UNIVERSITY OF LOUISVILLE

MICRO/NANO TECHNOLOGY CENTER

Micro/Nano Technology Center (MNTC)

http://louisville.edu/micronano

FY18 Annual Report

Research at the speed of business

Executive Summary

This document serves as the MNTC's official annual report for FY18 ending June 30, 2018. The University of Louisville's Micro/Nano Technology Center (MNTC) is a service center established in 2004. The MNTC is consists of four labs:

- The class 100/1000 $30M 10,000 ft^2 cleanroom facility contains processing equipment that is used for fabrication of novel materials and devices.
- The Huson Imaging and Characterization Lab (HICL) contains scanning electron microscopes (SEM) and atomic force microscopes (AFM).
- The 1,000 ft^2 packaging and characterization lab.
- The 300 ft^2 design/layout/simulation lab for MEMS and IC devices.

Together, these four labs provide facilities and equipment for users to perform research on a wide variety of micro- and nano- technologies. The University of Louisville faculty, other academic institutions and external businesses utilize the facility for research, training and device prototyping.

Highlights:

- $8.8 Million is the total value of the grants that utilize the MNTC.
- Every $1 spent by a grant on the MNTC represents $129 in grant funding.
- Revenue was $294,000 in FY2018. This sets a record for the MTNC.
- External revenue was $183,000 in FY2018. This sets another record for the MNTC.
- Internal revenue increased 10% to $110,000 in FY2018.
- The number of internal and external clients (30 and 34, respectively) increased from the previous fiscal year.
- The cleanroom usage by clients doing their own processing increased 25% over the previous year.
- The MNTC hosted a summer program for high school students.
- The MNTC worked closely with Dr. Walsh on an NSF funded Research Experiences for Undergraduates where students from other universities learned to use the equipment in the cleanroom and made a photovoltaic cell.
- The MNTC participated in the Girls Rule STEM Summit on April 14, 2018.
- The merger between the Huson Nanotechnology Core Facility (HNCF) and the MNTC was completed.
- The name of the HNCF was changed to the Huson Imaging and Characterization Lab (Huson Lab, or HICL) to better reflect the use of the equipment in that room. This change was approved by the Huson family.
- A chemical mechanical polisher (CMP) was added to the packaging lab. This piece of equipment was donated by Indiana Integrated Circuits (IIC).
- The MNTC is part of the NSF funded NNIN. This site, lead by Dr. Walsh, is called the Multi-Scale Manufacturing and Nano Integration Node (MMNIN).

- The MNTC is supporting the 2018 KY Nano+AM Symposium to be held in August 2018.

Several changes to the personnel have occurred. The MNTC hired Jasmin Beharic to help maintain the Huson Lab. Xiaojin Wang left the MNTC in June and the MNTC is in the process of hiring his replacement.

Issues:

- Infrastructure maintenance needs to be addressed. See below.
- Funding sources for staff need to be addressed.
- The MTNC needs to increase the internal user base.

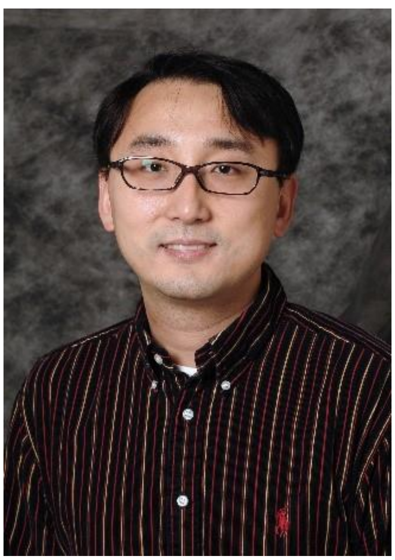
Meet Our Staff

Prof. Shamus McNamara
Executive Director

Julia Aebersold, Ph.D.
Manager

Evgenia Moiseeva, Ph.D.
Senior Process Engineer

Curt McKenna, M.Eng
Senior Process Engineer



Xiaojin Wang, Ph.D.
Senior Process Engineer
(left MNTC in June 2018)

Jasmin Beharic, Ph.D.
Senior Process Engineer
(started at MNTC in April 2018)

Mary Watson
Administrative Specialist

Mallory Lucas
Student Assistant

Education and Outreach

The MNTC was used as a laboratory for ECE 544, a graduate course titled "Microfabrication and MEMS Laboratory" and ECE 634, "MEMS Design and Fabrication". These classes provide hands-on experience with important microfabrication processes, semiconductor measurement techniques, MEMS microstructure design, modelling and MEMS testing for real world manufacturing applications.

For the third year, the MNTC hosted a NSF funded program that provides research experience for undergraduates (REU) during the summer (NSF Award #1542164, PI: Kevin Walsh). For 10-weeks, nine undergraduate students targeted initially from underrepresented populations were afforded the potentially life-changing opportunity to gain experience in micro/nano fabrication *up close and hands-on*. This year students from institutions within Kentucky included Western Kentucky University, Elizabethtown Community and Technical College and Georgetown College. The majority, however were from outside the state and included University of Texas-Austin, University of Wisconsin, Louisiana State and the University of Florida.

After an introductory period, the students paired with faculty mentors and chose a research project to pursue. Then they were trained by the experienced MNTC engineers to use state-of-the-art micro/nano fabrication and characterization tools. The students were integrated into their mentor's research group to help design, fabricate and test a variety of micro/nano devices. During this program the students participated in a unique *5-day Concentrated uFab Cleanroom Experience* where they fabricated and tested solar cells and gained hands-on experience with key microfabrication tools that they used during the remaining weeks.

On April 14th, 2018, the MNTC hosted a group of girls from the Girls Rule STEM Summit put on by the Speed School of Engineering. The girls gained an understanding on how nanoparticles are used in daily products such as paint and cosmetics. The discussion with the girls taught them how titanium dioxide is typically used as a colorant for paint, sunscreen and cosmetics, but is also used to make semiconductor devices and sensors for a myriad of applications. Titanium dioxide particles were placed in the MNTC's Zeiss Scanning Electron Microscope (SEM) in the Huson Imaging & Characterization Laboratory for the girls to gain an understanding of the size of the particles in the powder and their shape. After seeing the particles in the SEM each of the girls were able to make a lip balm for themselves to take home. The activity was a great method to connect engineering with items used every day. The MNTC was featured in this video about the Girls Rule STEM Summit: https://www.youtube.com/watch?v=rw84I36X02Y

On September 18, 2017 the cleanroom staff provided a guided tour of the MNTC to a ECE 210 Logic Design class offered by Dr. Welch. They were shown different equipment by staff complete with a hands-on experience. Afterwards, the staff also provided a seminar where they discussed some of the processes performed in the cleanroom and how the equipment they just saw is used. Finally, the staff discussed some of the recent projects that were performed at UofL to help the students understand some of the uses of the equipment.

The MNTC was again a featured stop for this year's E-Expo on March 3, 2018. This was an opportunity for the staff to provide short tours for prospective students to get them excited about the cleanroom. Over a two hour period, guided tours were given to an estimated 70+ people. The short tours were customized to the knowledge of the guests. Some tours focused on simple questions such as "What is a cleanroom?" and "What kind of things do you make?" while other tours for more knowledgeable guests went more in depth into what kind of capabilities our cleanroom may have compared to other cleanrooms and how different machines work.

Finally, the MNTC participated in reciprocal tours with Freudenberg Medical MIS, Inc. On February 15, 2018, the MNTC staff visited Freudenberg Medical MIS, Inc. On March 29, 2018, Freudenberg Medical MIS, Inc. visited the MNTC.

Facilities and Infrastructure

There are a significant number of unique ancillary systems that are used for the operation of the MNTC. Some examples include the reverse osmosis (RO) and deionized (DI) water systems, air makeup and filtration systems, chiller for the air makeup handler, motorized exhaust systems, acid waste neutralization, effluent abatement, compressed air and vacuum systems. Appendix B contains a summary of the facilities maintained by the center. When the Shumaker Research Building was completed an agreement was developed between the Speed School of Engineering (SSoE), the Executive Vice President for Research, and Physical Plant stipulating that the Speed School would provide financial support for the infrastructure maintenance and the MNTC would provide oversight to ensure that these systems were properly maintained. The financial support from the Speed School was estimated to be $32,000 per year in 2007. Compared to other buildings on campus and cleanrooms at other universities, this agreement is unusual as it shifts a significant financial responsibility from Physical Plant to the SSoE. Traditionally, this agreement has been implemented by the SSoE providing the MNTC with two accounts against which the MNTC charges for infrastructure maintenance. In FY2018, the SSoE cut the amount of money available for maintenance, resulting in a deficit of over $10,000. This is projected to be a problem in the next fiscal year as the money supplied by the SSoE is cut while the expenses increase. This is a major issue that will need to be addressed in FY2019.

In FY2018, the MNTC replaced the Toxic Gas Monitoring (TGM) system. This was a major upgrade to ensure the continued safe operation of the cleanroom.

The University of Louisville is constructing the new Belknap Academic Building in place of the former Crawford Gymnasium. This new building is located adjacent to the Shumaker Research Building. As part of the construction, the loading dock at the rear of the Shumaker Research Building is being re-routed and the liquid nitrogen access is being moved. The MNTC is heavily involved in the planning and execution of these changes to ensure continued operation of the cleanroom. These changes will be completed in the next fiscal year. In the meantime, the consequences of the construction included limited building access for deliveries, and an increase in electrical power failures and brown-outs that caused damage to several computers controlling equipment throughout the center. Uninterruptable power supplies were purchased and installed to mitigate future problems.

Research Equipment

The MNTC's 17-year old Deep Reactive Ion Etcher (DRIE) suffered a failure of the main turbo pump and controller in December 2017. This is a major problem because many research projects depend on the DRIE, and there is no substitute for this process within the state of Kentucky. The DRIE as a whole is no longer supported by the vendor, SPTS. The pump and controller are no longer manufactured by its vendor, Leybold. Furthermore, there are no replacement models by Leybold or any other pump company. The MNTC sent the pump to both Leybold and a third party vendor, but neither were able to repair it. Our best option at the end of FY2018 is to purchase a similar DRIE from Case Western Reserve University that is for sale. The entire system will be purchased from them for $40,000 in early FY 2019.

The used pump and controller from Case Western University will hopefully address our immediate needs, but the MNTC does not have a good recovery plan if this pump fails. In the long-term, the MNTC is pursuing two other options to maintain DRIE capability at UofL. First, an NSF MRI was submitted in Feb. 2017 to request a new DRIE. Unfortunately, this proposal was rejected. Second, the MNTC is pursuing an upgrade to the DRIE by a 3rd party vendor. This will upgrade the control system and enable us to use a turbo pump that is currently manufactured and supported.

This year, the service contract for the scanning electron microscopes (SEMs) in the Huson Imaging and Characterization Laboratory was extensively utilized to repair and maintain the instruments. This included nearly weekly trips by service personnel to maintain and troubleshoot the Supra SEM and a complete replacement of the computer on the EVO SEM. In addition to regular maintenance, the Peltier (thermo-electrically cooled) stage was repaired at a cost of ~$2,200, and the failed energy dispersive x-ray spectroscopy (EDS) system was replaced with a Quantax EDS from Bruker for $40k. The actively cooled SEM stage enables a rather unique capability of imaging biological and other "wet" sample in the microscope. The EDS system is the gold standard for determining elemental composition as a function of position near the surface of samples.

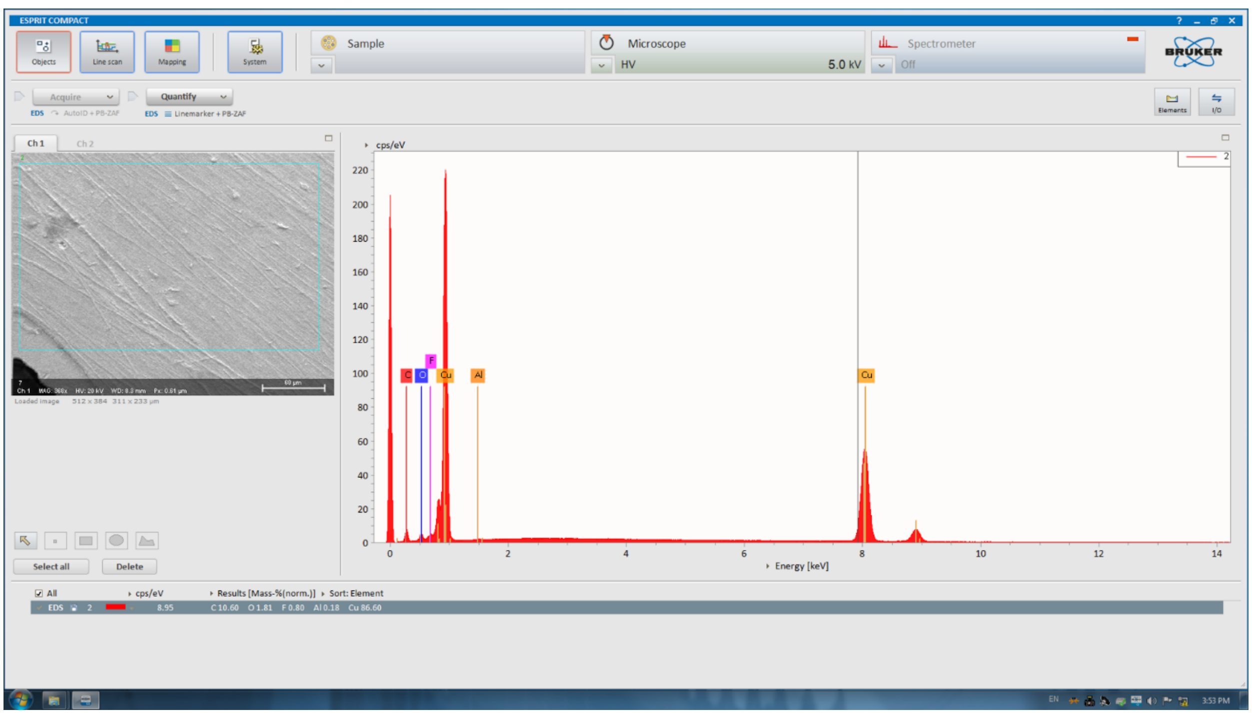


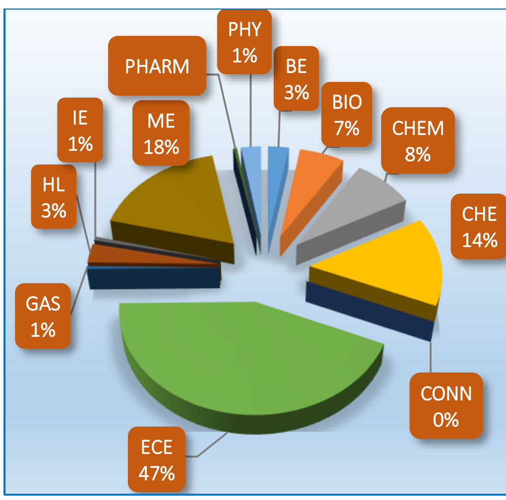
Figure 1: Example EDS image showing the elemental composition of a piece of copper. The sample is 86.6% copper, 10.6% carbon, and small amounts of oxygen, fluorine, and aluminum.

This year also saw the sale of a 10 year old combination electron microscope and electron beam writer, a Raith 150, back to the company for $18,000. This instrument was notorious for maintenance problems and functioned for no more than 6 months after it was purchased used from the University of Minnesota.

Facility Usage

The MNTC is utilized by both internal and external users. Faculty that perform research with the MNTC typically have post-doctoral or graduate students trained on tools needed for their process. When time, inexperience or logistical issues arise, the MNTC staff will step in to process for internal and external clients.

For the third straight year, the MNTC continued to experience external revenue outpacing internal revenue. Figures 2 and 3 breaks down the overall usage of the MNTC by department. The breakdown is in terms of revenue in Figure 2, and the breakdown is in terms of cleanroom entries in Figure 3.



BE	3,005.20	3%
BIO	7,482.40	7%
CHEM	9,140.75	8%
CHE	15,905.70	14%
CONN	-	0%
ECE	51,512.78	47%
GAS	504.00	1%
HL	3,300.00	3%
IE	671.50	1%
ME	21,429.63	18%
PHARM	471.00	1%
~~PHY~~	~~201.75~~	~~1%~~

Internal Clients	38%	$110,542.41
External Clients	62%	$183,884.03

Figure 2: Breakdown of the users of the MNTC by department.

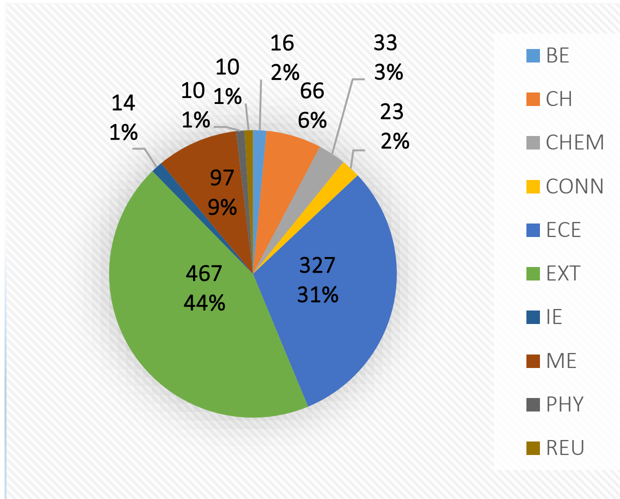


Figure 3: Days of cleanroom use by department.

The number of days of cleanroom access are reported in Table 1. This table does not include staff entries, even though staff entries often represent processing for external clients. This table also under-represents usage due to a class, summer camp, or other training where a group of students enter the cleanroom using the card access of a single instructor or TA. A day of cleanroom access may count one or more entries in a given 24-hour period. The number of days of access have increased from 857 in 2017 to 1,063 in 2018.

Table 1: Days of Cleanroom Access

Name	Dept.	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Total
ASPT	EXT	1	4	3	1	3	2	4	1		1	2	2	**24**
Intelligent Data Reco	EXT	1				1		2	1	1	1	2	2	**11**
Harnett, Cindy	ECE	2											5	**7**
Chromatography	EXT	2	3					1	2					**8**
Breath Diagnostics	EXT								1		8	5	11	**25**
Sunkara, Mahendra	CONN	5	12	4	2									**23**
Berfield, Thomas	ME	1			1	5		7	3	9	11	18	12	**67**
IIC Indiana Circuits	EXT	3				19	1	14	2	19	8	10	3	**79**
Baldwin, Richard	CHEM	6	4	5	3	3	6	1	2			1	2	**33**
Alphenaar, Bruce	ECE		1											**1**
Dobrokhotov	PHY			2		3								**5**
Fu,Xiao-An	CH		5	6	2	2	2	9	4	7	7	9	13	**66**
ECE	ECE		1	9	11	3	1			5	5			**35**
Fried, Joel	ME										1			**1**
MEMStim, LLC	EXT	33	40	33	28	18	27	25	24	21	17	20	13	**299**
Willing, Gerold	BE												2	**2**
Ngimat	EXT	3	1											**4**
Popa, Dan	ECE	21	5	9	2	20	8	11	3	4	5	17	23	**128**
Alphenaar, Bruce	ECE	1	24	2	8	5	3			1		8		**52**
Smadici, Serban	PHY								1				4	**5**
Walsh, Kevin	REU	8	1										1	**10**
McNamara, Shamus	ECE					1	15	19	16	15	20	6	11	**103**
Steinbach, Jill	BE							2	1				1	**4**
UofK	EXT												2	**2**
Vaon	EXT	4			1		6						4	**15**
Yang, Li	IE	3	2	3	3				1	2				**14**
Hsu, Keng	ME											2		**2**
Kopechek, Jonathan	BE		1	2	2	1		1	1	1			1	**10**
Williams, Stuart	ME	3	3	1	1		2	2	5	2	7		1	**27**
Yang, Zhong	ECE										1			**1**
		97	**107**	**79**	**65**	**84**	**73**	**98**	**68**	**87**	**92**	**100**	**113**	**1063**

The number of times each piece of equipment was used is presented in Tables 2 and 3. There were two significant changes compared to the prior fiscal year. The use of the SEMs increased approximately 40%, while the use of the AFMs dropped in half.

Table 2: Number of times each piece of equipment in the cleanroom was used.

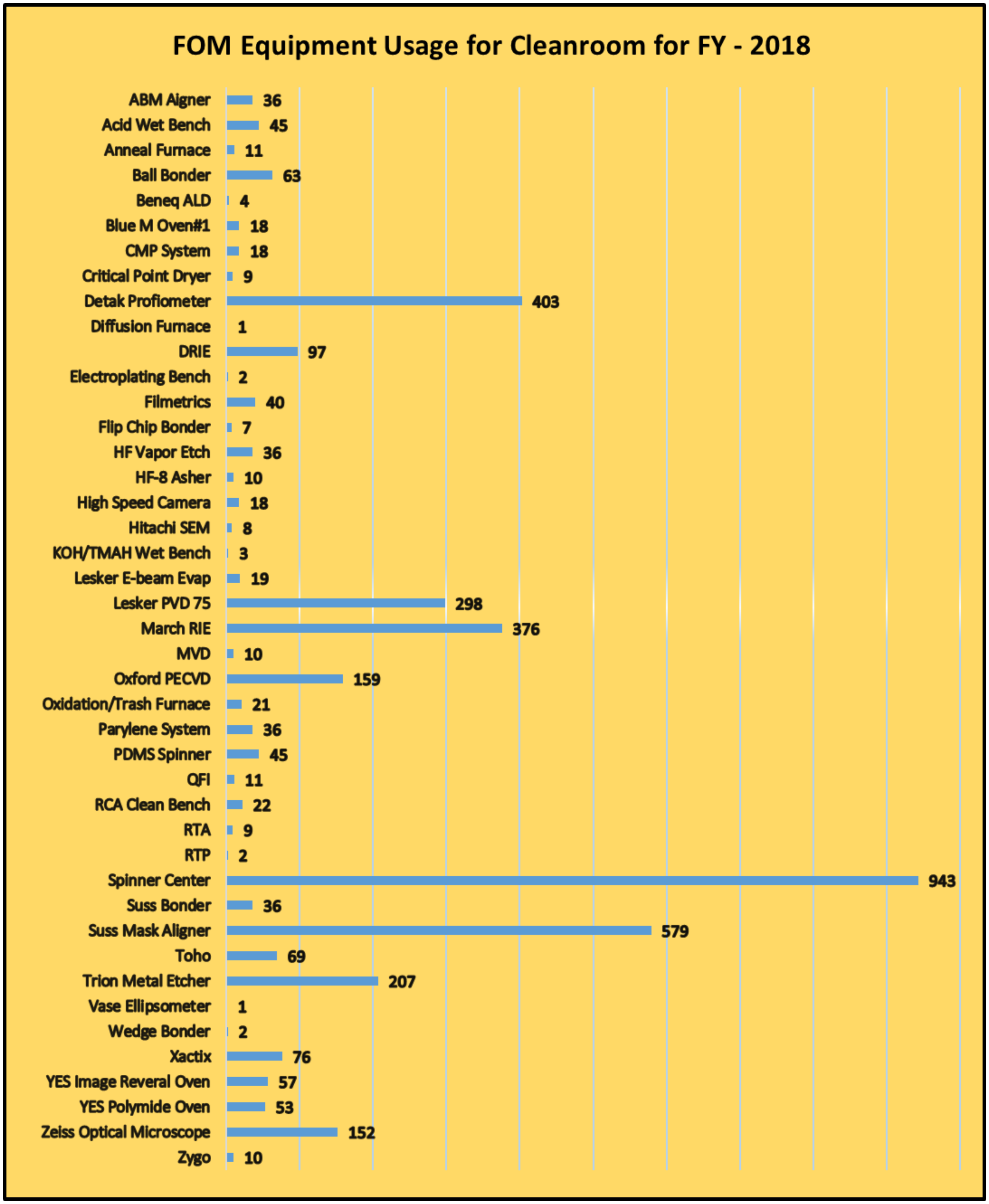
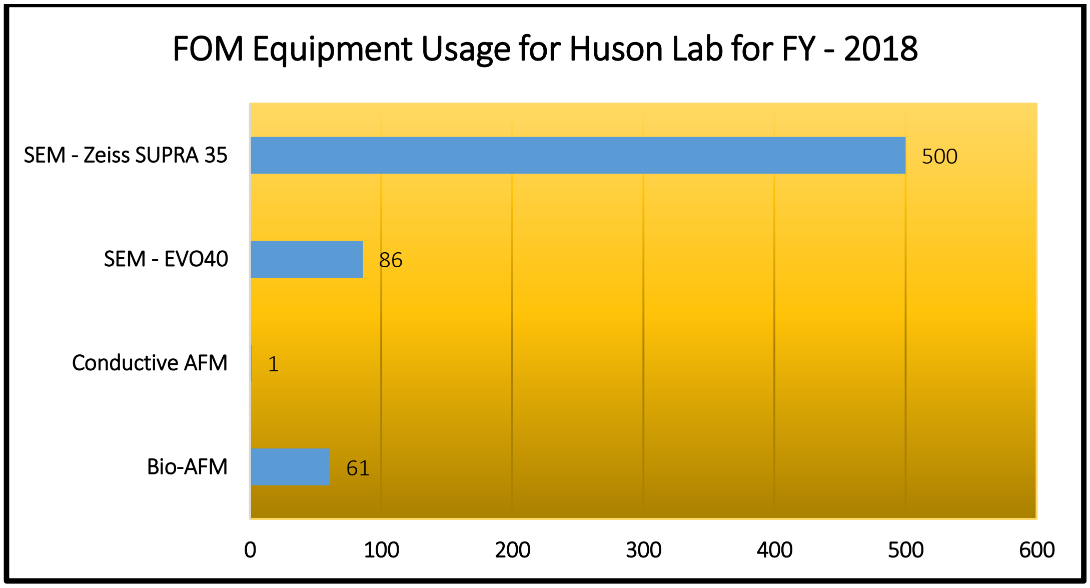


Table 3: Number of times each piece of equipment in the Huson Lab was used.



Financials

In FY2017, the MNTC was merged with the Huson Characterization and Imaging Lab (HICL). The HICL was originally called the Huson Nanotechnology Core Facility, but was renamed during FY2018 to better reflect the equipment and use of the room. Due to the merging of the accounting system, the MNTC received a one-time injection of funds.

The MNTC started the year with a deficit of $9,638. The MNTC ended FY18 with a surplus of $132,057.83. This is due to the one-time injection of funds, and because a $50,000 charge for the SEM maintenance contracts did not clear in FY18, but it will show up in early FY2019.

Table 4 shows the revenue and expenses for the MNTC. Excluding the one-time injection of funds, the revenue exceeded expenses for FY18 by approximately $30,000. Had the SEM maintenance charge hit in FY18, the MNTC would have lost $20,000 for the year. This shows that revenue and expenses are matched within 10% of each other, which is appropriate for a service center that is supposed to break even.

Table 4: Revenue and expenses for FY18.

Revenue	$292,403.63
Expenses	$261,781.75
Difference	$30,621.88

Revenue

Revenue is derived from two categories: internal revenue and external revenue. Table 5 lists the revenue by internal and external clients. Table 6 breaks down the revenue of the internal clients by their accompanying departments.

Table 5: Internal versus External Revenue

External Revenue	62 %	$183,884.03
Internal Revenue	38 %	$110,542.41
Total	100 %	$292,403.63*

* These do not add up due to a small accounting error that we have not identified.

Table 6: FY18 Internal Revenue Sources by Client and Department

Internal Revenue		Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	TOTALS
TOTAL		**15,855.70**	**-1,730.30**	**25,737.45**	**6,316.75**	**3,467.75**	**11,315.13**	**6,465.20**	**5,526.00**	**5,667.20**	**7,860.00**	**15,987.73**	**8,073.80**	**110,542.41**
Abell	GAS	252.00	252.00											504.00
Alphenaar	ECE	152.80		2,817.70		2,308.80		1,206.30	1,262.60	87.60	1,261.90	388.00	1,428.80	10,914.50
Atre	ME				2,200.00									2,200.00
Baldwin	CHE	1,853.40		1,449.60	172.30		581.20	170.50	42.90		109.80		20.50	4,400.20
Bara	BIO			45.00										45.00
Berfield	ME	1,302.10		77.90		57.25		94.00	640.00	526.60	2,775.90	2,492.70	1,740.00	9,706.45
Cohn	ECE			1,400.00				93.00						1,493.00
ECE Class	ECE						7,427.63							7,427.63
Farag	ECE	480.00												480.00
Fu	CHE			3,474.50				45.00	561.70	282.80	122.90	833.10	370.00	5,690.00
Fried	CHE											105.00		105.00
Grapperhaus	CHEM	90.00		225.00		180.00		135.00		135.00	45.00	405.00	90.00	1,305.00
Gupta	PHAR			471.00										471.00
Harnett	ECE	237.50		885.00	173.50				179.50			333.35		1,808.85
Hsu	ME											125.00	249.20	374.20
Huson Lab	HL	3,300.00												3,300.00
Keynton	BE			193.50										193.50
Kopechek	BE	369.00		840.70		530.00	40.00		472.00	40.00	40.00			2,331.70
Lian	ME													0.00
McNamara	ECE							182.00		2,197.30	2,376.50	6,107.00	1,500.00	12,362.80

O'Toole	BIO			2,318.00		202.00			299.00		64.50	233.50	900.00	4,017.00
Park	ME													0.00
Popa	ECE	2,522.10		4,668.60	145.00		2,450.70	1,949.40	1,151.30	400.00		1,889.60	1,574.30	16,751.00
Remold	BIO	45.00					45.00				45.00			135.00
Running	BIO		1,100.00											1,100.00
Smadici	PHY		-3,082.30	86.75			45.00				70.00			-2,880.55
Soucy	BE	45.00		300.00	45.00				45.00			45.00		480.00
Spurgeon	CnCtr													0.00
Steinbach	BIO				1,100.00				175.00	226.00		393.40	66.00	1,960.40
Stolowich	CHEM	90.00			45.00		90.00	45.00			45.00	90.00	45.00	450.00
Sunkara	CHE	2,713.10		2,027.10	724.70		245.60							5,710.50
Walsh	ECE	175.00		100.00										275.00
Williams	ME	1,913.70		3,368.10	53.00	63.70			517.00	502.90	678.50	2,052.08		9,148.98
Worley	BIO							90.00	45.00	45.00	45.00			225.00
Yang	IE			515.50		126.00	30.00							671.50
Zamborini	CHEM			338.50	1,478.25			2,320.00		1,224.00				5,360.75
Zhang	CHEM	315.00		135.00	180.00		360.00	135.00	135.00		180.00	495.00	90.00	2,025.00

The MNTC helps the faculty at the University of Louisville obtain grants. The following table shows the PIs who use a grant to pay for their MNTC invoices, the total grant award sizes, and the leverage between the MNTC revenue and the grant size. The grants are significantly greater than the MNTC revenue because the MNTC revenue is really just a "supply line" on a grant. Grants also pay for other supplies, tuition, and salaries. This table shows several key things:

1. The total amount of the grants enabled by the MNTC is almost $9 million.
2. The total grant dollars for the Speed School of Engineering is $6.7 Million. This is a substantial portion of the SSoE total grant dollars.
3. For every $1 in MNTC revenue from a grant, the faculty bring in $129 in grant funds.

Table 7: Grants and contracts that utilized the MNTC in FY2018.

PI	Total Grant Size	MNTC Revenue	Leverage
Walsh (SSoE)	$ 2,472,164	$275	8990:1 *
Alphenaar (SSoE)	$ 1,050,000	$10,915	96:1
O'Toole (SSoE)	$ 1,047,933	$4,017	261:1
Williams (SSoE)	$ 516,900	$9,149	56:1
Fu (SSoE)	$ 449,390	$5,690	79:1
Steinbach (SSoE)	$ 423,500	$1,960	216:1
Berfield (SSoE)	$ 332,757	$9,706	34:1
Atre (SSoE)	$ 181,267	$2,200	82:1
Yang (SSoE)	$ 77,685	$672	116:1
Kopechek (SSoE)	$ 75,000	$2,332	32:1
McNamara (SSoE)	$ 75,000	$12,362	6:1

Mauer (A&S)	$ 540,914	$1,100	492:1
Grapperhaus (A&S)	$ 450,000	$1,305	345:1
Zamborini (A&S)	$ 438,605	$5,360	82:1
Running (A&S)	$ 181,267	$1,100	165:1
Abell (Med)	$511,000	$504	1014:1
Total:	**$8,823,382**	**$68,647**	**129:1**

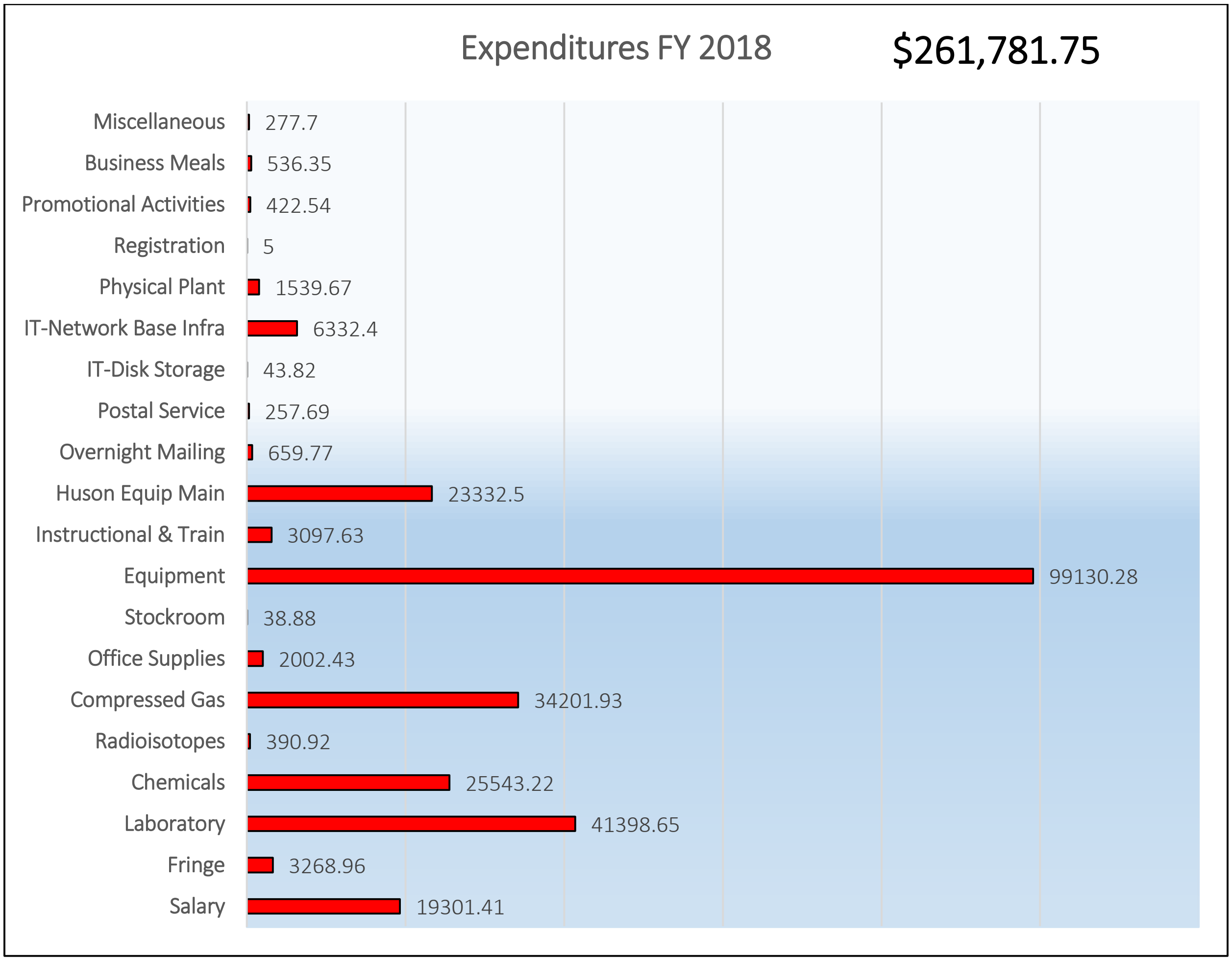
* This leverage value is artificially high because revenue from REU students was allocated to the mentors, which also artificially lowers the leverage for the mentors. The overall leverage is unaffected.

Expenses

The breakdown of the MNTC expenses are in Table 8. A few items of note are:

- The Huson equipment maintenance line is the cost of the Bruker EDS.
- The equipment line includes the cost of the TGM upgrade as well as equipment maintenance expenses.
- The salary line includes a one-time charge that the Dean's office forced upon the MNTC to pay to cover the cost of Xiaojin Wang's unpaid vacation time.
- The single largest component from the "Compressed Gas" category is for liquid nitrogen.

Table 8: Breakdown of expenses for FY 2018.



Historical Perspective and Future Trends

Figures 4 & 5 show historical data of revenues and expenses for the lifetime of the MNTC since 2004. It is noted that the current cleanroom did not come online until 2007 in the Shumaker Research Building after it was moved from Lutz Hall.

There are several conclusions that may be drawn from Figures 4. First, the overall revenue is at an all-time high. Second, the external revenue outpaced internal revenue for the third straight year and the external revenue is at an all-time high. Third, internal revenue has increased 10% compared to the prior year.

Figure 6 shows an increase in the number of internal clients (i.e. students, post-doctoral students, etc.) using the facility, while the number of faculty remained the same as FY 2017. The number of external users reached an all-time high of 34.

Figure 7 shows the number of cleanroom accesses per month (excluding staff). This graphs shows that the use of the cleanroom has increased over the past three years.

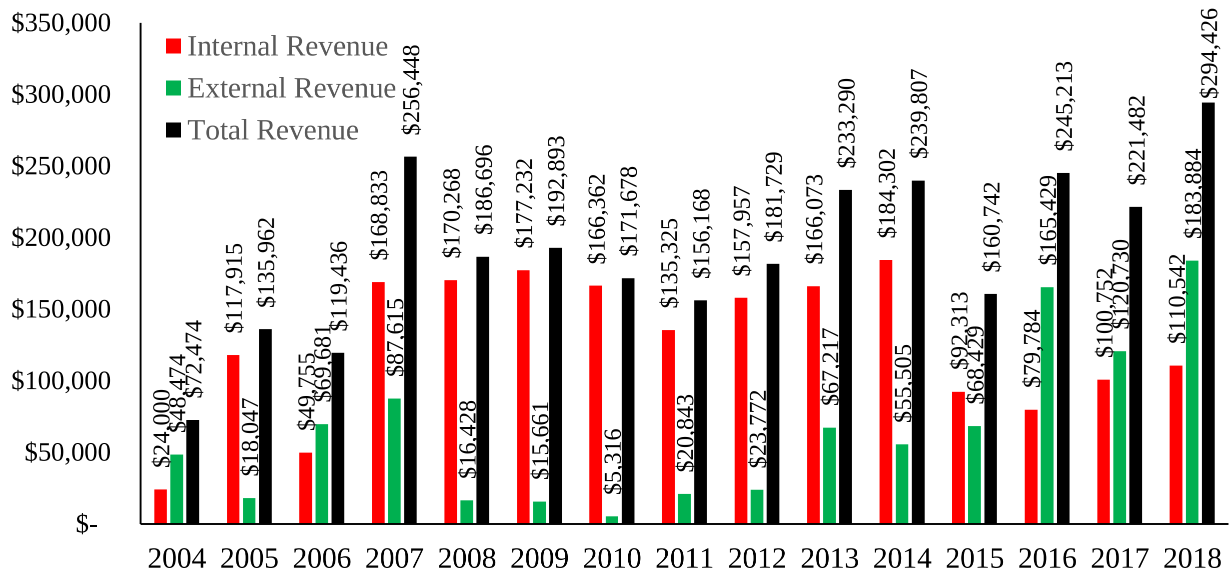


Figure 4: A comparison of internal and external revenue over the life of the MNTC.

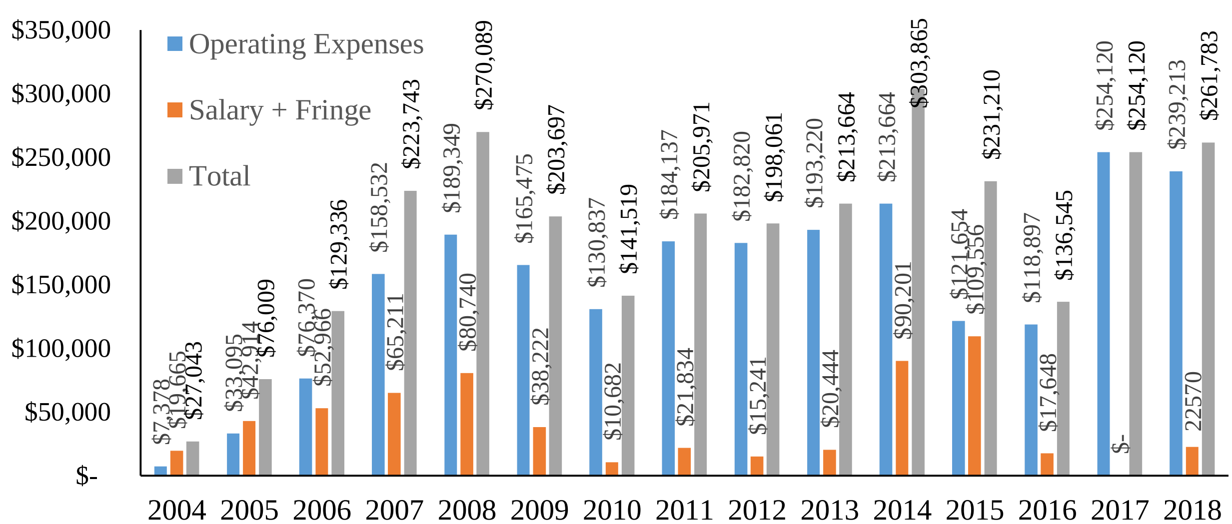


Figure 5: A comparison of the expenses over the life of the MNTC.

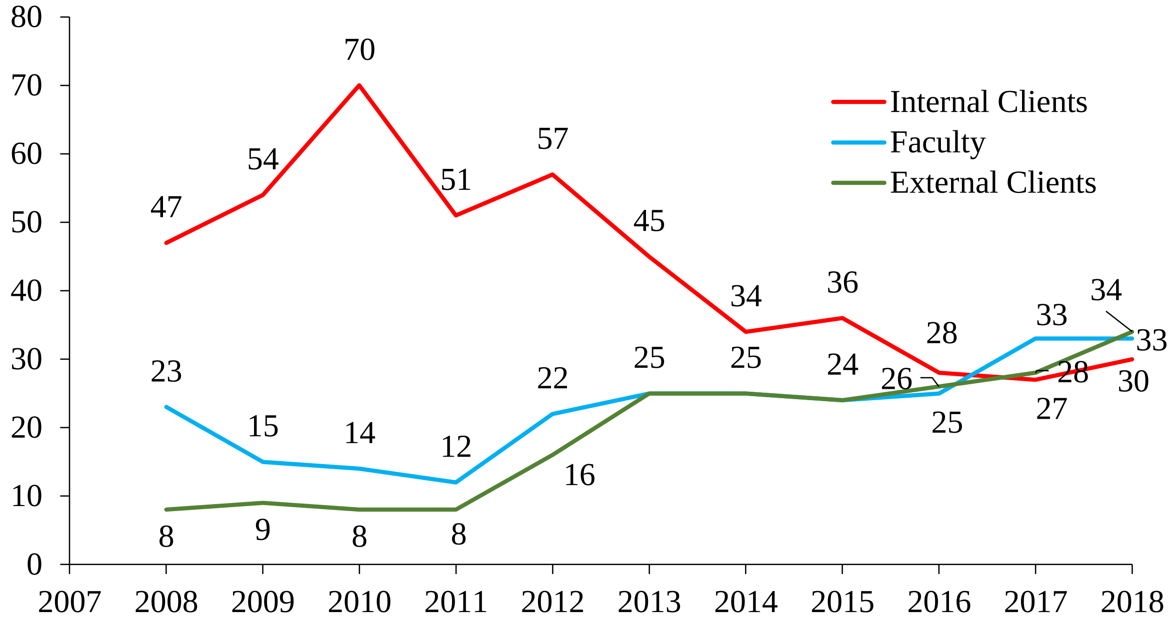


Figure 6: Number of clients who use the MNTC, reported by internal clients, faculty, and external clients.

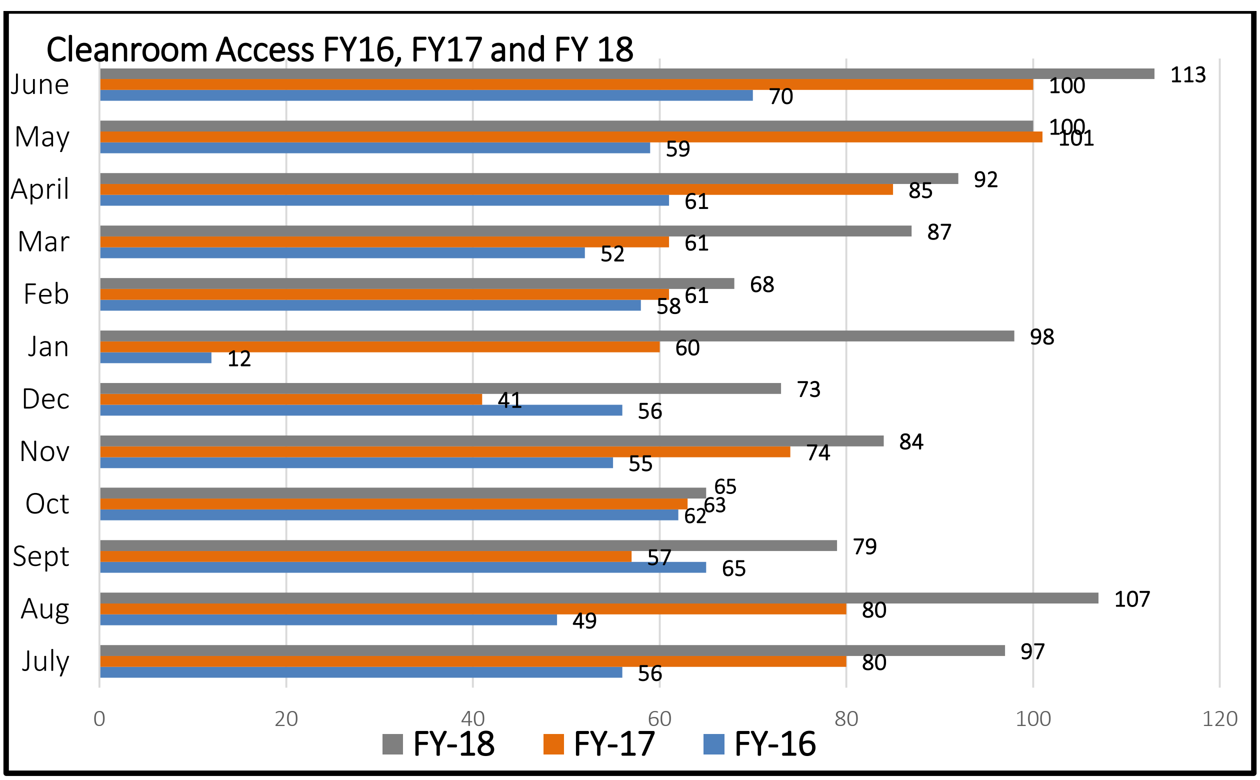


Figure 7: Comparison of the number of cleanroom accesses per month for the

past three fiscal years.

Appendix A: Equipment

The MNTC has many capabilities available for clients to use while carrying out their research in the facility. The following is a listing showing the equipment by category.

Photolithography

Photomasks and Direct Write:
A Heidelberg DWL 66FS UV laser patterning system for the generation of photomasks and direct write onto substrates, such as wafers or individual die. The Heidelberg can provide write resolution capabilities down to 600 nm for substrates up to 9" square. Additionally, it can perform direct write on wafers or individual die and write 128 levels of grayscale.

Contact Photolithography: Suss MA6 and AB-M mask aligners provide front and backside alignment capabilities. Alignment can be performed on individual die up to 6" wafers.

Image Reversal: An ammonia based photoresist image reversal systems by YES that can also perform HMDS vapor prime.

Thin Film Deposition

Plasma Enhanced Chemical Vapor Deposition system: Oxford PECVD system capable of depositing silicon nitride, silicon dioxide, oxynitride, amorphous silicon (undoped/doped), polycrystalline silicon (undoped/doped), silicon carbide, silicon nanowires and generation of carbon nanotubes. The Oxford tool includes a 700°C high temperature chuck and a TEOS delivery system.

Sputtering: Lesker PVD 75 three source tool and Technics two source system for deposition of both metals and dielectrics. The PVD 75 features RF, DC, RF/DC stacking and ion beam assisted sputtering, which includes throttled pressure control and reactive gas mixing.

Electron Beam and Thermal Evaporation: A Lesker electron beam and a Denton thermal evaporation system for depositing a variety of thin films on substrates up to 6".

Parylene Coating: An SCS vapor deposition tool for Parylene C and Parylene N.

Molecular Vapor Deposition: An Applied MST MVD system for the conformal deposition of hydrophobic coatings for lubricants, anti-stiction layers, molecular glues, reactive adhesion layers, or to tune hydrophilicity of a substrate.

Electroplating: Pulse or continuous DC electroplating systems for Au, Cu and Ni processing using high aspect ratio photoresists.

Atomic Layer Deposition: A Beneq ALD system for the deposition of alumina (Al_2O_3), zinc oxide (ZnO) and titanium dioxide (TiO_2) films.

Thermal Processing

Oxidation, Diffusion & Annealing: Multiple tube furnaces for thermal processes include wet/dry oxidation, high temperature annealing and boron/phosphorous diffusion.

Rapid Thermal Processes: An RTP system for silicon based gate oxide growth and rapid thermal annealing of implanted layers. Additionally, a Rapid Thermal Annealing (RTA) system is available for annealing metal contact layers.

LPCVD Furnace: Low pressure chemical vapor deposition of polysilicon for 4”and 6” wafers.

Vacuum Cure Oven: Multiple programmable vacuum ovens capable of heating to 400°C.

Etching, Machining and Bonding

Deep Reactive Ion Etch (Silicon): An STS DRIE tool for anisotropic (vertical only) silicon deep trench etching using the Bosch process. This tool has a pulsed plate bias to minimize “footing” at oxide etch stops.

Anisotropic Silicon Wet Etching: KOH and TMAH wet etchants for silicon substrates.

Plasma Etching: Multiple reactive ion etching (RIE) and oxygen/plasma based systems capable of providing selective silicon, SiO2 and Si_3N_4 etching and oxygen plasma ashing.

Trion Phantom III Reactive Ion Etch System: A Trion ICP Phantom Minilock III Etcher for etching nitrides, oxides, polymers, metal, compound semiconductor and other materials using fluorine (CHF_3, SF_6, CF_4), oxygen and corrosive (Cl_2 and BCl_3) chemistries.

SPTS Anhydrous HF Etcher: A vapor phase anhydrous-HF etcher that selectively etches SiO_2 without affecting silicon or most metals, such as aluminum.

Xenon Di-Fluoride Etching: A Xactix XeF_2 system for isotropic (vertical and lateral) dry etching of silicon microstructures prone to stiction.

Wafer Level Bonding: A Suss SB6e for wafer level bonding of silicon/glass anodic bonding, glass/glass or gold/gold thermal compression bonding and Si/Si fusion bonding. All processes are capable of a 5 micron alignment with the adjacent Suss MA6 mask aligner.

Ion Milling: A two source ion beam based etching system capable of nanometer scale etching.

Critical Point Dryer: A critical point CO_2 dryer for drying substrates, where stiction needs to be avoided.

Packaging

Dicing: A Disco programmable saw for dicing silicon, glass and alternative substrates up to a 6" diameter.

Wire Bonding: Multiple Kulicke & Soffa wedge, ball and deep access wire bonders for aluminum and gold 1-mil wire bonding.

Flip Chip Packaging: A Finetech Fineplacer "Pico" system for flip chip die placement accuracy up to 5 microns. This tool can accommodate surface-mount components SMCs with a side length up to 17 mm.

Metrology & Testing

Thin Film Stress Measurement: A Toho thin film stress measurement system using non-contact multi-wavelength surface flatness techniques for evaluating thin film stresses from room temperature to 500°C.

3-D Contact Profiling: A Veeco contact profilometer that can provide down to a 7.5 angstrom step height measurement with a vertical range up to 1 mm and a maximum scan length of 200 mm. The low stylus force allows scratch-free measurement of soft materials.

Non-contact 3D Optical Profiler: A Zygo non-contact profilometer that is capable of measuring surface topology of micro scale systems. Its capabilities include field stitching and dynamic module for measuring MEMS devices during actuation.

Ellipsometry: VASE Woollam Variable Angle Spectroscopic Ellipsometer for non-contact thin film thickness measurements and determining optical constants of single and multilayer films.

Mid-wave Thermal Imaging System: A Quantum Focus Instruments (QFI) thermal imaging system for capturing thermal images and video of devices featuring 0.1°C temperature and 5 µm spatial resolutions.

Filmetrics systems for non-contact thin film thickness measurements and determining optical constants of single and multilayer films.

Testing: Veeco FPP-5000 Four-point Probe and suite of probe stations and electronic test instruments for measuring sheet resistance, TCR, I-V curves, C-V curves and device performance.

SEM / AFM Imaging

Scanning Electron Microscope (SEM): Zeiss Supra 35 with sub 100 nm resolution, STEM detector, Backscatter Detector, Energy Dispersive X-Ray (EDS) Spectroscopy, Zyvex 5 nm resolution nano-manipulator and gold-palladium sputter coater.

Scanning Electron Microscope (SEM): Zeiss EVO-40 Extreme Variable Pressure (3000 Pa) scanning electron microscope, Peltier stage -25C to 50C, Humidity control option with Heating Peltier stage up to 1100°C.

Atomic Force Microscope: Asylum MF3D Bio-AFM with liquid cell option for biomaterials and thermal/vibration control and an additional Asylum MF3D Conductive AFM.

Design, Layout and Modeling

A full suite of computer-based tools for photo mask layout, custom analog and digital IC design, micro-scale tooling, and 2D/3D finite element models for virtual device evaluation. Software packages include: Tanner EDA, Silvaco TCAD, CoventorWare®, Solid Edge. These packages are available for academic purposes only.

Appendix B: MNTC Facilities

The MNTC is located throughout the Shumaker Research Building. Some locations are solely used by MNTC or other areas contain infrastructure that are maintained by physical plant. The following is list of locations and major uses of these locations:

SRB 106: Huson Imaging and Characterization Laboratory - This 1,200 ft^2 facility houses the MNTC's complete suite of Scanning Electron Microscopes, Atomic Force Microscopes, thin film characterization system and thermal imaging capabilities.

SRB 121: Cleanroom & Chase Areas - The cleanroom is a 10,000 ft^2 class 100/1000 facility that houses multiple pieces of equipment available to clients. Chase areas are corridors adjacent to the open bay areas of the cleanroom and along the exterior wall of the cleanroom. This space is used for return air from the cleanroom, various utilities, location of chillers, pumps and other auxiliary equipment, storage for supplies and chemicals, gas cabinets, and transport of equipment and supplies in and out of the cleanroom.

SRB 119A: Hazardous Production Materials (HPM) Room – This explosion proof room contains chemical storage cabinets for chemicals waiting to be transferred to the service corridor, gas cabinets for pyrophoric and toxic gases with an associated scrubber and several inert cylinders that supply the cleanroom.

SRB 119: Loading Dock - This room is adjacent to the HPM room, service corridor and outdoor loading dock. The area is utilized to move equipment in and out of the cleanroom and is the location of the primary DI water tank and pumping station that supplies the cleanroom. The location also serves as the 90 day satellite location for the pickup of non-hazardous or hazardous waste for DEHS.

SRB 199J: Service Corridor – This backside hallway allows for entry chemical storage, movement of supplies and tools into the cleanroom, gas cabinets, utilities and fire exits.

SRB 111: Machine Shop - This dirty space is utilized for repair of equipment and sandblasting of components from the cleanroom to remove deposition buildup.

SRB 113B – DI Water Filtration Station – This small room houses the primary and secondary filter banks for DI water provided to the cleanroom.

SRB142 – Interstitial Space - This door provides access to the elevated catwalk above the cleanroom, which house fourteen air handlers to receive and circulate incoming air from the air make up handler in the penthouse and chase areas in the cleanroom. The air handlers discharge filtered air through the HEPA filters.

SRB 139B: Fire Command Center – This small room houses the TGM server and fire command center.

SRB 213: Packaging Lab - This room contains packaging equipment for wirebonding, Parylene C deposition, thermal imaging, lapping and polishing and a variety of bench top test equipment.

SRB 226: TCAD Lab - This room contains computer workstations for performing simulations and developing CAD drawings for photomasks.

SRB Liquid Nitrogen Cage – This caged and enclosed area contains the 6,000 gallon liquid nitrogen tank and liquid to gas expansion system that supplies the cleanroom. A fill area is adjacent to the tank that allows clients to refill LN_2 dewars. This area also serves as the outdoor bunker for the 5% and 100% Silane gas cabinets.

SRB Basement: The basement contains the cleanroom's vacuum and compressed air systems, chiller for its dedicated air makeup handler in the penthouse, RO water filtration and pumping system and acid waste neutralization (AWN) system and back-up generator. This space is serviced by Physical Plant with exception to the AWN system.

SRB Penthouse: The MNTC's dedicated air makeup handler and three exhaust systems (acid/caustic, solvent and silane) are located in this area. This space is serviced by physical plant, but expense and labor are paid by the MNTC.

Appendix C: MNTC Rates

This appendix contains the rates in effect in FY 2018.

There are two rate schedules shown in this appendix. First is the rate effective July 1, 2017. Following that is the rate effective Jan. 1, 2018. The revised rate reflects an increase in the staff hourly rate to $100 / hour for external customers to better reflect actual salaries.

UNIVERSITY OF LOUISVILLE
MICRO/NANO TECHNOLOGY CENTER RATES

http://louisville.edu/micronano

RATES EFFECTIVE FOR JULY 1, 2017

Go to the link below to learn how to gain access to the cleanroom.

http://louisville.edu/micronano/users/how-to-become-a-cleanroom-user

Clients of the MNTC will be charged a daily cleanroom access fee and associated equipment fees. All users will be charged including faculty.

Daily Access Fee for the Cleanroom: Internal User: $10/day
External User: $34/day

Equipment Usage Fee: The usage rates are defined below for internal users, external users and services. A cap of **$1,500** per month per researcher will be implemented for equipment usage, access fees and training for internal users only. This cap does not include consumables (wafers, wafer containers, tweezers, etc.) or services performed by the MNTC staff (i.e. dicing and photomasks). **A cap is not instituted for external users.**

Equipment	Internal Rate	External Rate	Service Center Rate
Flip Chip Bonder	$0.50/min	$0.75/min	$60/hour + Internal or External Rate
QFI Thermal Imaging System	$0.50/min	$0.75/min	
Zygo Optical Laser Profilometer	$0.50/min	$0.75/min	
Critical Point Dryer	$0.50/min	$0.75/min	
Ball /Wedge Bonder	$0.60/min	$0.90/min	
Hi-Speed Camera	$0.60/min	$0.90/min	
March RIE	$0.60/min	$0.90/min	
Rapid Temperature Processing (RTP/RTA)	$0.60/min	$0.90/min	
ABM Aligner	$0.70/min	$1.05/min	
DRIE	$0.70/min	$1.05/min	
Lesker E-beam Evaporator (**extra for Au)	$0.70/min	$1.05/min	
Molecular Vapor Deposition (MVD)	$0.70/min	$1.05/min	
Oxford PECVD	$0.70/min	$1.05/min	
Lesker PVD 75 (**extra for Au and Pt)	$0.70/min	$1.05/min	
Denton Thermal Evaporator	$0.70/min	$1.05/min	
Suss Aligner	$0.70/min	$1.05/min	
Suss Bonder	$0.70/min	$1.05/min	
Technics Sputterer	$0.70/min	$1.05/min	
Trion Metal Etcher	$0.70/min	$1.05/min	
Hitachi SEM	$1.00/min	$1.50/min	
Xactix XeF_2 Isotropic Etching	$1.00/min	$1.50/min	
HF Vapor Etcher	$1.00/min	$1.50/min	
Photoresist Spinners	$1.00/min	$1.50/min	
Beneq ALD	$1.00/min	$1.50/min	
Chemical Mechanical Polishing (CMP)	$1.00/min	$1.50/min	
LPCVD Polysilicon Tube	$3.00/min	$6.00/min	

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	Equipment	Internal Rate	External Rate	Service Center Rate
	HF-8 Axic Barrel Asher	$30/batch	$41/batch	$60/hour + Internal or External Rate
	Reynolds Electroplating Bench	$30/batch	$41/batch	
	Tube Furnace (Anneal, Oxidation, Diffusion)	$40/batch	$54/batch	
	RCA Clean Hood (RCA Cleaning)	$40/batch	$54/batch	
Wet benches	**305 Acid Hood** (Nanostrip, Aluminum Etch, Chrome Etch, BOE)	$40/batch	$54/batch	
	307 Base Hood (KOH, TMAH)	$40/batch	$54/batch	
	308 EDP Etch Hood (Gold Etch, Copper Etch)	$40/batch	$54/batch	
	YES Polyimide Oven	$45/batch	$65/batch	
	YES Image Reversal Oven	$45/batch	$65/batch	
	Parylene Deposition System	$45/batch	$65/batch	

ADDITIONAL FEES

Fees	Internal Users	External Users
Training	$60/hour and is not included with tool usage fee	
****Gold/Platinum Deposition**	$20/0.10 gram	$30/0.10 gram
Dicing (*Process performed by MNTC staff ONLY, Service fee included*)	$60/1st-hr flat rate $1/minute after 1st hr	$85/1st-hr flat rate $1/minute after 1st hr
Dewar Fill (LN_2)	$45/fill	N/A

Photomasks (*Process performed by MNTC staff ONLY, Service fee included*)	Internal Users	External Users
4" substrates Resolution 6 um and larger	$125	$175
6" substrates Resolution 6 um and larger	$225	$275
CAD File Development	$60/hour	

Smaller resolutions can be obtained down to 1 um for photomasks. Contact us for details and pricing at julia.aebersold@louisville.edu

The usage fee is not assessed on these items but does not exclude MNTC labor fee:

Dektak Profilometer, Filmetrics, Stereoscopes and Optical Microscopes, Toho Thin Film Stress Measurement System Spin Rinse Dryers Vacuum Ovens Four Point Probe, Probe Station, Solvent Wet Bench, Developer Wet Bench (LF8-1A Solvent Develop Hood), Developer Wet Bench (115X Base Develop Hood), Spinner Benches (153X Hot Plate Spinner Combo), PDMS Spinner, Blue Ovens.

HUSON NANOTECHNOLOGY CORE FACILITY

Equipment	Membership (Internal Users ONLY)	Hourly Rates
AFM's (Bio and Conductive) Ellipsometer Thermal Imaging System	$300 Membership Fee per User per Year	
SEM's (Supra and EVO) AFM's (Bio and Conductive) Sputter Coater Ellipsometer Thermal Imaging System	$1,100 Membership Fee per User per Year	
AFM's (Bio and Conductive) Sputter Coater Ellipsometer Thermal Imaging System		Internal: $25/hour External: $35/hour Training/Staff Time: $60/hour
SEM's (Supra and EVO)		Internal: $50/hour External: $100/hour Training/Staff Time: $60/hour

CONSUMABLES/SUPPLIES

Item	Internal Rate	External Rate
4"Non-Oxidized Prime SSP Wafers	$25/wafer	$34/wafer
4"Oxidized Prime SSP Wafers	$35/wafer	$48/wafer
4"Non-Oxidized Prime DSP Wafers	$35/wafer	$48/wafer
4"Oxidized Prime DSP Wafers	$45/wafer	$61/wafer
6"Non-Oxidized Wafers	$35/wafer	$43/wafer
4"Borosilicate Glass Wafers	$25/wafer	$34/wafer
4"Wafer Container	$4/each	$5.44/each
4"Wafer Container Lid	$4/each	$5.44/each
8.5"×11" Cleanroom Notebook	$12/each	$16.32/each
Metal Tipped Wafer Tweezers	$50/each	$68.00/each
Plastic Tipped Wafer Tweezers	$50/each	$68.00/each
Petri Dishes	$3/each	$4.08/each
Gel pack	$8/each	$10.88/each
Microscope Slides	$5/box	$6.80/box

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UNIVERSITY OF LOUISVILLE
MICRO/NANO TECHNOLOGY CENTER RATES

RATES EFFECTIVE FOR January 1, 2018

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http://louisville.edu/micronano/users/how-to-become-a-cleanroom-user

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UNIVERSITY OF LOUISVILLE
Micro/Nano Technology Center

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Equipment	Internal Rate	External Rate	Service Center Rate Internal	Service Center Rate External
Flip Chip Bonder	$0.50/min	$0.75/min		
QFI Thermal Imaging System	$0.50/min	$0.75/min		
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Chemical Mechanical Polishing (CMP)	$0.50/min	$0.75/min		
Critical Point Dryer	$0.50/min	$0.75/min		
Ball /Wedge Bonder	$0.60/min	$0.90/min		
Hi-Speed Camera	$0.60/min	$0.90/min		
March RIE	$0.60/min	$0.90/min		
Rapid Temperature Processing (RTP/RTA)	$0.60/min	$0.90/min		
ABM Aligner	$0.70/min	$1.05/min		
DRIE	$0.70/min	$1.05/min		
Lesker E-beam Evaporator (**extra for Au)	$0.70/min	$1.05/min	$60/hour for training and labor (does not include tool rate)	$100/hour for training and labor (does not include tool rate)
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Oxford PECVD	$0.70/min	$1.05/min		
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Suss Aligner	$0.70/min	$1.05/min		
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HUSON NANOTECHNOLOGY CORE FACILITY

<table>
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Metal Tipped Wafer Tweezers	$50/each	$68.00/each
Plastic Tipped Wafer Tweezers	$50/each	$68.00/each
Petri Dishes	$3/each	$4.08/each
Gel pack	$8/each	$10.88/each
Microscope Slides	$5/box	$6.80/box