site critical walkthroughs of Fab.nano staff to collect as-built tool-specific information.



Phase 2 timeline for moving tools from Building 39 to Building 12, as well as new tool installations, during FY2021.

The following is a list of tools that were moved and installed into MIT.nano in FY2021.

- AFM-Veeco, Atomic force microscope for surface analysis
- Acid-Etch-Tank-L06, General purpose acid hood
- AFM-Asylum-JupiterXR, Atomic force microscope for surface analysis
- ALD-Ozone, Atomic layer deposition
- Asher-Barrel-Thierry, Plasma photoresist stripper
- CoatDevelop-picoTrack, Wafer coat and develop track
- CypherVRS_AFM, Atomic force microscope for surface analysis

- Develop-Brewer-200CBX, Spin developer and wafer hotplate
- Develop-L08, Developing hood
- DirectWrite-MLA150-AirAF, Direct write exposure system
- DirectWrite-MLA150-OptAF, Direct write exposure system
- DirectWrite-Nanoscribe-GT2, Nanoscribe 2-photon 3D lithography exposure tool
- Ebeam-Temescal-LL, Metal deposition, ebeam
- Ellipsometer-Semilab-SE2000, Spectroscopic ellipsometer
- Filmstress-Tencor-FLX, Non-contact profilometer, laser, measures wafer bow
- FloodExpose-OAI, Flood exposure tool
- Gemini_450_SEM, Scanning electron microscope
- HMDS-YES-U10, Vapor prime oven
- Liftoff-L08, General purpose solvent hood
- Liftoff-L10, General purpose solvent hood
- MaskAlign-EV620, Mask aligner and exposure
- Ops-Atlas-U07, Atlas burn-wet abatement
- Ops-BottleWasherLower, Chemical bottle washer
- Ops-DryBed-U05, Dry bed scrubber
- Ops-Housekeeping-Vac, Housekeeping vacuum skid
- Oven-EnvironmentalTest-ESPEC, Environmental test chamber
- OxideEtch-HF-BOE-L06, Wet bench for silicon dioxide etching
- RCA-Diffusion-L02, Wet bench for wafer cleaning
- RIE-2Chamber-AMAT-P5000, Plasma etcher: silicon and dielectrics
- RIE-Mixed-Samco-230iP, Mixed gas etching
- RTA-1100C-ASMicro, Rapid thermal annealing, small samples
- RTA-1100C-ASO150, Rapid thermal annealing
- RTA-1300C -ASOne150-5Gas, Rapid thermal annealing
- RTA-1300C-ASOne150, Rapid thermal annealing
- SEM-Zeiss-Sigma300, Scanning electron microscope
- SiliconEtch-KOH-TMAH-L06, Wet bench for silicon etching

- Solvent-L06, General purpose solvent hood
- Spinner-PMGI-U12, Spinner for PMGI polymer
- Spinner-Polymer, General purpose spin coater
- Spinner-Resist-L10, General purpose spin coater
- Sputter-AJA-LL, Metal deposition, sputterer
- Sputter-Balzer-Au, Gold sputterer for SEM prep
- Sputter-Lesker-LL, Metal deposition, sputterer
- Tencor-P10, Stylus profilometer
- ThermalEvap-Parylene, Parylene deposition
- VaporEtch-XeF2, XeF2 vapor system
- Veeco-Wyko-NT9800, Non-contact profilometer, white light
- Velion_FIB_SEM, Focused Ion Beam
- WaferBonderAlign-EV620, Bond aligner
- WaferBonder-EV501, Wafer fonder: fusion, anodic, thermo-compression

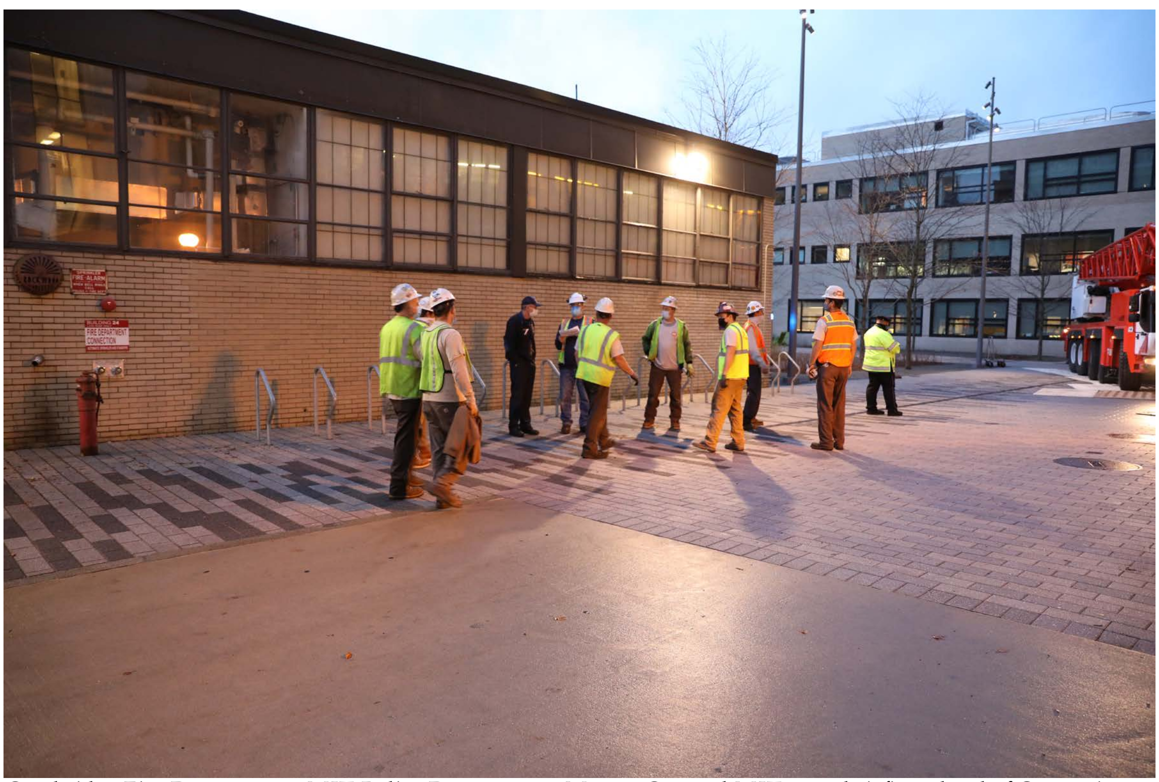
The following is a list of tools that were moved into MIT.nano in FY2021 and are currently being installed and/or qualified for use.

- Asher-Chuck-ESI, Automated plasma asher
- Dektak-XT, Stylus profilometer
- DRIE-SPTS-Pegasus, Silicon deep trench etcher
- DRIE-STS-MMPLEX, Silicon deep trench etcher
- Filmetrics-F20-Lower, Thin film measurement system
- PECVD-STS-MMPLEX, Plasma enhanced deposition
- Probestation-IV, Electric probe station, measures IV characteristics
- RIE-Cl2-SAMCO-200iP, Chlorine etching

Building 38 Bulk Tank Farm Upgrade

Nitrogen and oxygen are the lifeblood of the laboratory. This MIT.nano-led project replaced unreliable equipment and upgraded the vaporization and storage capacity of the tank farm as required to support increased utilization of MIT.nano. Both systems are pressurized, tested and operational as of December 11. This was an exceptional feat of planning and multi-group coordination by the MIT.nano technical team.

4:00 am start time protecting cobblestones.



Cambridge Fire Department, MIT Police Department, Messer Gas and MIT.nano briefing ahead of O_2 venting.

Controlled O_2 depressurization before tank removal.

240-ton lead crane and 175-ton helper crane.

Replacing O_2 tank.

Added 13,000-gallon N_2 tank and upgraded vaporizer.

Greenhouse Gas Reduction and Process Gas Abatement

MIT.nano technical team has installed process gas abatement systems, designed to reduce greenhouse gas emissions of the facility. The projected outcome of abatement, based on MTL gas utilization, is an estimated reduction of CO_2 emissions from 908 to 122 metric tons with use of Point-of-Use (POU) abatement (87% reduction) for all known tools. Additional benefit is obtained from increased utilization and abatement of other hazardous process gases and by-products. Abatement process results in increased NO_x, SO_x, and CO emissions. The equipment was obtained with MIT.nano Member Advisory Panel (MAP) in-kind dollars. Greenhouse gas abatement is unique for a university facility, and this is the first on the MIT Campus.

Operational Model and Financial Sustainability

Diversity, Equity, and Inclusion Initiative

MIT.nano aims to provide a welcoming, safe, and enriching environment for all, creating a workplace in which everyone can do their best and thrive. We are committed to understanding and addressing diversity, equity, and inclusion (DEI) issues in our community. The MIT.nano DEI Committee was formed in the spring of 2021 to help increase equity, provide growth opportunities, and foster belonging among the members of our community. Some of actions that have been initiated:

- Training for managers and interviewers and committee members on bias-free hiring
- Broad outreach to widen the diversity of our resume pool for upcoming hires
- Consideration for diversifying our guest speakers (e.g., seminars, trainings)
- One-on-one meetings for staff to talk with DEI Committee members to provide confidential feedback, suggestions, and/or express concerns
- Engaging with other DEI groups at MIT, such as the Institute Community and Equity Office, for guidance and resources
- Kedrick Perry, Vice President for Equity and Inclusion at Loyola University New Orleans, joined a DEI Committee meeting to share lessons learned and best practices

Financial Support

MIT.nano operations is financially supported by user fees, together with MIT.nano Consortium membership dues, MIT nonrecurring support, donations, and funding dedicated for support of MIT.nano programs. During the last year, MIT.nano received support from the Lord Foundation, NCSOFT Gaming Program, and Monterrey Tec program.

MIT.nano Leadership Council

The MIT.nano Leadership Council oversees the operation of the facility. The Council met once a month during FY2021. Council members include the following individuals:

- Brian Anthony, MIT.nano, MechE, Institute for Medical Engineering and Science (IMES)
- Robert Atkins, Lincoln Laboratory
- Karl Berggren, NanoStructures Laboratory, EECS
- Kathy Boisvert, MIT.nano
- Vladimir Bulović, MIT.nano
- Dennis Grimard, MIT.nano
- Pablo Jarillo-Herrero, Physics
- James LeBeau, DMSE
- Hae-Seung Lee, MTL, EECS
- Will Oliver, RLE, EECS
- Tomás Palacios, EECS
- Katharina Ribbeck, BE
- Frances Ross, DMSE
- Thomas Schwartz, Biology
- Carl Thompson, MRL, DMSE

MIT.nano Faculty Advocates Working Groups

These two working groups give guidance on, and promote the need for, the next toolsets to be introduced in Fab.nano and Characterization.nano and to help identify ways to secure funding for these tools and instruments. The working groups commenced their meetings in July, with the faculty leads of the two working groups joining MIT.nano Leadership Council.

- The Fab.nano Working Group is steered by Tomás Palacios, professor of Electrical Engineering, as the faculty lead, along with two technical leads: Jorg Scholvin, MIT.nano assistant director of User Services for Fabrication, and Vicky Diadiuk, MTL associate director of Operations,
- The Characterization.nano Working Group is steered by James LeBeau, associate professor of DMSE, as the faculty lead and Anna Osherov, MIT.nano assistant director of User Services for Characterization.

MIT.nano Internal Advisory Board

The internal advisory board (IAB) is an advisory group with membership comprised of intellectual leaders of the MIT community reflecting the Institute-wide perspective on the utility of MIT.nano. The IAB meets annually (the most recent meeting was in

February), and provides strategic advice to the MIT.nano faculty director as well as to the Office of the Vice President for Research on the tactical issues related to MIT.nano.

Current IAB members are:

- Marc Baldo—director, RLE; EECS
- Anantha Chandrakasan—dean, School of Engineering; EECS
- John Deutch—former MIT provost, Chemistry
- Elazer Edelman—director, IMES
- Jeff Grossman—department head, DMSE
- Paula T. Hammond—department head, ChemE
- Susan Hockfield—president emerita, Neuroscience
- Craig Keast—MIT Lincoln Laboratory
- Chris Schuh—DMSE
- Nergis Mavalvala—dean, School of Science; Physics
- Krystyn Van Vliet—associate provost, DMSE
- Evelyn Wang—department head, MechE

MIT.nano Consortium

As of June 30, MIT.nano Consortium consists of 11 Member Companies. Drawn from different industries and operating around the globe, the members of the MIT.nano Consortium share our belief that advancements in nanoscience and nanotechnology have brought humanity to the dawn of the Nano Age, an exciting new era for discovery, invention, and progress. The MIT.nano Consortium is rooted in MIT's deep commitment to bring our discoveries to the marketplace—pushing knowledge and technology far beyond the boundaries of our campus to where they will have the most impact.

For MIT, our potential to build a better world is dramatically enhanced through external partnerships. The financial support of the MIT.nano Consortium funds our operations, purchases of equipment, and seeds relevant research directions. As important, our industrial colleagues also introduce us to practical problems blocking the path to a better world, and when we overcome the challenges, they help to deliver 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.

MIT.nano Consortium membership has fluctuated slightly during the last year. Occasional changes in membership are expected. During FY2021, we lost Waters Corp and Agilent Technologies; lost then recovered Draper Laboratory; and gained Oxford Instruments Asylum Research as a new member.

Current MIT.nano Consortium members include: Analog Devices Inc., Draper Laboratory, Koninklijke DSM N.V., Edwards Lifesciences, Fujikura Ltd., IBM Research, Lam Research Corporation, NCSOFT Corporation, NEC Corporation, Oxford Instruments Asylum Research, and Raith GmbH.

Programs and Initiatives

MIT.nano draws researchers, inventors, and educators from departments and disciplines across our campus. In conjunction with our technical facilities and research spaces, MIT.nano offers programs to convene this diverse community of interests, to spark interdisciplinary interactions and collaborations, and to bolster MIT's ability to advance knowledge and innovation in service to a better world. Below are several examples.

National Microelectronics Network

Our work on developing a national microelectronics network led to a persistent engagement of 11 MIT campus faculty and MIT Lincoln Laboratory research staff since January. In that time, we held over 100 meetings between us and with external colleagues with whom we are developing a strategy on what the nation needs to reassert US leadership in microelectronics technologies. The white papers we generated are being broadly shared in academic, industry, and government circles.

START.nano

This year, we launched START.nano, an incubator for hard-tech ventures offering access to MIT.nano's cleanrooms and other laboratories. Our initial cohort is comprised of seven new, innovative companies.

- Atantares Corp.: Transforming medicine with smart chips
- Lydian Labs: Electrifying the chemical industry
- NeuroNexus Technologies Inc.: Monitoring cardiac signals in patients undergoing heart surgery
- SiTration Inc.: Ultra-durable filtration membranes for energy-efficient industrial separations
- Cambridge Electronics Inc.: Power electronics reinvented
- Mesodyne: Converting fuel into electricity via light
- Phenomyx: Accelerate the development and testing of cell-based therapies

Each startup receives:

- Discounted external user rate in MIT.nano.
- Mentorship support in developing pitches and business plans, to prepare for additional fundraising, and to develop the leadership, managerial, and entrepreneurship skills of the founders.

Startups will exit the program with more well-developed prototypes, validated data, and other advantages to set them on the path to success—and position them for the next stage of funding.

NCSOFT Immersion Lab Gaming Program

The NCSOFT Immersion Lab Gaming Program is supported by a four-year, $5 million grant from MIT.nano Founding Member NCSOFT. The grant funds equipment that outfits the Immersion Lab SEF and provides for annual seed grants for hardware and software technologies related to Gaming in Research and Education, new Communication Paradigms, Human-level Inference, and Data Analysis and Visualization.

The following seven projects were awarded the 2020 seed grants totaling $750,000:

- Mohammad Alizadeh: A Neural-Enhanced Teleconferencing System
- Luca Daniel: Dance-inspired Models for Representing Intent
- Frédo Durand: Inverse Rendering for Photorealistic Computer Graphics and Digital Avatars
- Jeehwan Kim: Electronic Skin-based Long-term Imperceptible, and Controller-free AR/VR Motion Tracker
- Will Oliver: Qubit Arcade
- Jay Scheib: Augmenting Opera, Parsifal
- Justin Solomon: AI for Designing Usable Virtual Assets

IMMERSED Seminar Series

The IMMERSED Seminar Series explores how immersive technologies and new modalities for manipulating and understanding data are shaping innovations across science, engineering, and art. These events are shaped as a mixture of lectures, demonstrations, and tutorials.

Our inaugural event, IMMERSED IN: MIT.nano—An exploration of the Immersion Lab's capabilities, took place on March 31. More than 80 attendees saw examples of how the space and tools of the MIT.nano Immersion Lab are connecting scientists, technologists, and artists through creative interdisciplinary projects, and learned about opportunities to create with the Immersion Lab. Additional talks this spring included:

- IMMERSED IN: Athletics, April 28—Using scientific tools to visualize what we know about pitching in baseball, and learn what we don't—with Todd Carroll, MIT baseball coach
- IMMERSED IN: Photogrammetry, May 19—Mixing bullet-time and light-painting using 176 cameras—presented by Eric Paré, visual artist

- IMMERSED IN: Medicine, June 30—Performing and understanding electrocardiograms in VR—presented by Elazer R. Edelman, MD, PhD, Edward J. Poitras Professor in Medical Engineering and Science, professor of medicine at Harvard Medical School, and director of IMES, along with Austin Edelman and students Trevor Carter, Trent Piercy, and Bowen Wu.

Nano Explorations Webinars

MIT.nano launched the nano Explorations virtual seminar series on March 31 as a way of keeping our community connected during the COVID-19 pandemic, and these talks have continued throughout the last 15 months. The seminars are held twice a month featuring MIT students and postdoctoral researchers who work in nanoscience, nanotechnology, and other advanced research fields. With its growing popularity, attendance at a typical nano Explorations webcast ranges from 40 to 140 engaged MIT listeners, alums, and industry partners.

Nanotechnology Seminar Series

The MIT.nano Nanotechnology Seminar Series, organized by Farnaz Niroui, assistant professor of EECS, offers monthly technology talks from research luminaries working across the spectrum of nanoscience and nanoengineering. The pinnacle of the seminar series is the annual Mildred Dresselhaus Lecture held each November (beginning in November 2019) honoring the contributions and legacy of one of MIT's most cherished professors—the "Queen of Carbon," Institute Professor Mildred Dresselhaus (1930–2017).

Mildred Dresselhaus Lecture

On November 13, the 2020 Mildred Dresselhaus Lecture was delivered by Evelyn Hu, Tarr-Coyne Professor of Applied Physics and Electrical Engineering, Harvard University; Co-Director, Harvard Quantum Initiative. Hu's research matches nanofabrication techniques with the integration of materials that allow the formation of structures and devices that demonstrate exceptional electronic and photonic behavior. This behavior can give rise to efficient, controlled and often coherent output of devices. One example of this is the focus on coupling artificial atoms, such as quantum dots or color centers in diamond, to carefully crafted nanoscale optical cavities.

Evelyn Hu, Tarr-Coyne Professor of Applied Physics and Electrical Engineering, Harvard University

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 2020 SENSE.nano Symposium was held virtually over three days, September 21, 22, and 29. Co-sponsored by the MIT Industrial Liaison Program (ILP), the symposium highlighted sensing and sensors for the body at all scales.

- Unique attendees: more than 626
- Total registrations: 1,046
- Unique organizations or companies: 257 (of attendees who specified an affiliation)
    - Academic or research organization: ~18%
    - Industry: ~82%
- MIT.nano Consortium Companies: 9 (39 individuals)

SENSE.nano Seed Grants

Each year, SENSE.nano seeks proposals for seed grants related to sensing technologies. The response to the 2019 SENSE.nano call for proposals was overwhelming, yielding 38 submissions. Due to the pandemic, the 2020 SENSE.nano call for proposals was postponed until AY2022.

ARTS.nano

The central location of MIT.nano with the visual connectedness both inside and outside the building enables us to utilize MIT.nano's galleries and public spaces as exhibit venues. For this academic year, we created an updated version of the One.MIT project. Building on the impact of the One.MIT 2018 art piece, the One.MIT 2020 art piece celebrates the never-ending drive of MIT's remarkable community. A team of faculty, students, and staff created One.MIT 2020 by incorporating the names of over 316,000 people associated with the MIT community from 1861 to November 2020 to form a mosaic that resembles the shape of the MIT seal. The mosaic was etched onto a 6-inch silicon wafer using the toolsets of MIT.nano and will be displayed next to the 6-foot tall image of the mosaic. The wafer will be installed in MIT.nano's first-floor gallery, alongside the physical installation of One.MIT 2018 wafer. MIT Museum expressed interest in featuring the image of One.MIT wafer in its new exhibit space in Kendall Square.

One.MIT 2020 version

Tecnológico de Monterrey-MIT Nanotechnology Program

Tecnológico de Monterrey (Tec) is a private, nonprofit university in Mexico. The Tecnológico de Monterrey-MIT Nanotechnology Program supports extended stays of Tec students, postdoctoral researchers, and professors at MIT. Postdoctoral researchers and professors are typically embedded in an MIT research group, while students are typically taking a week-long course of hands-on nanotech labs offered by MTL and MIT.nano. Because travel to and from Mexico was prohibited due to the ongoing pandemic, the summer nanoLab program was modified to allow for virtual lectures. Luis Velasquez-Garcia taught six sessions, each one week in length, composed of four 90-minute lectures. 191 personnel—both students and faculty—from Monterrey Tec took the course, averaging 32 attendees per week.

MIT Professors Elsa Olivetti and Jose Pacheco are working with MIT.nano to develop a Three-Way Engagement Program to connect MIT, the Tec, and industry in Monterrey, Mexico, that is focused on advanced manufacturing. This collaboration benefits from Olivetti's connection to NEET as she leads the Advanced Materials Machines thread, and Pacheco's experience as the industry co-director of the Master of Engineering in Manufacturing Program that provides a robust educational curriculum with a project-based thesis experience in an industrial setting.

Tool Talks

Tool Talks series was launched in 2017 as a monthly event designed to introduce the latest transformative technologies, tools, methods, and new science understandings that are emerging from technical research innovations. The talks are technical presentations presented and sponsored by individual tool suppliers, sometime including tool demonstrations. Tool Talks are geared towards the entire MIT community, but applicable to a generalized scientific audience for broadest impact, and aimed to provide educational value for all levels of students, postdoctoral researchers, staff, faculty, and collaborators. MIT.nano continued to host the monthly in person Tool Talks up until the shutdown in March 2020. They are now held virtually, which supports an even larger audience.

Community Engagement

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 and external engagements in the last year include the following.

Facility Tours

Although tours were paused because of the pandemic, in a typical year MIT.nano hosts hundreds of personal tours. Guests have included MIT students, faculty and staff, industry titans, foreign dignitaries, and researchers from institutions around the globe. Each tour is unique and always engaging, delivered by MIT.nano staff or a cohort of trained student tour guides.

Microsystems Annual Research Conference 2021

Co-sponsored by MIT.nano and MTL, the Microsystems Annual Research Conference (MARC) is a yearly gathering of students, faculty, and industry partners designed to bring colleagues together to exchange ideas, get to know each other, and launch new collaborations. While typically held in person in Bretton Woods, NH, MARC was held virtually on January 26–27 using the Gather program for online events. This year's conference had a record-breaking attendance of 327 individuals; included 87 student abstracts from over 30 research groups; and hosted for students and industry partners a virtual networking lunch—traditionally a highlight for the in-person event—that saw 87 attendees from MIT.nano and MTL member companies. The keynote was provided by Irwin M. Jacobs ScD '59, founding chairman of Qualcomm.

Screenshot of four attendees using a video conferencing platform to participate in the Microsystems Annual Research Conference 2021, which was held virtually.

Other MIT Collaborations

- MIT.nano and MTL held on November 3, the annual recruiting event, Consortia Career Fair.
- MIT.nano and ILP continue to partner, working to expand the MIT.nano consortium.

Awards and Recognitions

Facility Awards

During the design and construction of MIT.nano, the project team identified primary drivers of energy consumption and adjusted them to optimize performance while minimizing energy use. The team incorporated over 60 energy conservation measures, including a heat recovery system and high-performance curtain wall, resulting in 51% energy cost savings and 50% greenhouse gas emissions reduction over industry standards. Since its opening in 2018, this exceptionally performing facility has been recognized with a series of awards and honors. Three more were awarded in FY2021.

In September, MIT.nano received the AIA New England 2020 Design Honor Award. The AIA annually recognizes individuals and organizations for their outstanding achievements in support of the profession of architecture and the AIA. MIT.nano was one of 10 to receive a 2020 Honor Award.

In January, MIT.nano received the Boston Society for Architecture (BSA) 2020 Honor Award for Design Excellence. Each year the BSA, often in collaboration with other organizations, sponsors awards programs to honor design excellence in Massachusetts, throughout New England and elsewhere. Design awards celebrate excellent architecture and reward clients for investing in it.

This spring, MIT.nano was awarded the American Institute of Architects (AIA) 2021 Committee on the Environment (COTE) Top Ten Award for excellence in sustainability and design. The annual award recognizes 10 projects, located anywhere in the world, that meet AIA's Framework for Design Excellence—10 principles aimed at creating a zero-carbon, equitable, resilient, and healthy built environment. Projects are evaluated on how well they are designed for integration, equitable communities, ecosystems, water, economy, energy, well-being, resources, change, and discovery. In each criterion, MIT.nano excelled.

Personnel Awards

The annual MIT Excellence Awards acknowledge the extraordinary efforts made by members of MIT toward fulfilling the goals, values, and mission of the Institute. These highly coveted awards honor the "best of the best." This spring, a team of five MIT.nano technical staff—Whitney Rochelle Hess, Nicholas Menounos, Anna Osherov, Kristofor Robert Payer, and Jorg Scholvin—was presented with the Excellence Award for Innovative Solutions, which recognizes those in the MIT community who collaborate creatively to solve problems, break down boundaries to drive change, and are steadfast in the face of challenges.

Goals for the Next Three Years

MIT.nano team is remarkable in every way, succeeding over the last three years to stand up a multifaceted facility that is supporting hundreds of users from every corner of MIT and beyond. There is, however, still a lot of work ahead of us. Our whole team and sub-teams meet regularly to consider priorities, determine how we can provide the greatest impact and service to the MIT community, and outline what steps need to be taken to reach our goals. Below is a current list of areas we are focusing on include the following.

- Consolidate shared lab operations into Building 12 by turning off Building 39 fabrication facilities and moving any additional existing shared toolsets, in coordination with other DLCs
- Install new tools and instruments in MIT.nano and grow the user base to greater than 1,000 users
- Complete the "value-engineered" building projects in MIT.nano
- Establish financial stability
    - Work with the MIT administration to establish a formal annual support for MIT.nano
    - Grow the MIT.nano industry consortium to provide additional financial resources
    - Work with other DLCs to identify and apply for research, education, and entrepreneurship grants
    - Seek philanthropic donations, fundraise for programs that can support the building operation, research, education, and technology translation
    - Start building an endowment or an "opportunity fund" allowing us to make quick decisions on new opportunities and/or to use it as backing for loans or unforeseen events
- Use the convening power of MIT.nano to initiate discussions and host educational activities that can broadly define the next horizons of science and technology, informing the public and spurring activity in our immediate community and in the research world at large

Concluding Remarks

In recent decades, humanity has gained the ability to see into the nanoscale with breathtaking precision. This insight has led to the development of tools and instruments that allow us to design and manipulate matter like nature does, atom by atom and molecule by molecule. MIT.nano has arrived on our campus at the dawn of the Nano Age. In the decades ahead, its open-access facilities for nanoscience and nanoengineering will equip our community with instruments and processes that can further harness the power of nanotechnology in service of humanity's greatest challenges.

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