UW WNF

Washington Nanofabrication Facility
Annual Report 2015-2016

Front cover: WNF staff engineer Albert Bailey and Associate Director Michael Khbeis inspect the construction of the new lithography suite.

Foreword

The long-awaited renovation of the Washington Nanofabrication Facility (WNF) cleanroom finally started in April. We are eagerly anticipating the completion of Phase 1, scheduled for the end of October 2016, which will give us a new entrance and gowning area, a significant portion of the new lithography and wet etch suites, and new administrative offices. Phase 2 will start in November, which will affect the central part of the existing cleanroom. Phase 3 will commence in spring and the completion of the project is anticipated for the summer of 2017. While our staff will make every effort to keep disruptions of service to a minimum, some downtimes will be unavoidable. Please bear with us during this transition! We are looking forward to offering our users a brand-new state-of-the-art facility by the time we write our next annual report. We are grateful to the University of Washington for committing substantial resources to this project.

In the meantime, the National Nanotechnology Coordinated Infrastructure (NNCI) has been ramping up. As one of the 16 sites in this NSF-supported network of leading nanotechnology nodes, we are working together with our colleagues across the country to make nanotechnology infrastructure and education accessible to a broad community of users. This report features just a few of our diverse users, from undergraduates to faculty and from interns to entrepreneurs. You may meet them, and many others, at our first NNCI User Appreciation Night on October 31, 2016 at the UW Club. I hope to see you there!

Executive Summary

Now in its fifth year of operation under the College of Engineering (COE), the UW Washington Nanofabrication Facility (WNF) has experienced continued growth of its user base, operating revenue, technical capabilities and number of lab staff. This year our primary focus is the major renovation of the WNF cleanroom that will double the cleanroom space and improve cleanliness by 2 to 3 orders of magnitude. The renovation project represents $37M in infrastructure investment for the WNF that will enable the lab to meet researchers' needs for the next 20 years.

Starting in April 2016, the lab staff has focused on mitigating impacts by working closely with UW Capital Projects & Development (CPD), Hoffman, HDR and Affiliated Engineers Inc. (AEI) on the cleanroom renovation project. The construction team originally requested a 10-to-12 month long shutdown of the WNF in order to remodel the cleanroom; however, this would have been too disruptive to our clients. Instead, the project will commence in 3 phases with a small number of systems offline during each phase. Phase 1 of construction will be completed in late October 2016.

Despite the construction, lab activity as measured in user hours has continued to increase, with annual revenue from lab users passing the $2M mark for the first time. At the same time, disruptions due to construction and a prolonged downtime of our electron beam lithography system has affected in particular our outside academic and government usage numbers.

This year's annual report features a new section that profiles some of the many users of the WNF and shares some of the exciting work that our clients are completing using the facility.

This year we welcomed Mark Morgan and Fred Newman as new Research Scientists and Engineers. Mark's fabrication experience stems from development work done at a local R&D firm while Fred's experience most recently involved device development with SOITEC in Arizona. Mark replaces Andrew Lingley as the primary etch engineer while Fred is working on pulsed-CVD and Atomic Layer Deposition (ALD) technology development. Sadly, the lab lost two talented staff members to industry, but still assist WNF part-time. Andrew Lingley, now an industrial client, took a position at a spin-out from Intellectual Ventures. In addition, Rick Bojko took a position as Head of Technology at GenISys, a vendor for EBL proximity correction tools.

User Statistics

Active average monthly user trends were flat when compared to FY2015, with 4-percent growth in industrial users, a 7-percent decline in UW users, mainly attributed to not offering EE527-PMP this year, and a 24-percent decline in outside academic and government users. However, usage by active clients has dramatically increased with a 12-percent increase in UW academic use and a 78-percent increase in industrial use. Outside academic use declined by 52-percent mainly due to a reduction in Electron Beam Lithography operations during a prolonged outage of the beam source.

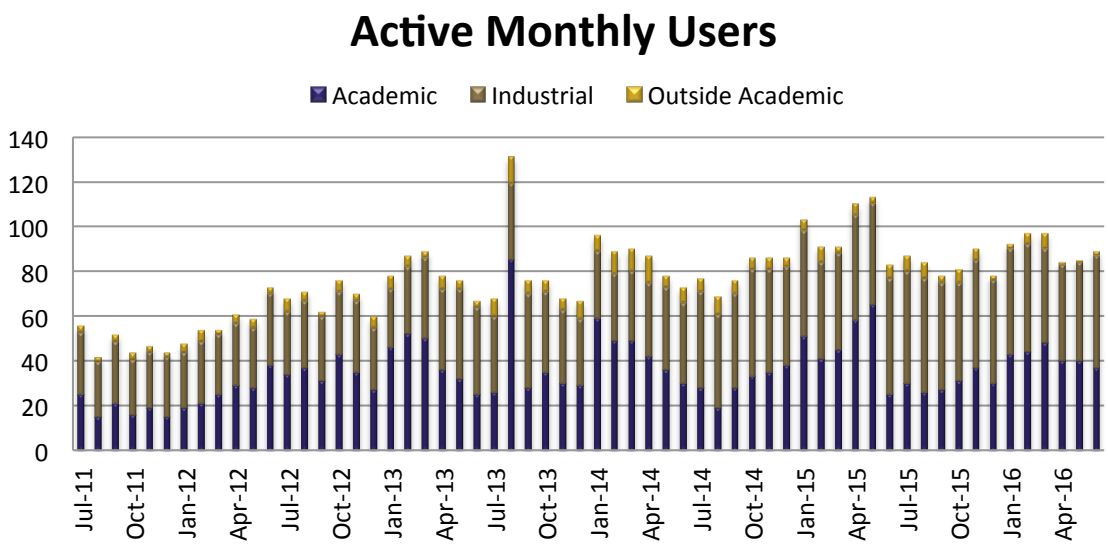


Figure 1. Active users per month with billable activity since inception

Active users continue to engage in increased utilization and initiation of projects conducted within the WNF facilities, also supported by this year's external revenue of 56-percent to $2.1M. UW revenue increased by 1-percent to $364,000 and grant revenue decreased by 2-percent to $1M. In total, recharge revenue grew to $2.5M, an increase of 44-percent from FY2015. Grant activity and supplemental funds resulted in a total income of $4M. Non-capital expenditures shrunk to $2.9M with no capital purchases due to a severe lack of installation space during construction activities.

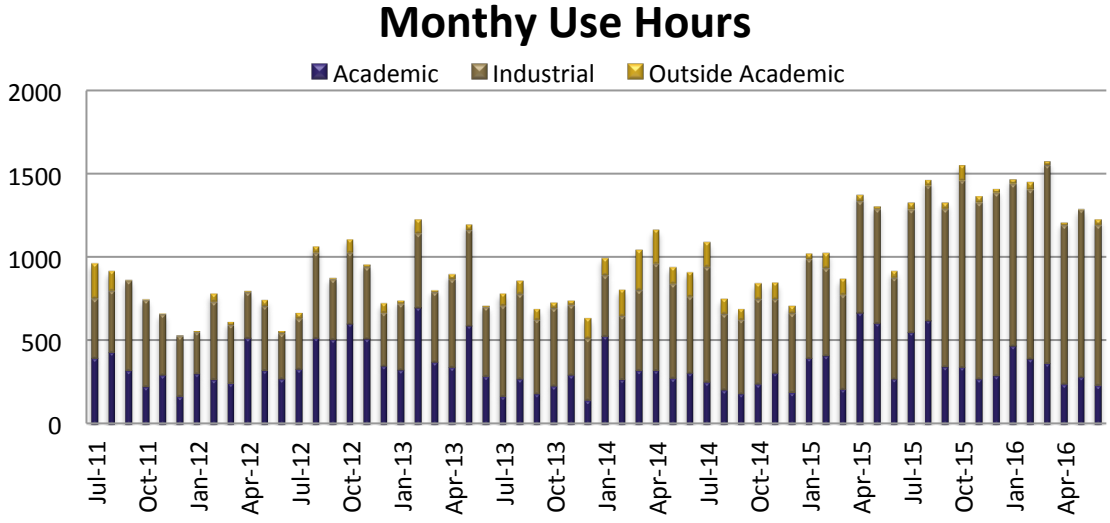


Figure 2. Monthly usage hours (equipment enabled)

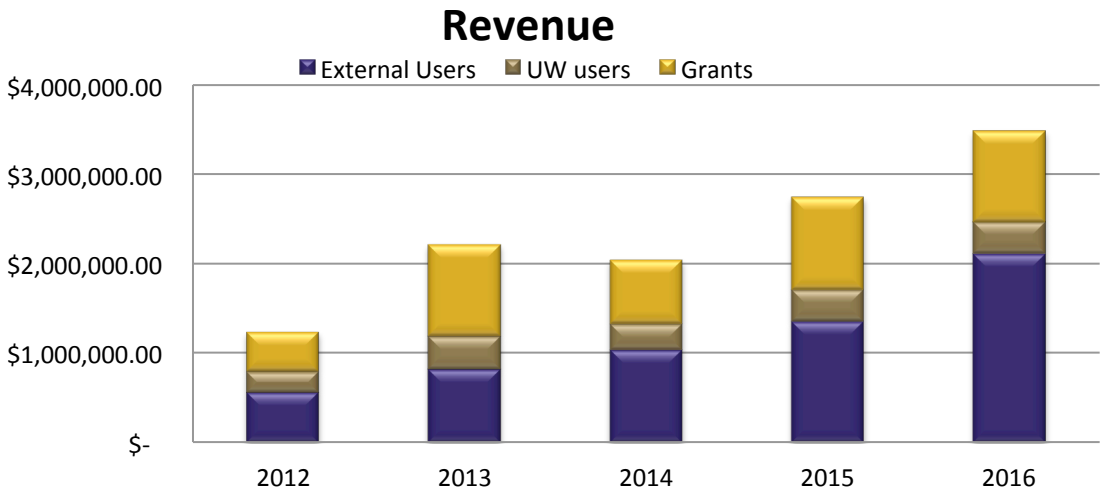


Figure 3. Recharge center revenue since inception

User activity growth continues without notable impact to the average machine uptime of 97.4-percent. There is an expectation of prolonged planned outages of several tools due to construction; however, construction should improve system reliability for the long term. The WNF continues to make investments in spare parts and components to minimize impacts.

Infrastructure Updates

The user population of WNF facilities continues to grow, as does demand for space. Construction both temporarily and permanently exacerbates the shortage of space. As the cleanroom doubles in size, storage and office spaces are lost. Furthermore, WNF has lost its spaces on the second floor of Fluke Hall. There simply is no space to store equipment spares and client samples. During construction, the WNF elected to use off-site storage to hold equipment awaiting installation during construction. Legacy systems were sent to UW surplus to the extent possible. WNF personnel and other users are facing a severe shortage of available space. The hallways are currently being used for equipment storage as well as overflow workspace for clients that are unable to acquire any available desk space; nevertheless, this is also one of the most active construction spaces resulting in the inability to use the working/livable main corridor that was designed and furnished last year. The end of Phase 2 of construction will result in the provision of extra offices, shown in Figure 5, and desks for staff, freeing up 6 additional workstations; however, as the population grows, the space shortage will remain a critical issue.

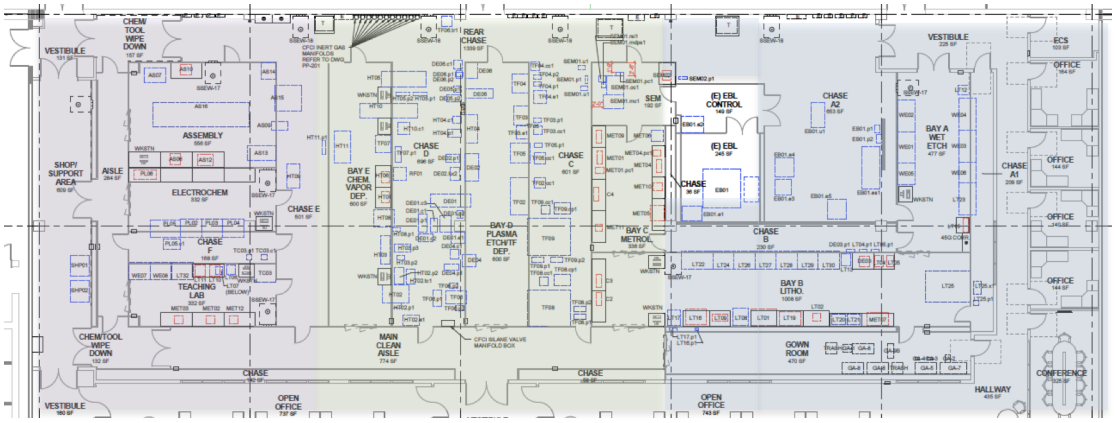


Figure 4. Cleanroom remodel floor plan with Phase 1 (blue), Phase 2 (green), and Phase 3 (purple)

Figure 5. New offices and conference room hallway built out in Phase 1

Figure 6. New rooftop mechanical equipment

Figure 7. Future Lithography Bay B under construction

Phase 1 of construction has been a flurry of activity. We have a dedicated suite of mechanical equipment that has been installed on the lower roof of Fluke Hall, shown in Figure 6, that provides tightly controlled (temperature 70°F ± 2°F and relative humidity 45% ± 5%) air for the new cleanroom. Two new exhaust systems for general and corrosive fumes have also been installed as well as a new roof on the building to mitigate the leaks Fluke Hall once had. On the first floor, the old NTUF spaces were demolished to make way for new administrative offices and a conference/classroom as well as the future lithography and wet processing bays, shown in Figure 7. Phase 1 is slated to be completed in late October with tools being installed starting on November 3rd. During Phase 2, WNF will operate the new cleanroom and old cleanrooms independently while construction commences in the central area of the first floor. The project is scheduled to complete Phase 2 in April with Phase 3 completed summer of 2017.

Client Profiles

We mark the 5th year of operation with a collection of profiles from a few of our clients. WNF's success is dependent on the success of our clients that are provided with a high level of customer service and world-class capabilities. We celebrate the diversity of our clients who range from entrepreneurs to college students working with us via internships that lead to jobs. We asked clients to tell us a little about themselves, their role at the WNF, and their organization.

To the extent possible for public disclosure, we asked what exciting things they are currently working on and the broader impacts of their work. We asked what made them decide to join the UW WNF community, how the WNF enabled or helped them achieve their goals, and what else could the WNF do to make them more successful with their future research.

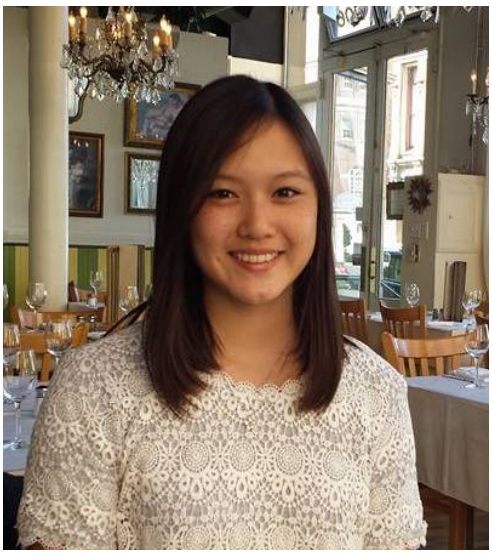
Dr. Jevne Micheau-Cunningham – Flexforge

My name is Dr. Jevne Micheau-Cunningham and I am the owner and CEO of FLEXFORGE. I have over fifteen years of successful product development experience creating devices and solving organizational needs in industries ranging from automotive (Ford Motor Company), medical device (Guidant-CRM/ Boston Scientific-CRV) and eddy current materials inspection (Zetec, Inc.). I hold both a Masters of Engineering degree from Cornell University in Engineering Mechanics (focus on composite materials) and a PhD in Applied Physics from the University of Michigan-Ann Arbor (magnetic materials and nanoscale magnetic material mechanics). My company offers custom design and fabrication of novel Anisotropic Magneto Resistive (AMR) and Giant Magneto Inductive (GMI) sensors to suit customer needs at the die level. FLEXFORGE is the only MBE (Minority Business Enterprise) in the United States that can manufacture magnetic sensor arrays, bridges and monolithic devices in surface mount device (SMD) packages.

I am currently working on magnetic sensing systems that have broader applications spanning from automotive (focus on electric vehicles), aerospace, materials inspection to medical device. The broader impact of my work is that the current suppliers of these types of devices have never really addressed or optimized their device capability for the end user. Currently these devices are packaged in a manner that creates a challenge for optimal system integration in certain fields. The niche of FLEXFORGE is the ability to design and fabricate systems to fill this need that actually advances the technology and effectiveness of ventures in these spaces.

Colleagues in the Seattle technical community referred me to the WNF as a resource that I should explore and with whom I should build a bridge. I chose to join and utilize the UW WNF under the direction of Drs. Böhringer and Khbeis because of their individual rich histories in the MEMS and nanofabrication spaces. The current leadership of the UW WNF not only understands the technical needs and requirements in this space but also the unique needs of the entrepreneurial and start-up ventures that utilize their facility. They have created a technical community that very much follows in the distinct Seattle history of technical development.

A suggestion for the WNF that would greatly aid both users and staff would be added staff bandwidth to allow the individual tool/process SMEs (subject matter experts) to map all tool capabilities at the extremes of the tool space (not just the median of usage). This initiative might allow SMEs to travel to conferences and absorb where the cutting edge of work in nanofabrication is trending and then do the work to fully understand the lab capability to execute these processes. This work would have long-term rewards as potential customers would convincingly and enthusiastically utilize the WNF, as their confidence level in the ability to efficiently execute their corporate initiatives would increase. I currently utilize the WNF for device fabrication. My corporate plans are to continue to utilize the WNF for full production fabrication for the foreseeable future.



Amy Chiu – UW Junior – MSE Department

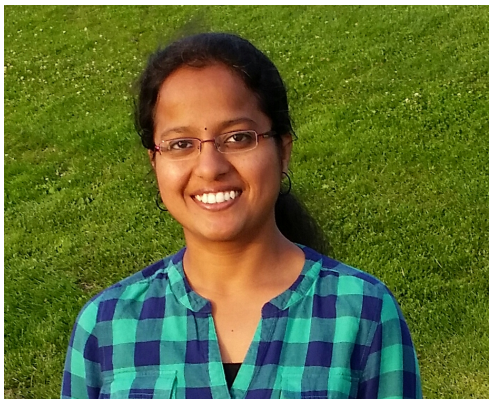
My name is Amy Chiu, and I am a rising junior in the Materials Science and Engineering department at the University of Washington. I've been working at the

Washington Nanofabrication Facility (WNF) as a research and laboratory assistant since the summer of 2015. This past summer I was interning at Portland State University under their Research Experience for Undergraduates (REU) program. This opportunity, in which I was researching nanoparticles for biomedical purposes, was only made possible because of my experience at the WNF. The projects I worked on at the WNF included optimization of tools, improving basic processes, and providing help to the professional staff engineers. I did not know about the WNF before I started working there, and I found the job on UW's job searching website. The opportunity sounded too amazing to give up; it was a 3-year experience where I would be able to do work on my own and be put on projects that were connected with local companies and professional engineers. The WNF has given me the chance to improve upon skills that I will use for the rest of my career such as working with a team of engineers, training on several tools, learning the basics of the semiconductor industry, and applying what I've learned in my classes to real life applications. The engineers at the WNF were extremely friendly and helpful to me whenever I needed it. At the WNF, I was introduced to both research and industry, and that's not an opportunity that comes around often. Now that I have a general understanding of the semiconductor industry, I am very interested in continuing my future career in that same path. I have enjoyed all the time I've spent in the lab, and I couldn't have asked for a better job at UW.

Prof. Arka Majumdar – UW EE/Physics

I am Arka Majumdar and I am an Assistant Professor at UW in Electrical Engineering and Physics. My group extensively uses the WNF, with 4 graduate students actively using the cleanroom. In my group, we are pursuing two big directions: in one, we integrate new materials with existing silicon or silicon nitride photon platforms to enable ultra-low power optical information technology. The second project uses nano-structured photonic devices for a new way of imaging and sensing to build ultra-compact optical sensors. I heard about the WNF when I joined UW from the WNF-director Karl Böhringer because nanofabrication is very important for my research. In fact, I chose to join UW because of the availability of the nanofabrication facility.

The WNF is the most critical element for my research. The availability of the electron beam lithography (EBL) machine and etchers are essential to build the nanostructures we are interested in. To better serve my research needs, the equipment down time could be minimized. Also having a more informed WNF-community will be better. While there might be more unwanted emails, I recommend a single alias for all lab members to foster knowledge transfer and collaboration. This will help us be a more successful academic research team resulting in more publications and funding.



Gowri Balasubramanian – NSC Intern

My name is Gowri Balasubramanian. I am a Materials Science graduate with experience in the areas of microfabrication, materials characterization, and failure analysis. I work for a start-up named Dekaris Technologies, based in the Redmond, Washington area. The company develops processes, executes fabrication, and facilitates testing of devices based on customer needs. The WNF plays a huge role in this initiative as all our fabrication processes are carried out in the clean room facility. Recently, I worked on a couple of exciting projects at the WNF. My latest

project involved fabrication of Organic Light Emitting Diode (OLED) displays for a customer. These high-resolution devices are designed to be an improvement of the OLED displays in use today.

My certificate course in nanotechnology at North Seattle College introduced me to the WNF. I did my summer internship at the WNF where I got an opportunity to contribute towards an exciting project for an aerospace client. I enjoyed the learning experience, the opportunity to work with cutting edge technology and the abundant resources available at the WNF. The WNF provides all necessary resources for our company to achieve its goals. The cleanroom facility houses various fabrication tools that help us build prototype devices for our clients. In addition, the staff engineers at the facility play a huge role in upkeep of the equipment, and offer assistance in process and equipment related issues. I am happy with the facilities that were available to me as a user at the WNF; however, availability of the staff could be improved. In the future, Dekaris Technologies aims at growing its client base and continuing to utilize the resources at the WNF.

New Equipment Acquisitions

With the start of construction, the WNF has had to practically halt new equipment acquisitions. There simply is not enough space in the cleanroom or hallways to facilitate or store new equipment. One exception was the purchase of a new Heidelberg DLW 66+ laser writer, shown in Figure 8. This system will enable the on-site writing of stepper reticles for advanced optical lithography down to 350nm as well as contact masks to be used for direct-write lithography down to 800nm features. In addition, the existing MicroPG101 system will be upgraded with a faster writing capability at a 3 micron laser spot size to expedite mask masking and direct write applications for large feature patterning.

Figure 8. Heidelberg DWL66+

Education and Outreach

The WNF remains committed to the educational mission of the University of Washington on an institutional level. In FY2016, over 1,635 hours of staff time was allocated for training and advising students in the areas of nanofabrication, characterization, process engineering and integration. WNF actively collaborates with North Seattle College to promote and provide access to education and professional development for nanotechnology technicians. WNF staff and clients hold positions on the NSC technical advisory board and sponsored 4 interns this year.

In 2015, the WNF continued its participation in the Undergraduate Research Program and currently employs 16 (mostly new) undergraduates that are performing research. Their work is showcased annually in the Undergraduate Research Symposium. Last year, we were very pleased to have four WNF student employees present their work at the symposium. We continued with a cohort model for this year's undergraduate recruits during the summer through which the WNF staff were given the opportunity to conduct classroom and group lab equipment training for the students, allowing for efficient training and preparation for these undergraduate students' involvement in the lab. The cohort model, a recommendation from Janice DeCosmo, the Associate Vice Provost for Undergraduate Research, allows students to leverage opportunities to use joint learning both in the classroom and in the laboratory to help each other out. Adopting this model, where students aid, reinforce concepts, and teach each other has tremendously improved the quality of student training. This means students are able to access the lab and provide a return on our time investments much earlier in the program than before. Last year's graduating students participated with the WNF staff at the semiconductor industry's premiere trade show, Semicon West 2016, which gave them an opportunity to present the lab's capabilities and network with industry leaders as shown in Figure 9.

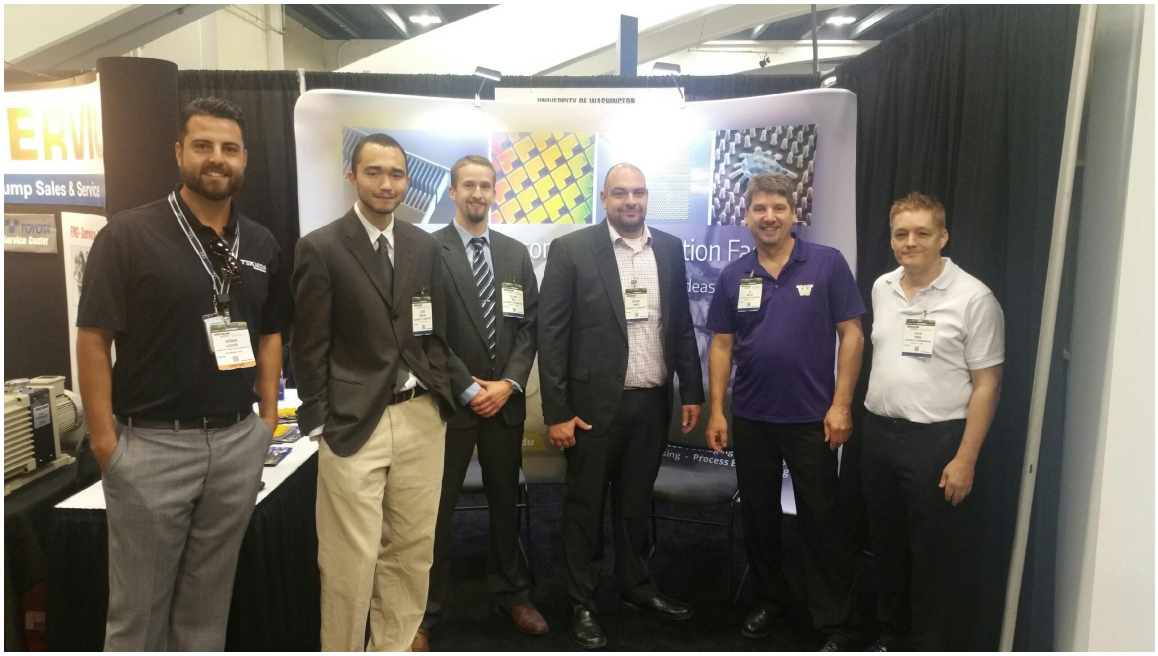


Figure 9. Networking with industry at Semicon West 2016: Keenan Lazzar from Teknon, undergraduate researchers Lucas Moyer and Taylor Rau, and WNF staff members Michael Khbeis, Albert Bailey and Duane Irish

WNF continues to lead for nanotechnology outreach activities with multiple staff and students volunteering at Paws on Science, UW College of Engineering Discovery Days, and Northwest Association for Biomedical Research's Life Sciences Research Weekend. Furthermore, WNF has been working with local colleges and high school science fairs by hosting demonstrations of nanofabrication techniques. Collectively, WNF has reached nearly 20,000 students in the past year through outreach activities.

Upcoming Projects and Improvements

Construction will continue on the major phased renovation of the cleanroom through the summer of 2017. While construction will detrimentally impact overall equipment uptime in the short term, the long-term benefits will be paramount to maintaining the WNF's technical dominance for nanotechnology research in the region as well as providing space to continue expanding the leading-edge technical capabilities that we offer our clients.

Acknowledgements

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WNF offers the following processing capabilities (from pieces to 200mm*):

Lithography:

- Electron Beam Lithography (JEOL JBX-6300FS)
- Canon i-line Stepper
- Contact Aligners
- Direct Laser Imaging (DLI) / Mask Making
- Spin Coaters
- Soft Lithography
- Nano Imprint Lithography (NIL)

Etch:

- High Rate / Low Scalloping Deep Reactive Ion Etcher (DRIE)
- Chlorine and Fluorine Inductively Coupled Plasma (ICP)
- Reactive Ion Etchers (RIE)
- Downstream Plasma and Barrel Ashers
- Wet Etch / Micromachining

Deposition:

- Chemical Vapor Deposition (CVD)
- Low Pressure Chemical Vapor Deposition (LPCVD)
- Plasma Enhanced Chemical Vapor Deposition (PECVD)
- Physical Vapor Deposition (PVD)
- Electron Beam Evaporation
- Atomic Layer Deposition (ALD)
- Pulsed CVD / Metal Organic CVD (MOCVD)
- Electrodeposition / Electroplating

Thermal Processing:

- Diffusion Furnace
- Rapid Thermal Annealing
- High Temperature Curing Ovens
- Magnetic Poling

Back End of Line:

- Dicing
- Chemical Mechanical Polishing (CMP)
- Post CMP Cleaning
- Wafer Level Packaging (WLP)
- Wafer Bonding
- Wire Bonding
- Flip-Chip Assembly
- Parylene Coating

Metrology:

- Inspection Microscopy
- Scanning Electron Microscopy (SEM)
- Contact and Laser Non-Contact Profilometers
- Reflectometer
- Mapping 4-point Probe
- Ellipsometery
- Wafer Level, Automated, and Cryogenic Probes
- Full Electrical Characterization Suite