NANOFAB.SDSU

INDUSTRIAL CONSORTIUM AND RESEARCH CENTER

WWW.NANOFAB.SDSU.EDU

Center Profile & Policy File

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Center Director

NanoFab.SDSU

A. Introduction, Vision and Goals

NanoFab.SDSU is micro and nanofabrication industrial consortium and research facility that operates and manages a brand-new 2500 square feet, ISO 9001-certified, Class 100/1000 cleanroom facilities in the EIS (Engineering and Interdisciplinary Sciences) building. The Center provides a comprehensive and expanding selection of state-of-the-art process equipment for lithography, wet and dry etching, thermal processing, CVD/PECVD, thin-film deposition, and characterization.

The principal and distinguishing focus area of **NanoFab.SDSU** is the micro and nanofabrication of carbon-based and hybrid carbon/silicon-based devices and device components, including those that incorporate organic and biological polymers. The Center has specialized tools and processes that support conventional silicon micromachining and specialized carbon-based microfabrication processes such as pyrolysis and electrospinning. The Center's unique strength in integrating polymers, carbon, and silicon-based micro and nanofabrication will allow the fabrication of new and innovative devices and systems such as inertial and biochemical sensors, energy conversion and storage (battery, photovoltaic and fuel-cell), microfluidics chips, as well as electrodes.

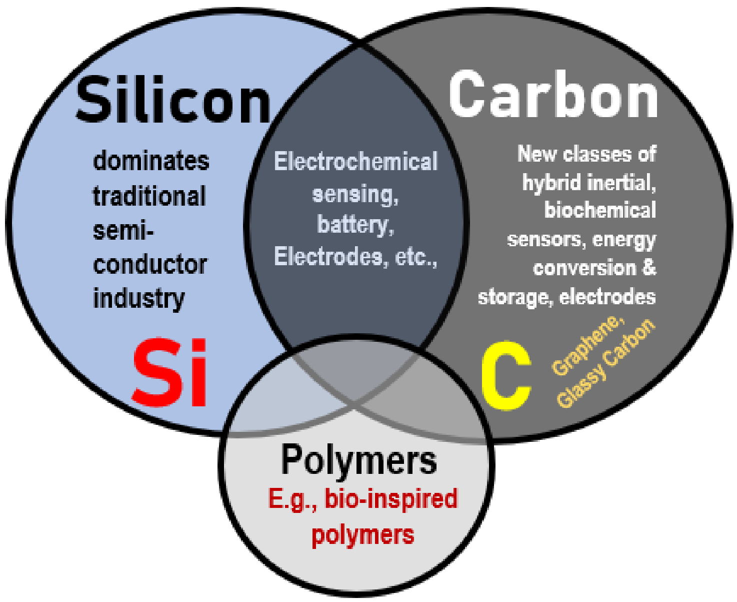


Figure 1. NanoFab.SDSU's unique material capabilities in Group IV elements.

The Center's vision is to become a leading national and international center of integrated silicon and polymer/carbon-based micro and nanofabrication facility to support user needs in newer areas of nanoscale science, engineering, and technology domains. The distinguishing focus area of our facility is micro and nanofabrication using polymers and Group IV materials (carbon and silicon), with an emphasis on polymer nano-composites and carbon fabrication supported by critical and highly specialized tools and processes (pyrolysis, polymer electrostatic deposition, near-field electrospinning, etc.) that also enable integration with conventional silicon fabrication. Figure 1 shows our unique material capabilities. In its core, the Center has a strong focus on educating undergraduate, masters and doctoral students in the various areas of nanotechnology.

B. Management

NanoFab.SDSU is part of the College of Engineering (**CoE**) at SDSU and is open for university-wide use by qualified users who undergo the required training. Policy of the Center is determined by Executive Council that consists of Dean of CoE, **NanoFab.SDSU** Director, and selected members of Industry Consortium Advisory Board (ICAB), and external prominent member from academia or industry. The Director will report to the Executive Council regarding **NanoFab.SDSU** policy matters.

B.1 Management Structure

The management structure of **NanoFab.SDSU** is given in detail in the organization chart (Figure 2) and consists of the Director, Executive Council, Advisory Boards (SAB – Scientific Advisory Board and ICAB - Industry Consortium Advisory Board), consortium faculty, Cleanroom staff, and the user community. Detailed description of the task of each of these groups is given below.

B.1.1 Director

The Director of **NanoFab.SDSU** is the executive responsible for running the Center's overall administration, including budgeting, staffing, assessment, and oversees the day-to-day as well as strategic operations of the Center. All technical and office personnel will report directly to the Director. The Director will serve for a period of 5 years. Upon the end of the term, The Director's continuation or replacement is determined through the Executive Council.

B.1.2 Executive Council

The Executive Council is the body that acts as an oversight body. The Council consists of Dean of CoE, **NanoFab.SDSU** Director, and selected members of Industry Consortium Advisory Board (ICAB), and external prominent member from academia or industry. The Council's term is 3 years.

B.1.3. Scientific Advisory Board (SAB)

A Scientific Advisory Board (SAB) made of leading scientific figures in the field selected by the Director and Executive Council together with selected consortium faculty members will serve to keep the Center at the forefront of emerging technologies. SAB's term is 3 years.

B.1.4. Industry Consortium Advisory Board (ICAB)

An Industry Consortium Advisory Board (ICAB) is made up of industrial consortium users and is selected by the Director. This Board will advise the Center and its Director in technology and outreach efforts. The ICAB term is 3 years.

B.1.5. Consortium Faculty

The Consortium Faculty consist of SDSU faculty who are members of the consortium and carry out active and funded research that is of interest to the industry members of the Consortium. Consortium Faculty are expected to maintain funded research activity that is in line with the mission of the Center and are admitted as members for a renewable 2-year term. The Consortium Faculty are required to participate in the Center's research, teaching, and outreach activities. Their students are required to participate in the annual "**Industry Day**" where the Center showcases its research portfolio.

B.1.6. Cleanroom Manager

The Cleanroom Manager is appointed by the Director and is responsible for the safe and appropriate operation of the Facility. The Process Manager is required to have an expert-level knowledge of microfabrication and is responsible for developing and managing lithography and fabrication processes and training users on equipment usage and processes. Further, the Cleanroom Manager and his team are also responsible for managing our existing Cleanroom Certification Program where users are certified at different levels after passing relevant exams (Appendix C). The team will work closely with external users in defining processes and reconciling them with our processes and equipment, in addition to training students and new users.

B.1.7. User Community

The User Community consists of industry members, undergraduate and graduate students, trainees, and interns. Typically, students are sponsored by a professor who uses the services of **NanoFab.SDSU** as Consortium member or renewable one-time payments as per the price schedules of Table 1. Users are required to the following requirements:

1. complete EHS (Environmental and Health Hazard) safety practice training,
2. certified in cleanroom fabrication processes (such a training is offered by **NanoFab.SDSU** on regular basis)
3. make arrangement for payment of services as indicated in Table 1.

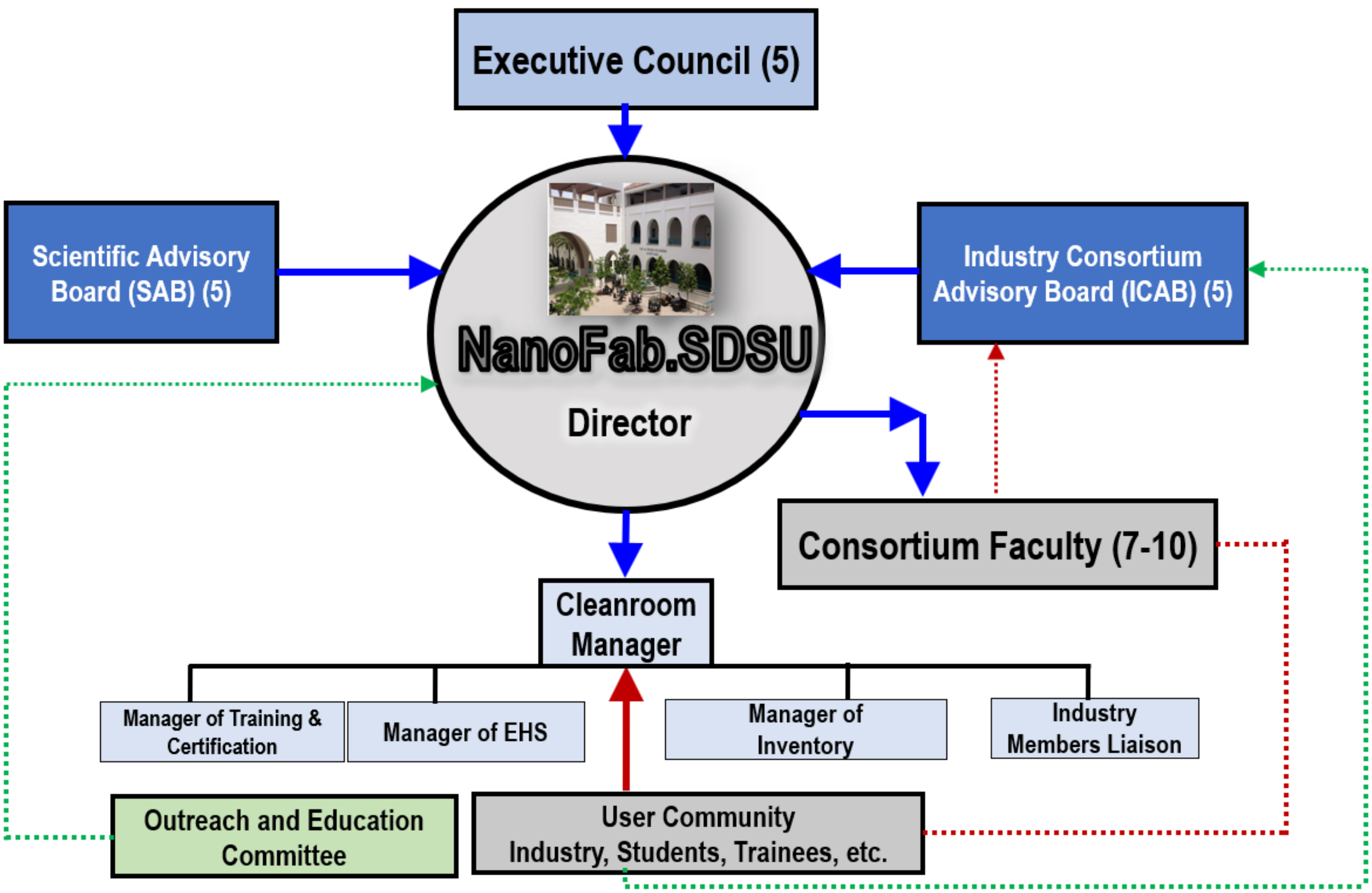


Figure 2. NanoFab.SDSU organizational chart. The center Director is responsible for running the Center's overall administration, including budgeting, staffing, assessment, and overseeing the day-to-day as well as strategic operations of the Center.

B.1.8. Outreach and Education Committee

Further, by virtue of its emphasis on interdisciplinary research, **NanoFab.SDSU** will serve as a focal point of education and research in the intersection of engineering, physical and life sciences. Outreach and education committee consisting of the ICAB, tech staff, and partners will provide input to the center Director.

B.2 Planning Process

The overall Center requirements and vision for future research directions are determined by the Center Director and ICAB. This core leadership team will set the allocation of resources and prioritization of equipment acquisition, development, and staffing based on this site requirement and vision for growth. The leadership has biannual meetings to review progress in this and make the necessary arrangements to meet its goals. Monthly internal meetings will be held where needs are assessed regularly and compared against the resources allocated. In an annual meeting, SAB (Scientific Advisory Board) and ICAB (Industrial Consortium Advisory Board) provide their input regarding the overall vision of the Center.

As shown in the organizational chart (Figure 2), **NanoFab.SDSU** is part of College of Engineering at SDSU, with the Director being responsible for running the Center's overall administration, including budgeting, staffing, assessment, and overseeing the day-to-day as well as strategic operations of the Center. Table 1 gives the pricing structure.

Table 1. Fee structure for consortium, internal, and external users of **NanoFab.SDSU**.

Item	Internal Users ($/hour)	Consortium Users ($/hour)	External Users ($/hour)
Cleanroom access time	**$20**	**$20**	**$50**
Lithography (Positive and Negative)	**$15**	**$15**	**$25**
Metal Deposition (Au/Pt) – 10 nm	**$30**	**$30**	**$50**
Wet and Dry Oxide Growth	**$30**	**$30**	**$50**
Acid Etching	**$20**	**$20**	**$40**
DRIE/Plasma Etching	**$20**	**$20**	**$40**
PECVD & CVD	**$30**	**$30**	**$50**
3D Imaging	**-**	**-**	**$10**
Training on Specialized Equipment	**$35**	**$35**	**$55**
Training for Certification (Flat Rate)	**$250**	**$250**	**$400**
Staff Assistance	**$35**	**$35**	**$55**

C. User-Engagement Policy

NanoFab.SDSU has an established record over the past 10 years as a shared user facility with increasing user-base. The user-base included companies who are covered by our IP agreements and confidentiality as well as academia with various levels of confidentiality agreements. **NanoFab.SDSU** has a web-site (www.nanofab.sdsu.edu) where details regarding equipment, process capabilities, fees for cleanroom and equipment usage, etc. are given. Typically, engagement with external users occurs through users contacting the Center with a description of their process and equipment needs. The Cleanroom Manager then evaluates the process and equipment requests and starts communication with the potential user. Once all technical needs are discussed and made compatible with **NanoFab.SDSU** capabilities, the user and

NanoFab.SDSU enter an agreement. On the other hand, non-traditional users will be encouraged to use the facility through the web-site. External users will follow the procedure described below. All fees for equipment usage, facilities, and personnel time will be posted on the web-site of the Fab.

Two models will be used in serving external users. In **model 1**, researchers will use **NanoFab.SDSU** facilities by carrying out the fabrication themselves at the site, while in **model 2**, users will submit their designs (i) remotely through our multiuser process called **NanoFabMUP** (Group IV Multi-User Process), or (ii) remotely using their custom processes that are worked out together with **NanoFab.SDSU** process personnel. **NanoFabMUP**, which is ideal for beginners in hybrid nanofabrication, consists of 1 carbon layer, 1 metal layer, 1 insulation layer, 1 flexible substrate layer, and 1 layer for electrostatically deposited nano-composites. Figure 3 illustrates the mechanism for engaging external, internal, and nontraditional users.

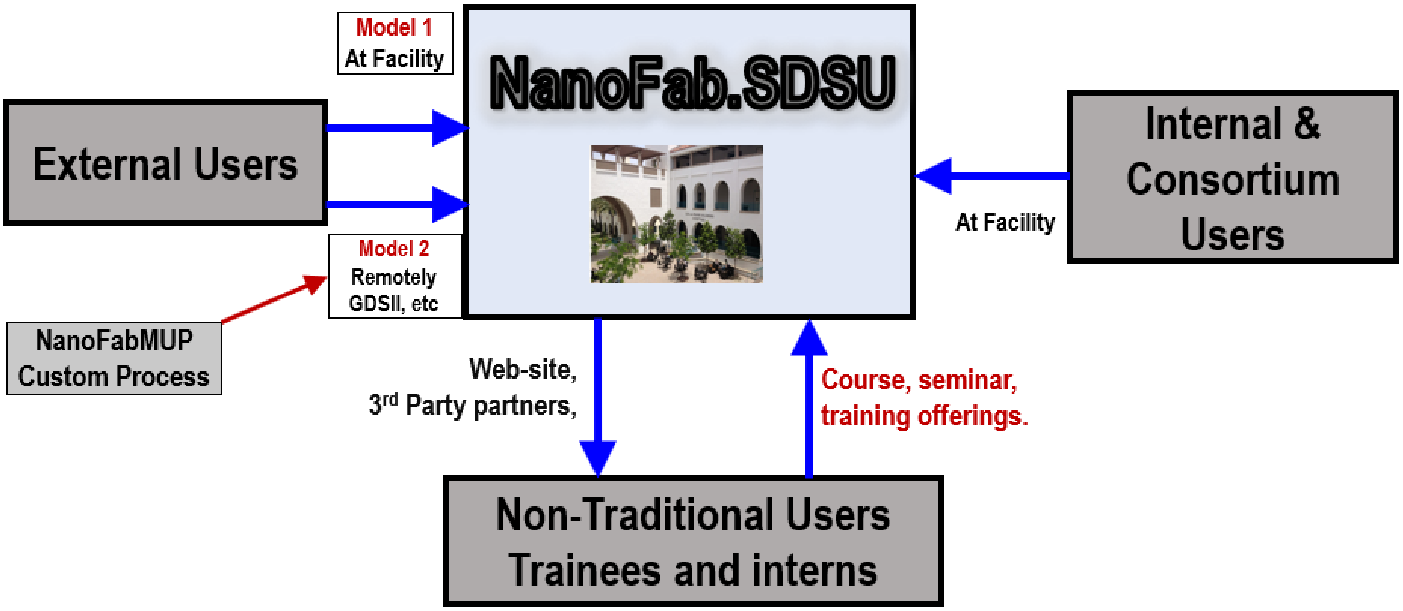


Figure 3. User Access Mechanism for **NanoFab.SDSU.**

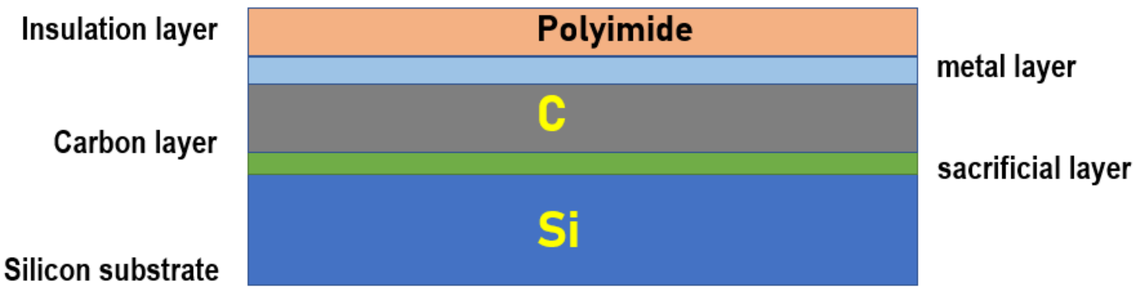


Figure 4. NanoFabMUP process**,** one of our hybrid nanofabrication processes.

C.1 Intellectual Property (IP)

IP policies are developed by SDSU's TTO (Technology Transfer Office). In general, the policy states that, for work developed by consortium members without SDSU personnel, IP belongs to the company. Any IP resulting from the work of SDSU employees or students of SDSU is considered SDSU property. However, external users who perform their work on a fee-based usage own IP arising from any work that is done at **NanoFab.SDSU** without disclosing the details of their work (subject to reasonable safety requirements). It is the policy of **NanoFab.SDSU** that our staff will not disclose details of processes or work performed to assist users, without the expressed consent of the user. The fee structure is given in Table 1.

C.2 Acquisition and Development of New Tools and Instrumentation

As the Center's uniqueness is its emphasis on polymer and Group IV elements, emphasis will be placed on maintaining that unique position and further expanding it. For this, the following steps will be taken:

1. Twice a year, the PI, Co-PIs, and the technical staff will meet and review all fabrication processes. The review will concentrate on improving processes and evaluation of new processes. Decisions regarding purchase of new equipment will be made based on the outcomes of these meetings.
2. The professional technical staff will be encouraged to continually improve processes and introduce new ones. The staff will also be encouraged to request acquisition or development of new tools and instrumentations through the official bi-annual technical meetings.

C.3 Social and Ethical Implications

We believe that our unique geographical location in one of the top technology centers in the country (biomedical, wireless, IT, etc.) where there is a significant minority population (Hispanic) offers us tremendous opportunity in addressing societal implications of nanoscience and nanoengineering. Our approach in addressing this is based on three levels: (i) working with stakeholders - public seminars and talks that will be attended by stake-holders in the community (community leaders, policy-setters, etc.) will be organized in the areas of societal implications such as human health and safety, environmental justice, and public policy, (ii) setting responsible research environment - where safety and environmental considerations are of paramount considerations in the site's operation (all Center users and personnel will be trained in this aspect), and (iii) studies in ethics (nano-ethics) – we will work with faculty in philosophy department (to develop a course in nano-ethics for socially-acceptable, and ethically-justified technologies (this will include topics in methods of embedding ethics in design of nano-systems). Our association and active research with CSNE (Center for Sensorimotor Neural Engineering) which has a strong record in neuro-ethics, will be leveraged to enable cooperation and interchange with leading institutions in ethics in technology.

C.4 Education, Outreach, and Knowledge Dissemination

We envision that **NanoFab.SDSU** facility will serve as an incubator and resource center for a range of educational and outreach activities in nanoscience and nanoengineering, which in the long term, will expand and diversify the U.S. science and technology workforce. A unifying theme of these efforts will be to teach and demonstrate that nanoscale science and engineering is an exciting and truly interdisciplinary area in which both disciplines work in concert to optimize the design and manufacture of devices that benefit society.

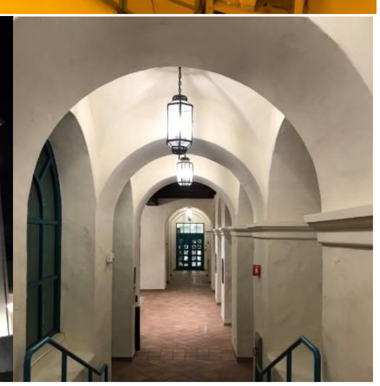
D. Assessment & Criteria for Success

The strategic goals of the Center are developed at two levels, i.e., (i) specific metrics in terms of expected internal and external user-base, financial performance of the Center, and (ii) competitiveness and ability to stay ahead of the curve in national nanotechnology needs. The goals are set by the Director and ICAB and are reviewed annually. The education and outreach programs will be evaluated by a combination of surveys, questionnaires, interviews, and focus groups to determine if participant outcomes are in alignment with our overall education goals. Courses will be assessed with the established course evaluations of that university.

Evaluation reports will be analyzed annually. In the case that programmatic evaluation indicates that an activity is out of alignment with our research or education goals, and/or the program is consistently unable to meet programmatic goals and milestones as set forward in this strategic plan, the Director will review the activity to determine a course of action, which may include significant programmatic changes or elimination of the program.

E. Facts and Figures

NanoFab.SDSU is Class 100-1000, ISO 9001-certified cleanroom facilities with 2500 square feet area in the EIS (Engineering and Interdisciplinary Sciences) building of San Diego State University. The total value of cleanroom equipment in the facility is about $5 million. The cleanroom air is changed 150 times per hour. The temperature and humidity are kept constant throughout the year.



Appendix A. User Policy Compliance Agreement

All users of the **NanoFab.SDSU** (students, staff, faculty, and industrial visitors) are expected to act in a professional manner giving courtesy and respect to other users in our research community. The actions of any one user has the potential to affect the successful outcome of research and the safety of all users in our shared community. Therefore, it is essential that our users and their responsible PI or Supervisor understand our policies to promote a safer, cleaner and more useable lab.

The following is required of all Users:

I. MINIMUM Requirements & Competencies

II. Certified in Cleanroom microfabrication technology at Level I or Level II classifications or equivalent (See Appendix C).
III. Have prior experience working in a lab environment or have a research group that will mentor you
IV. EHS Safety Training Certification
   A. Hazardous Waste
   B. Know and understand basic hazards of chemicals in **NanoFab.SDSU**
   C. Understand proper procedures for collection, storage and disposal of hazardous waste

II. READ
   A. Lab Safety Manual
   B. **NanoFab.SDSU** Policy Overview
   C. Chemical Hygiene Plan
   D. The MSDS Literature and SOP's for each chemical that you use
   E. The SOP's for each equipment that you use

III. BE RESPONSIBLE (Each user is responsible for the equipment and chemical used)

Each user must follow the minimum guidelines. Violation will result in denial of access to Facility.
1. Wear proper personal protective gear and safety glasses or chemical splash goggles at all times
2. Always log-in when entering the Facility and log-out when leaving
3. Fill out the log for all equipment that you use
4. Complete Chemical In-Use forms for all chemicals presently in use, including contact phone number
5. Leave all equipment in the same way it was or better, if possible. This includes turning off microscopes and cleaning
6. spinners when you are finished using.
7. Store all personal equipment or supplies in designated areas or lockers. DO NOT store chemicals in your locker.
8. Follow the proper disposal procedures for all chemicals. If you do not know how to dispose of something, ask staff.
9. Notify staff immediately in the case of an accident resulting in a chemical spill, broken equipment or injury
10. Each user will be issued an access card for entering the Facility. Users will not share their access card with anyone and must report to staff if lost or stolen.
11. Report potential safety hazards to staff
12. Pay close attention to signs of Do's and Don'ts

IV. RESPECT

1. Treat all equipment and experiments in the lab as if they are your own. DO NOT dispose of or dismantle an experiment or chemical without first checking with staff
2. If you observe someone failing to follow policy or proper procedure, help them in a kind manner
3. Make an appointment with Lab Staff for equipment or process training, DO NOT interrupt staff for personal training while they are working
4. Attend weekly Lab Meetings whenever possible as this is dedicated time with our Lab Manager

Policy Violations

Users that violate **NanoFab.SDSU** Policies and Procedures, as specified in this agreement and in our Lab Safety Manual, will be subjected to the following consequences listed below. Lab Staff reserves the right to enforce additional consequences if deemed necessary.

1. Safety Violations will result in immediate 2-week suspension.
2. 1st – 3rd Occurrence of policy violations: Written warning to the violator and responsible PI/Supervisor
3. 4th Occurrence: 2-week suspension from Cleanroom
4. 5th Occurrence: 30-day suspension from Cleanroom and requirement to re-take the Lab Orientation for an additional cost of $150 internal / $350 external user.

Lab Protocol Violations include (but are not limited to):
• Improper Use of Lockers (ex: storing chemicals, leaving a mess)
• Improper Entry (ex: Using another user's key card or username, not logging in, signing in as a guest when you are a user)
• Failure to follow SOP's for equipment or processes (this will lead to suspension from tool)
• Failure to log equipment use and parameters
• Failure to clean up after yourself (ex: after use of spinner, wet bench and utensils)
• Using equipment or supporting infrastructure that you are not trained or authorized to use
• Removing other users samples from equipment or chemicals
• Altering process parameters during other users run
• Theft or unauthorized removal of equipment, materials or chemicals (may result in expulsion)

Safety violations include (but are not limited to):
• Failure to comply with the buddy policy
• Improper chemical glove use (ex: touching equipment or door handles with chemical gloves)
• Unauthorized use of the wet bench (users must be qualified before use)
• Improper use of chemical fume hoods or wet benches
• Improper chemical handling, transport, storage, use or labeling
• Improper waste disposal or failure to clean and dispose of empty chemical bottles
• Bringing non-approved chemicals, materials, or people into the lab
• Not following Do's and Don't signs in the lab
• Failure to immediately respond to and/or report equipment problems, injuries or safety hazards including chemical spills

PI/Supervisor Acknowledgment

I certify that the user named below has met the minimum competencies as listed under Section I.

I have read and understand the **Nanofab.SDSU** Policies listed in the Lab Safety Manual and will ensure that user violations are limited.

I understand that there are consequences to policy violations that could potentially lead to additional cost and expulsion of the user named below:

____ ________________________

PI/Supervisor Signature Date

____ ________________________

PI/Supervisor Name (Printed) E-mail

User/ Employee Acknowledgment

I have read and will follow the policies in the Lab Safety Manual.

I understand that failure to follow these policies may endanger the entire lab environment and serious consequences will result in loss of lab privileges.

I understand that I will be held responsible for any damage caused if I fail to follow these.

____ ________________________

User Signature Date

____ ____________________

Name (Printed) E-mail

Appendix B. Industrial Consortium Fee

Annual Membership

COMPANY SIZE	FULL MEMBER
> 100	$5000
10 to 100	$3500
Start-up	$1,000

Appendix C. Microfabrication Technology Certification Program

Course Objectives

Upon completion of the course work, the trainees will gain skills in:

1. Fundamental micromachining processes such as lithography, surface and bulk micromachining.
2. Layout for MEMS using CAD and then populate a wafer with these layouts.
3. Simulation of MEMS devices.
4. Developing and exercising critical thinking in microengineering design issues such as fabrication, packaging and testing.
5. Micro-scale physics for use in designing MEMS

Course Outlines

The outline for the course is as follows:

Session #	Cleanroom/Lab (4hrs)
1	Mask Preparation
2	Photolithography
3	Metal Deposition
4	Etching of Si
5	FEA Simulation
6	DRIE
7	Electrical Characterization + SEM Characterization.

A detailed description of the Lab sessions is given below:

Lab 1: Mask Preparation. In this session, the students will be trained on the use of MEMS CAD (CoventorWare) to prepare masks. Concepts such as cells, tree structures, and GDS II formats, layers, references will be introduced. The students will then build a standard mask for an example problem of a MEMS switch.

Lab 2: Photolithography. In this session, the students will perform positive and negative lithography and learn the standard procedures of pre-baking, UV exposure, post-baking, developing, and stripping resists.

Lab 3: Metal Deposition. In this session, the students will learn how to do metal deposition through evaporation and sputtering. Metals include gold, aluminum and gold-palladium.

Lab 4: Etching of Si. In this session, the students will perform wet etching of silicon with KOH. Effect of rates of etching will be demonstrated.

Lab 5: FEA Simulation. The students will be trained to do multi-physics simulation of typical MEMS such as resonators, accelerometers, and microfluidics devices.

Lab 6: DRIE. In this session, the students will be trained on DRIE and will be expected to carry out DRIE of silicon and polysilicon.

Lab 7: Electrical Characterization. In this session, students will be trained to electrically characterize MEMS devices they had built in the preceding sessions using Four-Point Probe Station (for bulk resistance). AC impedance measurements will also be done using Solartron Analytical Model 1070E. Students will also be trained in the use of Phillips FEI Quanta^{TM} 450 Scanning Electron Microscope for optically characterizing their MEMS devices.

NanoFab.SDSU Cleanroom Certification

Level 1 Basic: 1 Layer Lithography (Positive, Negative)

- Basic knowledge of negative lithography
- Basic knowledge of positive lithography
- Basic knowledge of mask polarity
- Basic handling and operating of desiccator
- Basic handling and operating of plasma etcher
- Basic handling and operating of mask aligner
- Basic handling and operating of Hirox microscope
- Basic handling and operating of old and/or new spin coater
- Basic knowledge of safety and biohazard protocols required by the lab

Level 1x Basic Exclusive: Exclusive to Specific Equipment

- Depending on needs, basic handling and operating of particular equipment (typically for students from outside the MEMS lab)
- Basic knowledge of safety and biohazard protocols required by the lab

Level 2a Basic+: Level 1 + metal deposition

- Level 1 Basic certified
- Basic knowledge of metal lift off process
- Basic handling and operating of metal deposition system
- Basic handling and operating of 3D microscope
- Basic knowledge and handling of BHF

Level 2b Basic+: Level 1 + soft lithography

- Level 1 Basic certified
- Basic knowledge of soft lithography process
- Application of soft lithography process using PDMS
- Basic handling and operating of 3D microscope

Level 3 Advanced: Level 2a + layout, multilayer fabrication, electrochemistry

- Level 2a Basic+ certified
- Basic knowledge of electrochemistry
- Basic knowledge of mask layout and multilayer fabrication
- Basic handling and operating of **SolarTron/Gamry station.**

Level 4 Advanced+: **Level 3 + dry/wet etching, pyrolysis, PECVD, training** ★★★★

- Level 3 Advanced certified
- Proficient knowledge of dry and wet etching
- Proficient knowledge of operating and internal functions of all/most equipment from all previous levels
- Proficient knowledge of operating and internal functions of pyrolysis
- Proficient knowledge of safety and biohazard protocols required by the lab

Level 5 MEMS Guru: **Level 4 + New Process Discovery or Implementation** ★★★★★

Appendix D. Sample List of Equipment at NanoFab.SDSU

Category	Equipment
Lithography	**High Resolution Mask Alignment and Exposure System. 500 Watt DUV/UV** Exposure System. Uniform/Collimated **6.0" Diameter Exposure Beam.** Dual CCD Camera Alignment System with Zoom Magnification. Fiber Optic Illumination
	SPC-200 Spin-Coater. 200 mm pre- alignment wafer processing system (12000 rpm)
	Baking Ovens (Inert Environment)
Thin-Film Deposition	PECVD System with gas MFC with touch screen control
Soft Lithography	PDMS
Metal Deposition	Thermal Evaporation + Sputtering
DRIE + Plasma Etch	Technics Series 85
SEM + EDX + TEM	FEI, Quanta 450 450 ESEM with Oxford EDS detector. TEM-FEI Tecnai 12
3D Microscope	Hirox 3D Microscope
Probe Station	SignProbe Probe Station
Raman/FTIR/etc.	Thermo Scientific DXR Raman Microscope and iS50 spectrometer
Characterization (Elec & ElecChem)	Gamry & Solartron Analytical Cyclic Voltametry & Impedance Measurement
Carbon-Based Micro/nanofabrication	
Pyrolysis	PECVD Split Tube Furnace with Vacuum System - OTF-1200X-4CLV-PE-UL. Split Long Tube Furnace with 5" Dia Quartz Tube (36" Heating Zone) & Vacuum Flanges - OTF-1200X-5L. Temperature Control System. Pyrolysis chamber.
Nano-imprinting	New system to be acquired in 2019/2020. Enables features as small as 1—20 nm
NFES - Near-field Electrospinning	To be acquired in 2019/20. Enables carbon nano-wires of ~20 nm dia and less