UNIVERSITY OF WATERLOO | Quantum NanoFab

Quantum NanoFab Core Facility

Two-year special Annual Report
2012/13 to 2013/14

Covering period May 2012 to August 2014

Vito Logiudice

6/30/2015

Quantum NanoFab Fit-out Activities (Winter 2014)

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April 2013: Ontario Premier Kathleen Wynne visits *Quantum NanoFab* with Raymond Laflamme and Mike Lazaridis

SPECIAL THANKS

We remain deeply indebted to:

Mike and Ophelia Lazaridis
The University of Waterloo
Canada Foundation for Innovation
Ontario Ministry of Economic Development and Innovation
Industry Canada

A huge debt of gratitude is owed to two exceptional people whom played exceedingly important roles during the many phases of the *Lazaridis Quantum-Nano Centre* project:

Byron Murdock *Senior Projects Construction Co-ordinator, Plant Operations,* for his leadership, perseverance, diligence and outstanding work ethic throughout the many challenging chapters of the building construction and lab fit-out projects.

Scott Nicoll *Manager, Space Planning, Office of the Associate Provost, Resources*, for his exceptional and innumerable contributions throughout all stages of QNC design, construction and lab fit-out activities. His role in successfully and safely ramping up lab operations post-occupancy cannot be overstated. Special thanks for being a trusted friend.

Special thanks to the following people and their respective teams whom together contributed greatly towards the implementation of our excellent infrastructure:

Stephen Cook	*Manager, Procurement & Contract Services*
Dan Parent	*Director, Design & Construction Services, University Architect, Plant Operations*
Rick Zalagenas	*Director, Maintenance & Utilities, Plant Operations*

In addition, we are grateful to the following individuals for their strong support throughout the construction and fit-out phases of the *Quantum NanoFab* facility:

Arthur Carty	*Executive Director, Waterloo Institute for Nanotechnology (WIN)*
David Cory	*Faculty, Quantum NanoFab Scientific Director (representing IQC)*
George Dixon	*V.P., University Research*
Dennis Huber	*V.P., Admin and Finance*
Raymond Laflamme	*Executive Director, Institute for Quantum Computing (IQC)*
Tong Leung	*Faculty, Quantum NanoFab Scientific Director (representing WIN)*
Terry McMahon	*Dean of Science*
Adel Sedra	*Adjunct Professor and Distinguished Professor Emeritus*
Pearl Sullivan	*Dean of Engineering*

1. EXECUTIVE SUMMARY

This report summarizes the operational activities and financial highlights of the Quantum-Nano Fabrication Core Facility (*Quantum NanoFab*) for the period May 2012 to August 2014. Key construction activities and milestones related to the final implementation of the QNC cleanroom, prior to commencement of fab operations in September 2014, are also presented.

The *Quantum NanoFab Team* grew over this period to further enhance its ability to provide excellent service to its broad customer base. In March 2014 Mai-Britt Mogensen assumed the role of *Cleanroom Certification & Inventory Specialist*. In December 2014 Matthew Scott assumed the role of *NanoFabrication Equipment Technologist*.

A key financial highlight over this reporting period was a formal joint agreement between the Deans of Engineering and Science and the Executive Directors of IQC and WIN to fund the $2.34M in additional monies needed to complete the QNC cleanroom fit-out project. The services of *AdvanceTEC LLC* were secured in April 2013 to complete the project at a total final cost of $3.95M. This exceeded May 2012 estimates by 7%.

Many challenges were faced and successfully dealt with prior to and during the nine month cleanroom fit-out project. Some of these included augmenting the capacity of the cleanroom power feed, stabilizing facility temperature and humidity control, designing and installing an RO/DI water plant and distribution loop and dealing with building envelope issues which wreaked havoc with fit-out activities and project timelines.

Overall use of the RAC1 temporary facility grew substantially over the course of the 2012/13 fiscal year to over 6000 hours of lab equipment bookings. This was up from just over 3500 hours the previous fiscal year. Several new process recipes and statistical process control initiatives were implemented over this period to improve the Lab Member experience and to increase research output. Some of the devices fabricated by the facility's growing membership are detailed in section 5.1.

Operating costs for FY2013/14 grew substantially to just under $800k. This was largely due to the acquisition of annual service contracts for five of the lab's most complex and widely used systems. Several backup roughing pumps were also acquired with an aim of augmenting lab equipment uptimes to the overall benefit of the Lab Member community.

Facility access fees remained stable over the period April 2012 to December 2013 when RAC1 temporary operations were suspended in preparation for the move to QNC. Revised internal and external fees were implemented on September 1, 2014.

Several initiatives were not fully completed as originally planned prior to commencement of QNC operations. The decision was made to move forward with the published September 2, 2014 grand opening date and to complete these on a priority basis over the course of the ensuing months. The Quantum-Nano Centre's nanofabrication toolset is nearly triple the toolset available at the old RAC1 temporary cleanroom.

2. GOVERNANCE

The facility's organizational structure and management plan received the approvals of Raymond Laflamme, Executive Director of IQC, and Arthur Carty, Executive Director of WIN, in October 2010. This organizational structure remains in place in its original form (Appendix A). The detailed plan is available online: https://fab.qnc.uwaterloo.ca/governance

3. PEOPLE

The *Quantum NanoFab* team grew by two people in 2014. Mai-Britt Mogensen joined the team in March to fill the role of *Cleanroom Certification & Inventory Specialist*. Matthew (Matt) Scott joined the team in December as *NanoFabrication Equipment Technologist*.

***Quantum NanoFab* Team:**

Equipment Technologists	Brian Goddard Rodello (Rod) Salandanan Matthew (Matt) Scott
Process Engineering	Nathan Nelson-Fitzpatrick
Cleanroom Certification & Inventory Specialist	Mai-Britt R. G. Mogensen
Information Technology	Steve G. Weiss
Accounting	Mary Lyn Payerl
Director of Operations	Vito Logiudice

Management Team:

Faculty, Scientific Director (IQC)	David Cory
Faculty, Scientific Director (WIN)	Tong Leung
Director of Operations	Vito Logiudice

Leadership Team:

Executive Director, WIN	Arthur Carty
Executive Director, IQC	Raymond Laflamme
Faculty, Scientific Director (representing IQC)	David Cory
Faculty, Scientific Director (representing WIN)	Tong Leung
Director of Operations	Vito Logiudice

4. KEY ACTIVITIES & HIGHLIGHTS

This section presents a summary of financial highlights as well as QNC cleanroom construction and fit-out activities over the period May 2012 to November 2014. Highlights of RAC1 temporary cleanroom operations are also presented.

4.1. FINANCIAL HIGHLIGHTS

- Secured $2.34M in additional funds needed to complete QNC cleanroom fit-out
- RAC1 temporary cleanroom continued to operate until November 2013. All Principal Investigators received monthly invoices for their respective group's use of the facility over the period May 2012 to November 2013.
- Starting in June 2012, monthly invoices were issued together with detailed equipment booking activity reports. These reports detailed the time booked on each piece of equipment by users in a given PI's research group.
- Expenses related to salaries, supplies & consumables, equipment repairs and the acquisition of backup hardware were covered as follows:
    - *Direct* Fab Staff salaries were charged to the CFI-IOF fund, with portions covered by IQC on an exceptional basis (see section 7).
    - *Indirect* Fab staff salaries were jointly covered by a combination of IQC and WIN support (see section 7).
    - Supplies and consumables costs were covered by CFI-IOF funds, IQC funds (on an exceptional basis) and by access fees collected.
    - Equipment upgrades & backup hardware (pumps, e-guns, etc.) were paid for primarily via access fees collected.

4.2. QNC CLEANROOM & FIT-OUT PROJECTS

The scope of work relating to the physical implementation of the QNC cleanroom under the building base construction project was limited to the delivery of a laboratory meeting *NIST VC-E* floor vibration specifications with *ISO 5* and *ISO 6* certified "clean" workspaces. The base construction project also included the installation of the following basic services within the cleanroom envelope:

- House nitrogen gas (HN_2) loop beneath the raised access floor
- Compressed dry air (CDA) loop beneath the raised access floor
- House process vacuum (PVAC) loop beneath the raised access floor

- Domestic water lines & drains beneath the raised access floor
- Process chilled water (PCW) loop beneath the raised access floor (original cleanroom portion of PCW loop necessitated major modifications during fit-out as detailed below)
- Power panels located at the perimeter of the cleanroom (modifications & additions were needed post base construction as detailed below)
- Some corrosives and flammables 12” *Phoenix* exhaust valves at ceiling height
- Smoke & fire detection systems
- Emergency safety showers

Post building occupancy, the design, supply, installation and commissioning of the following systems and services were undertaken by a team composed of the University’s *Plant Operations* group (Byron Murdock), Scott Nicoll and this document’s author:

- Reverse Osmosis (RO) system for supplying high purity water to labs located throughout the building and to the DI water system dedicated to cleanroom operations
- De-Ionized (DI) Ultra Pure Water (UPW) system for supplying 18 megohm water to the cleanroom
- *Bead & crevice-free* supply/return loop made of PVDF material for distributing DI water throughout the cleanroom
- Acid Waste Neutralization (AWN) system for treating waste water/chemicals from the cleanroom
- Dedicated drain network for directing chemical waste from the cleanroom to the AWN system
- Installation of additional *Phoenix* exhaust valves throughout the cleanroom
- Installation of a bulk liquid nitrogen tank and evaporator for supplying high purity nitrogen gas to all occupants of the building and ultra high purity nitrogen gas (UHP N_2) to the cleanroom

The cleanroom fit-out project was a major undertaking for which the services of a specialized cleanroom design and construction firm, *AdvanceTEC LLC*, were secured. *AdvanceTEC* had originally been hired by the general contractor to build the cleanroom under the base building construction project and was therefore already familiar with the project. The scope of the university’s subsequent fit-out contract with *AdvanceTEC* included the following:

- Design, procurement, installation, testing and commissioning of:

- Automated UHP gas cabinet & delivery systems
    - UHP gas distribution networks to multiple points of use throughout the cleanroom
    - Exhaust gas abatement systems for safe disposal of toxic by-products
    - Fully automated toxic gas detection system for active monitoring of gas supply & exhaust systems throughout the cleanroom and its peripheral support labs
    - All stainless, all-welded UHP nitrogen distribution loop running from the exterior bulk N_2 tank out to each existing and future points of use throughout the facility
    - Upgraded Process Chilled Water (PCW) distribution loop to meet equipment flow and pressure requirements as well as the low conductivity requirements of process equipment making use of RF power supplies
    - Custom vibration isolation bases for sensitive lithography systems including the *Suss-Microtec* UV mask aligner and the *Raith* electron-beam lithography system

- Creation of detailed *Process & Instrumentation Diagrams* (P&ID's) for each distinct piece of lab equipment to ensure all necessary services were properly designed for and installed. These services included power, high purity gas lines, compressed air lines, chilled water lines, domestic water lines, DI water lines, house vacuum lines, vacuum pump forelines, house exhaust lines, etc.
- Uncrating and locating all new nanofabrication equipment in the cleanroom
- Moving nanofabrication equipment from the old RAC1 temporary cleanroom to the new QNC cleanroom
- Installing/connecting all services to and powering up all nanofabrication equipment installed in the QNC cleanroom
- Complete post-fit-out balancing of the air supply and exhaust systems
- Complete post-fit-out balancing of the process chilled water loop
- Complete post-fit-out super-clean of the cleanroom and certification to ISO 5 and ISO 6 standards

4.2.1. MAJOR MILESTONES

This section summarizes the major milestones achieved prior, during and after cleanroom fit-out activities started in June 2013.

- May 2012: Secured $2.34M in additional monies needed for the cleanroom fit-out project. This was accomplished via a formal joint agreement between the Deans of Engineering and Science and the Executive Directors of IQC and WIN.
- October 2012: Contract awarded to *Siemens Water Technology* for the supply, installation and commissioning of a high purity RO/DI water system as well as an UPW DI water distribution loop made of industry-standard bead & crevice-free PVDF tubing. *Siemens* also selected to supply and install a chemical waste treatment and drain system dedicated to cleanroom operations.
- November 2012:
  - The facility's "as-built" vibration and acoustic performance verified by *Colin Gordon & Associates*. Results confirmed that design specifications were met (data in Appendix B).

    Of note: Mr. Michael Gendreau of *Colin Gordon & Associates* made the comment that measurements taken in the e-beam lithography bay "are some of the lowest noise levels measured in a Class 100 cleanroom".
  - Pre-fit-out cleanroom power distribution changes completed:
    - eight isolation transformers upgraded to 45kVA units from 30kVA
    - two 75kVA transformers & related panels installed
    - several power panels relocated to better match lab equipment locations
    - low-impedence "clean" and "dirty" earth grounds installed to meet the requirements of both sensitive and high power lab equipment
- December 2012:
  - Completed major "slab-to-slab" clean of the entire cleanroom to address serious deficiencies noted during an earlier site survey
  - Temperature trends showed the 20 +/- 0.1°C specification in e-beam litho bay # 1701M was only being met for durations of 24 to 36 hours. Drifts beyond this specification to within +/- 1°C was noted over several days. Fine tuning of the controls sequence and final air balancing during the cleanroom fit-out project (Winter 2014) resolved the issue.
- January 2013: Third party testing of "at rest" cleanroom particle counts by *H.E.P.A Filter Services Inc.* confirm ISO Class 5 and ISO Class 6 rooms are within limits set forth by *ISO standard 14644-1*. Test data included in Appendix C.
- March 2013:

- Karen Jack, *Privacy Officer, UW Secretariat,* and Dan Anderson, *Director of UW Police Services*, formally approved the use of closed-circuit cameras and TV panels throughout the facility to enhance operational safety.
- Entered into a formal agreement with *Badger LMS* to implement and host the *Quantum NanoFab*'s lab management software backbone. Key features of the real-time *Badger Lab Management System* include:
  - Equipment scheduling
  - User permissions tracking
  - Equipment Enabling/Interlocking
  - Equipment problem reporting
  - Consumables tracking
  - User fees accounting
  - Powerful reporting capabilities

- April 2013: $3.5M contract signed with *AdvanceTEC LLC* for cleanroom fit-out project.
- June 2013:
  - Mechanical & electrical portion of pre-fit-out cleanroom ventilation remedial work completed.
  - Cleanroom fit-out engineering & design activities commence.
- July 2013: Routine maintenance of cleanroom ventilation infrastructure formally assumed by UWaterloo's *Plant Operations Maintenance & Utilities Group*.
- August 2013: *AdvanceTEC's* scope of work expanded to include:
  - Engineering study of the Process Chilled Water (PCW) distribution loop as required to confirm its ability to meet the requirements of existing and future nanofabrication equipment.
  - Design and installation of an all-stainless, orbital-welded, UHP nitrogen gas distribution network.
- October 2013: Construction crews mobilized and cleanroom fit-out construction activities started (six month planned duration).
- November 2013: Last full month of operations in RAC1 temporary cleanroom.
- December 2013: Decommissioning of equipment in RAC1 cleanroom started.
- January 2014: Discovery of water damage along interior north wall of QNC cleanroom. This issue delayed fit-out activities by several months. Damage caused by leaking skylight at the building main entrance.
- March 2014: Mai-Britt Mogensen hired on the *Quantum NanoFab Team* to fill the newly created position of *Cleanroom Certification & Inventory Specialist*.
- June 2014:
  - Within-cleanroom remedial activities related to water damage completed.

- Fit-out construction work completed.
- Final cleanroom "super-clean" completed.
- Third party testing of post-fit-out "at rest" particle counts by *SET3* confirm ISO Class 5 and ISO Class 6 rooms are within required specification limits. Test data included in Appendix D.

- July 2014:
  - Integrity of UHP gas lines re-verified after delay caused by water damage.
  - Third party testing of DI water quality by *Balazs NanoAnalysis* confirms water quality is within acceptable limits (results in Appendix E).
- August 2014:
  - Updated facility access fees announced & published on facility website (fees in effect as of September 1, 2014 listed in Appendix F).
  - New facility training modules and access protocols announced in preparation for September 2014 commencement of QNC fab operations.
- September 2, 2014: *Quantum NanoFab* opens its doors for business in the *Lazaridis Quantum-Nano Centre*.

4.2.2. NEW EQUIPMENT ADDITIONS

Appendix G lists the complete set of nanofabrication equipment available in the *Quantum NanoFab*. New additions since operations were relocated include:

- Two *J.A. Woollam M2000* ellipsometers: one stand-alone unit and one unit permanently mounted to the existing *Oxford Instruments FlexAL ALD* chamber. The latter enables in-situ monitoring of film parameters during deposition.
- 4-tube furnace stack (*Tystar Tytan 4600*) for the deposition of multiple thin film materials (LTO, SiN, Poly Si, SiC) and for atmospheric pressure substrate anneal & thermal silicon dioxide film growth.
- A complete ensemble of device packaging equipment installed in the *Quantum NanoFab Device Assembly & Packaging Lab*.
- A twin chamber sputter deposition system with common loadlock acquired from *AJA International*. One chamber dedicated to the deposition of insulating films and the second chamber dedicated to the deposition of conducting films. The system is equipped with four targets per chamber plus in-situ film-stress and RHEED crystal structure monitoring capabilities.
- Ion mill also acquired from *AJA International* equipped with a 22cm ion source. The system is for extremely uniform anisotropic etching of a wide range of materials including Pt, Au, NbN, etc. The system is equipped with an RF sputter source for in-situ, post-etch surface passivation.

- Two *Semitool* dual-stack rinser/dryers for batch rinsing and drying of wafers ranging in size from 3", 4" and 6" diameter.
- Nine custom wet benches and fume hoods acquired from *ReynoldsTech* in support of the following wet processes:
    - Bulk silicon etch
    - Advanced e-beam develop technologies
    - Pre-diffusion RCA cleans
    - Bulk photoresist strip via mixtures of sulfuric & H_2O_2 "piranha" solutions
    - Metal lift-off
    - etc.

4.2.3. FIT-OUT COST SUMMARY

In spring 2012 the cost of the cleanroom fit-out project was estimated to be $3.69M CAD. The budget available at the time however was limited to $1.35M. The funding shortfall was ultimately addressed via a formal joint agreement signed on May 15, 2012 between the Dean of Science (Terry McMahon), the Dean of Engineering (Adel Sedra at the time), the Executive Director of WIN (Arthur Carty) and the Executive Director of IQC (Raymond Laflamme). We are grateful to each of these individuals for their strong support and for agreeing to fund the $2.34M in additional monies needed to complete the project.

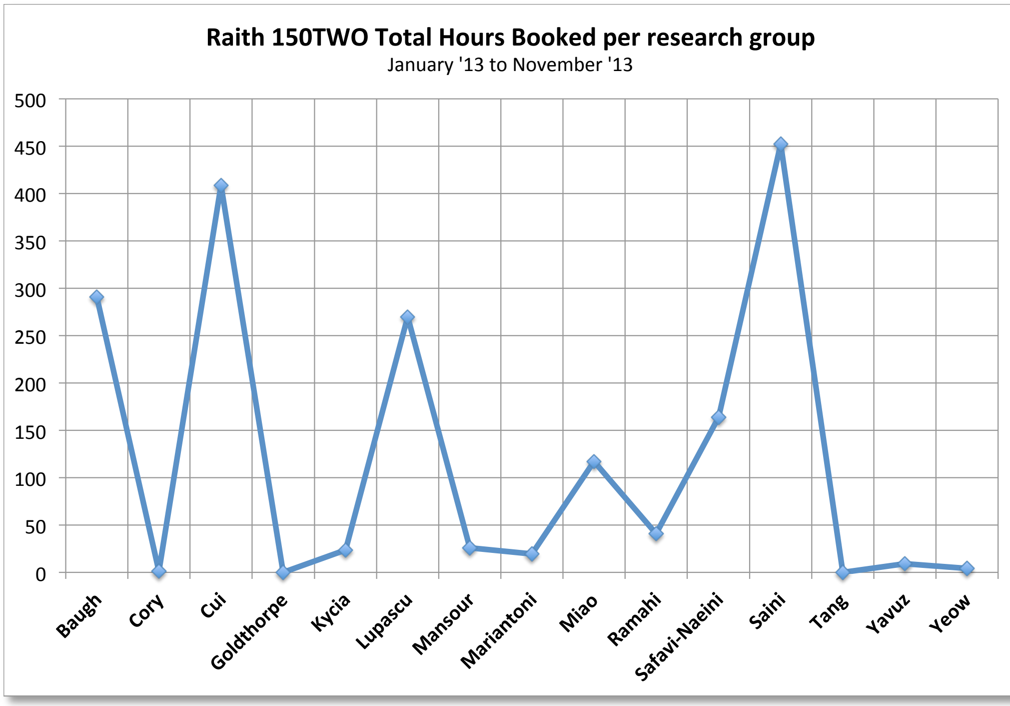
In the end, the final tally for the cost of the fit-out project totaled $3.95M CAD. The main contributors to the 7% over expenditure include:

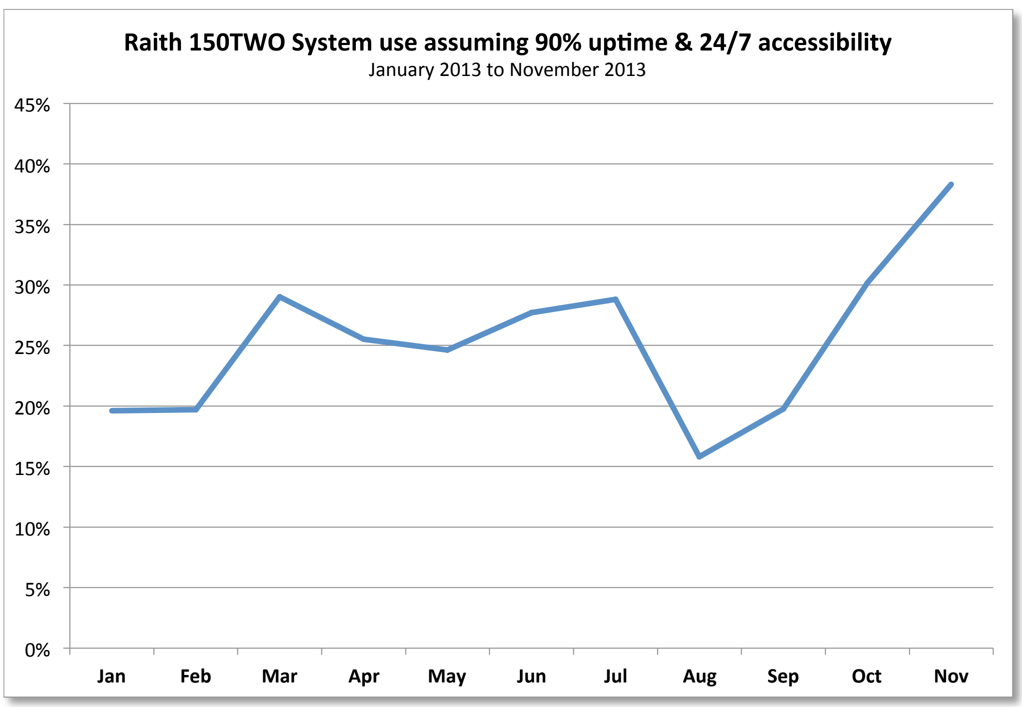
- The cost of an all-stainless steel, orbital-welded, tested and independently certified UHP nitrogen gas distribution network ($103k).
- The cost of verifying the capacity of the process chilled water (PCW) distribution loop together with the cost of converting the cleanroom portion of the loop to CPVC plastic (from stainless steel), and for installing multiple point of use ports/valves throughout the facility ($63k).
- Engineering design & construction general requirements related to the previous two items ($75k approx).
- Installation of five better-sized airflow stations in the cleanroom fandeck ($20k). These units played an important role in further augmenting temperature and airflow control within the cleanroom as needed to achieve and maintain lab design specifications.

4.3. RAC1 CLEANROOM OPERATIONS: MAY 2012 TO NOVEMBER 2013

- Implemented statistical process control charts for several key fabrication recipes (see section 4.3.1)
- Created and documented several new process recipes (see section 4.3.2)
- Substantial growth in facility use (see sections 5 and 6)
- Publication of many devices built by Lab Member community (see section 5)
- Good equipment uptime on entire toolset. Few issues resulting in extensive downtime were largely due to failed roughing pumps in need of routine rebuilding. Circumstances have been significantly improved by the acquisition of several backup pumps in 2013 via the use of fab access fees collected in the previous fiscal year.
- *Intlvac* e-beam & thermal evaporator:
    - This system is routinely used by a large number of lab members. A backup electron gun source was therefore purchased from *Island e-Beam Thin Film Technology,* also via the use of fab fees collected during the previous fiscal year.
    - The OEM e-gun from *MDC Vacuum* was fine-tuned by *Intlvac* to produce a much better beam spot diameter on the order of 2-3 mm vs its original 6-7 mm setting. Subsequent testing confirmed that the newly tuned gun did not exhibit the spurious PMMA exposure issue caused by excess secondary electrons consistently witnessed prior to the adjustment.
- *Raith 150^{TWO}* E-Beam Lithography system (Nov. 2013):
    - The electron beam column was replaced (under warranty) with a new, factory-tested unit from *Zeiss*. This closed a long-standing concern with the age of the previous column which had in turn replaced the original unit in 2011. We are grateful to *Raith* and *Zeiss* for addressing this concern.
    - For the period May 2012 to April 2013, system usage data confirmed an overall system uptime in excess of 90% on a 24/7 basis.
    - The *150^{TWO}* continued to be one of the most widely used pieces of equipment with 30 lab members from 15 different research groups trained and registered to use the system.
    - The next two graphs show machine use per research group as well as overall system use over the period January 2013 to November 2013.

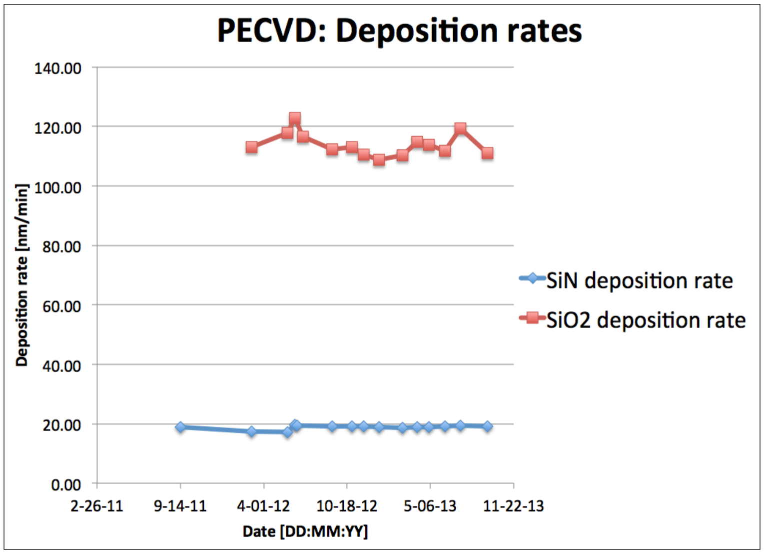
      The second graph indicates the system was never in demand more than 40% of the time it was available, with an average monthly usage rate on the order of 25 to 30%.

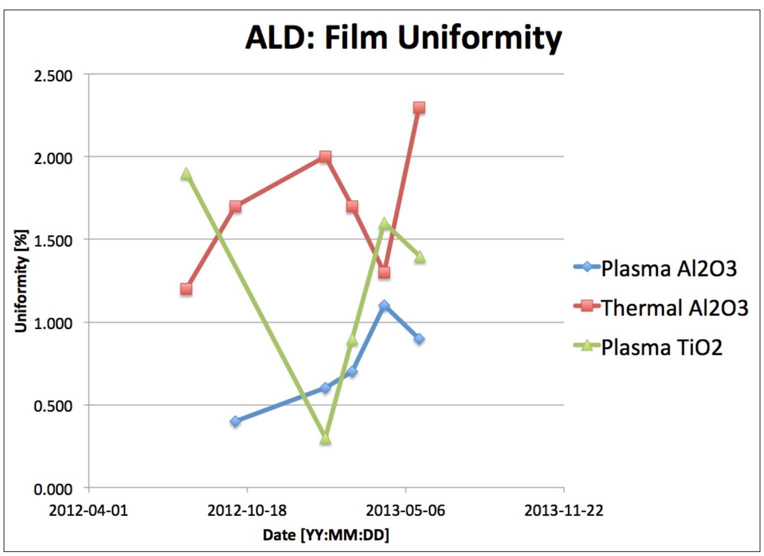

Raith 150TWO Total Hours Booked per research group
January '13 to November '13
500
450
400
350
300
250
200
150
100
50
0
Baugh
Cory
Cui
Goldthorpe
Kycia
Lupascu
Mansour
Mariantoni
Miao
Ramahi
Safavi-Naeini
Saini
Tang
Yavuz
Yeow

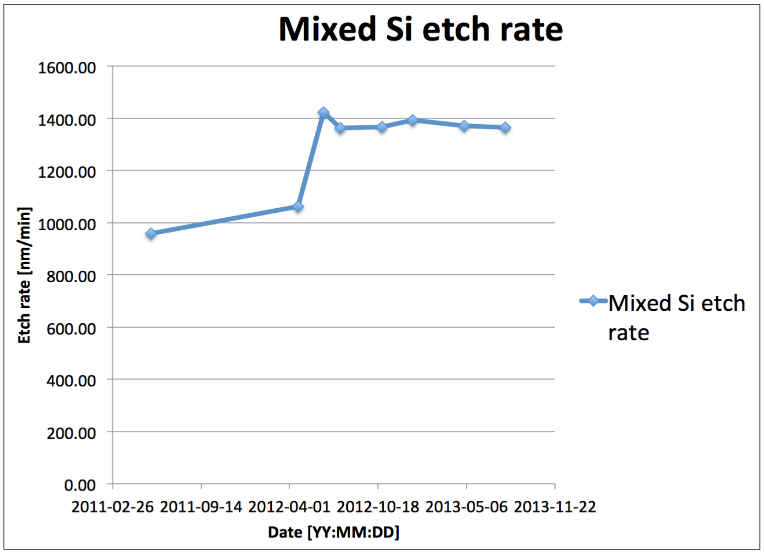

Raith 150TWO System use assuming 90% uptime & 24/7 accessibility
January 2013 to November 2013
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

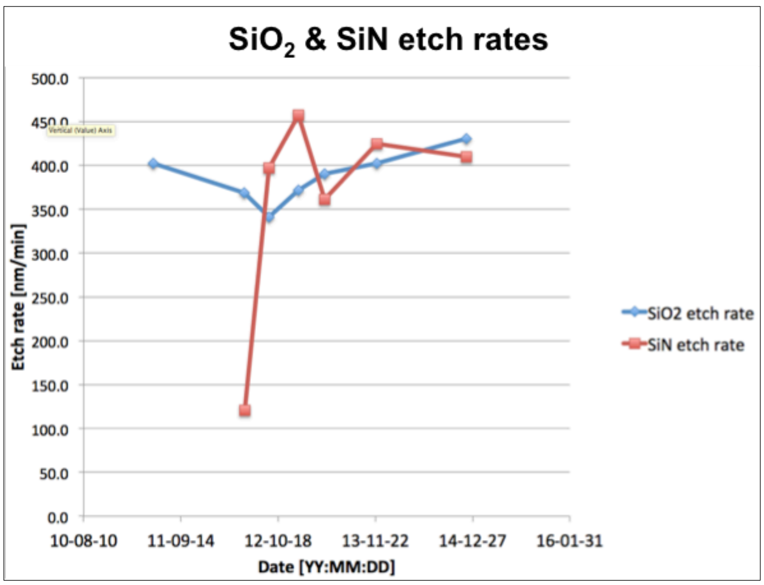
4.3.1. STATISTICAL PROCESS CONTROL (SPC) INITIATIVES

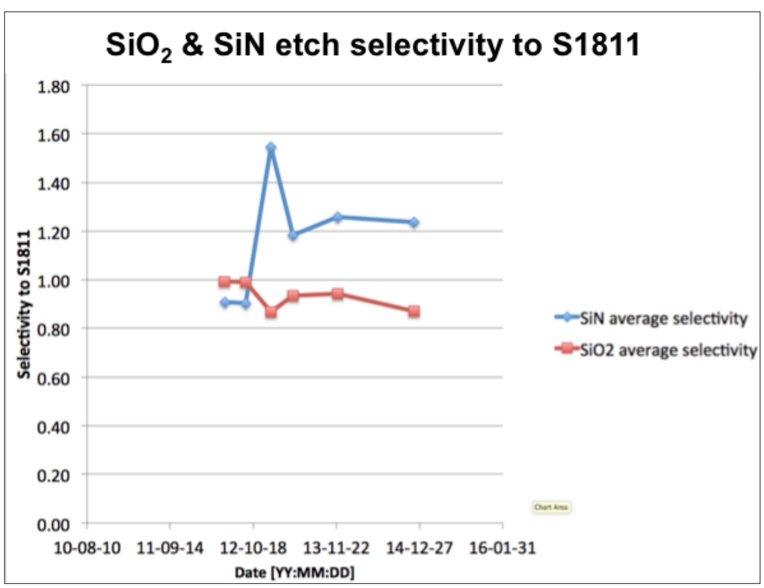
The Fab Team monitors the stability of a select group of baseline recipes via Statistical Process Control (SPC) charts. The data is accessible to all lab members and aims to provide an ongoing snapshot of individual process recipe stability. Sample SPC charts are shown below for reference.






Mixed Si etch rate
Etch rate [nm/min]
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
2011-02-26 2011-09-14 2012-04-01 2012-10-18 2013-05-06 2013-11-22
Date [YY:MM:DD]
Mixed Si etch rate


SiO2 & SiN etch rates
Etch rate [nm/min]
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
10-08-10 11-09-14 12-10-18 13-11-22 14-12-27 16-01-31
Date [YY:MM:DD]
SiO2 etch rate
SiN etch rate

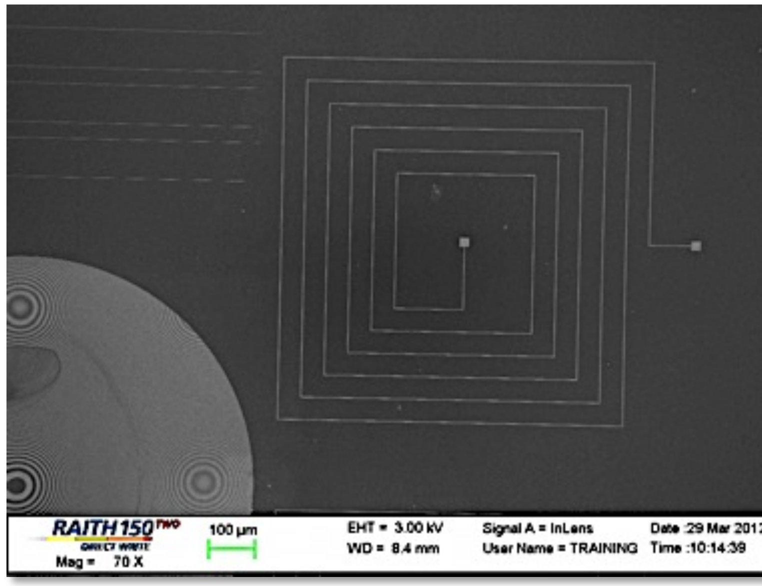

SiO2 & SiN etch selectivity to S1811
Selectivity to S1811
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
10-08-10 11-09-14 12-10-18 13-11-22 14-12-27 16-01-31
Date [YY:MM:DD]
SiN average selectivity
SiO2 average selectivity

4.3.2. DEVELOPMENT OF NEW PROCESS RECIPES

The Fab Team continues to develop and document new fabrication processes for the benefit of the facility's entire membership. The following shows some of the work completed over the course of FY2012/13.

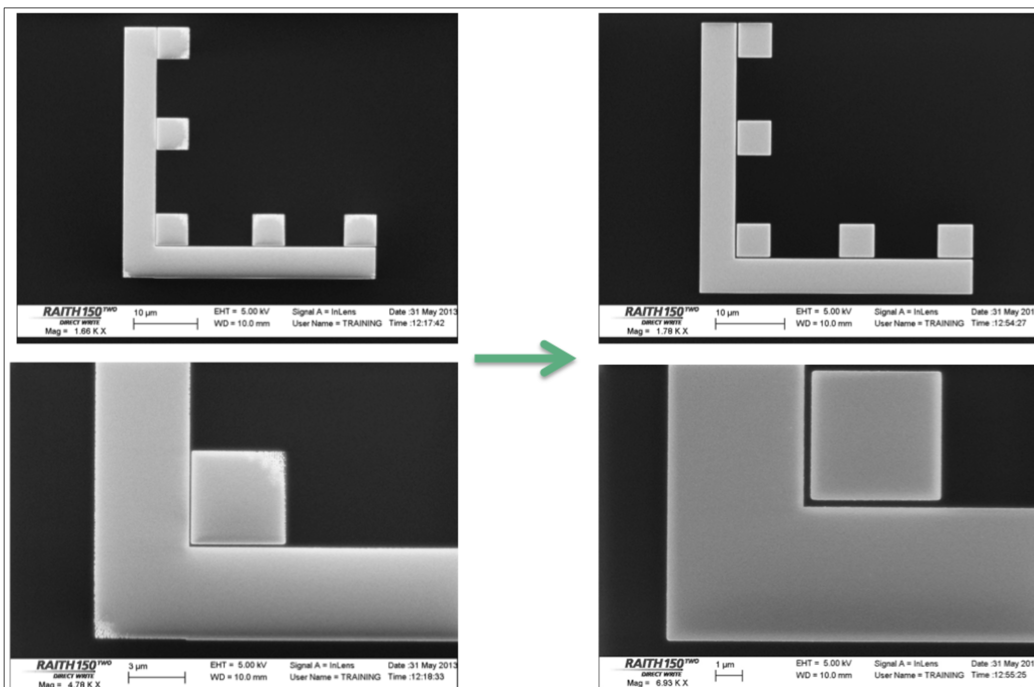
E-Beam Lithography: Large stitch-free structures *using Raith 150^{TWO} Fixed Beam Moving Stage* (FBMS) feature

N. Nelson-Fitzpatrick

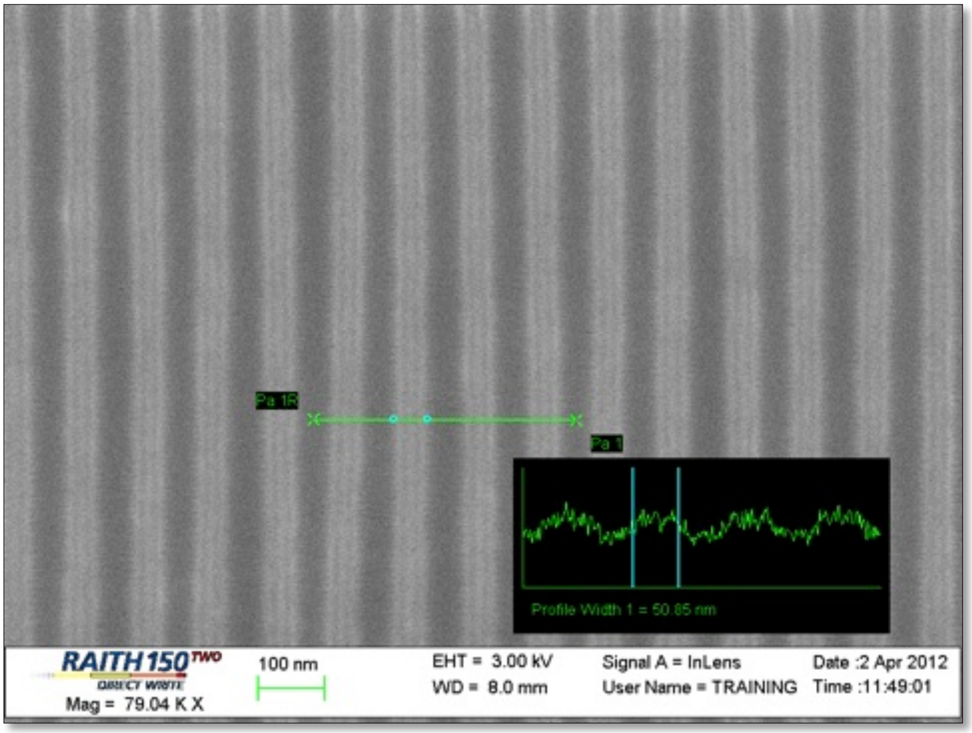


E-Beam Lithography: *Proximity Error Correction* efforts: detailed technical report available online to lab member community

N. Nelson-Fitzpatrick

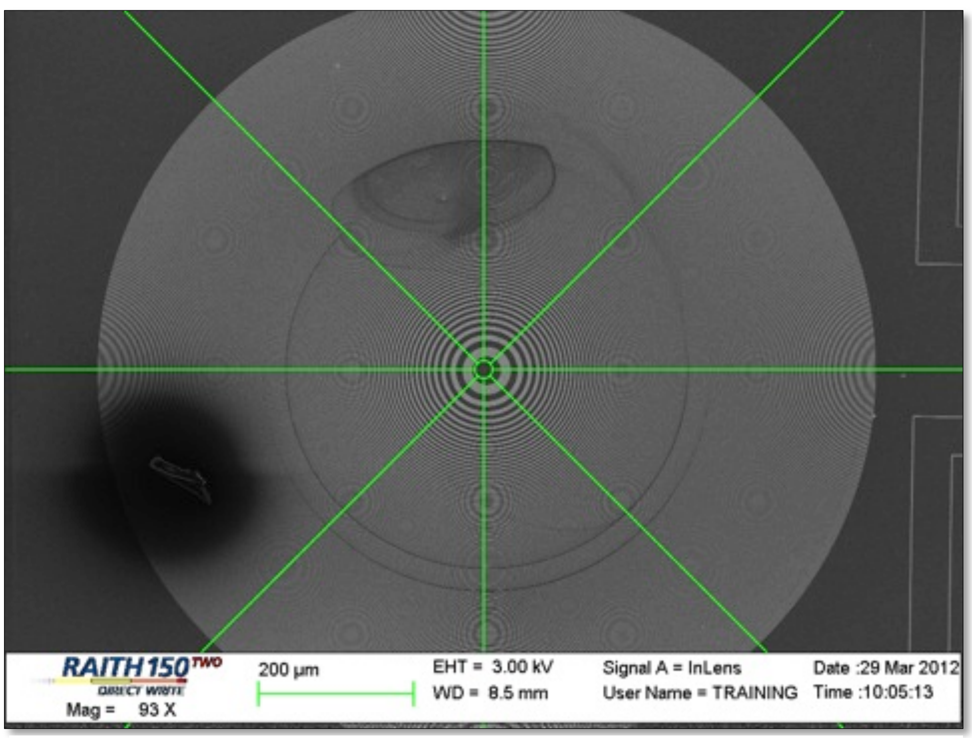


Before correction (25 kV exposure) **After** correction (25 kV exposure)



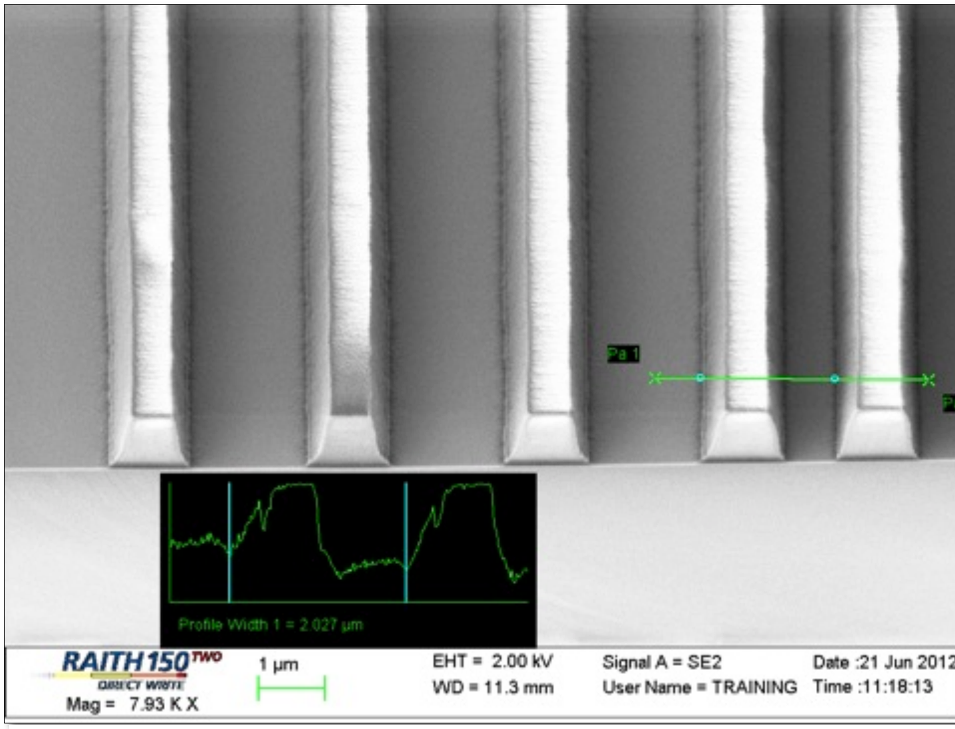
E-Beam Lithography: 1mm long grating, 100nm pitch (FBMS)

N. Nelson-Fitzpatrick



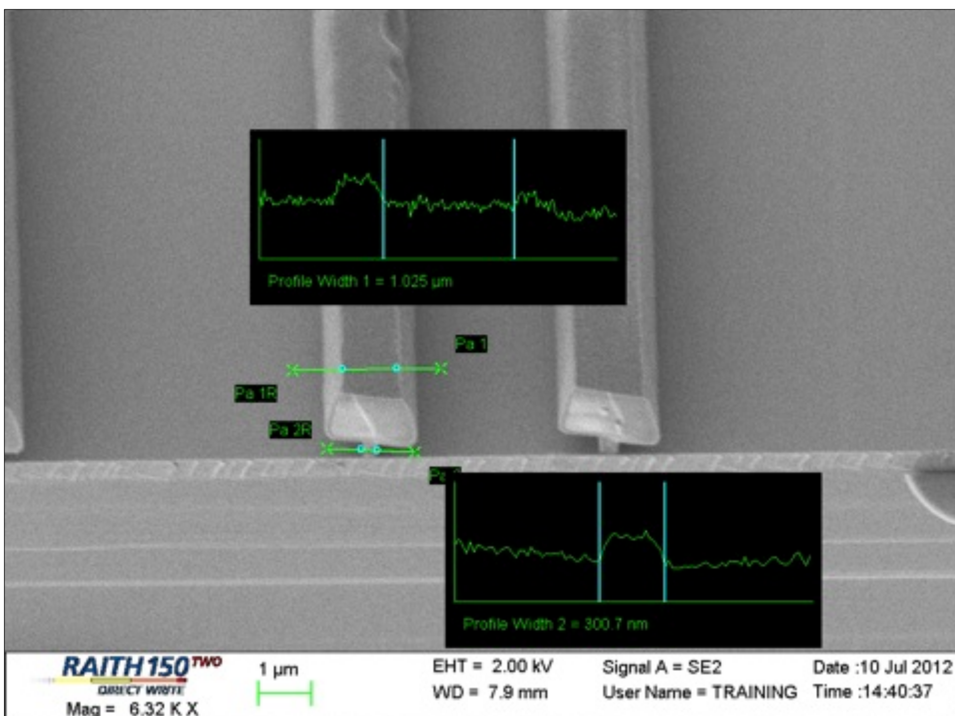
E-Beam Lithography: Fresnel Zoneplate FBMS Structure (PMMA)

N. Nelson-Fitzpatrick



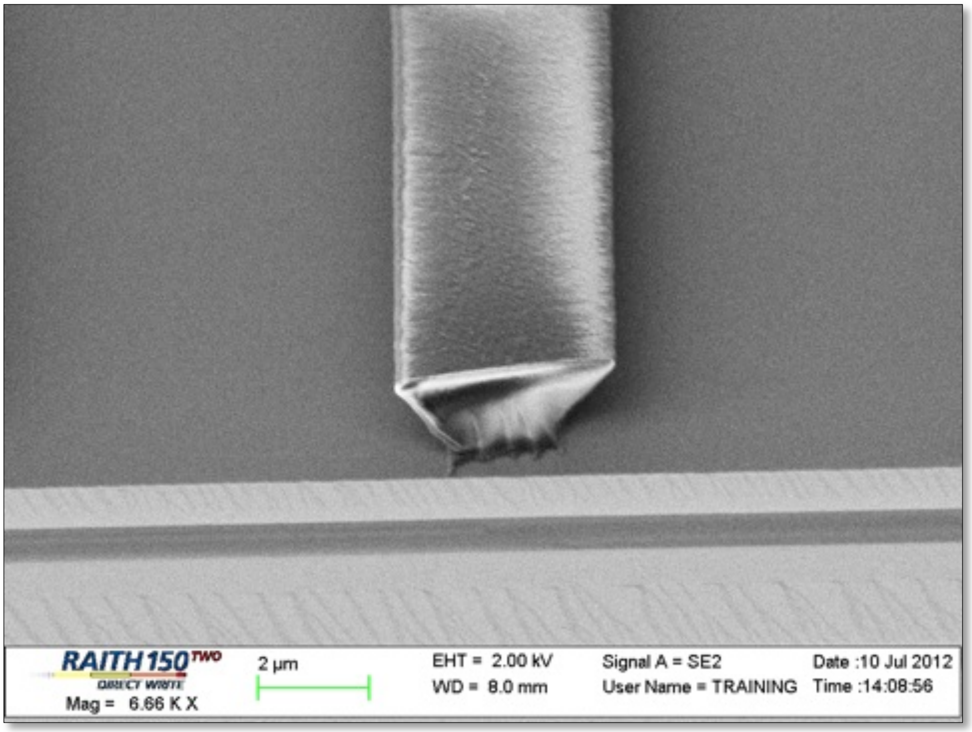
UV Lithography: S1811 lines, 1um pitch, ~ 1.2um tall resist

N. Nelson-Fitzpatrick



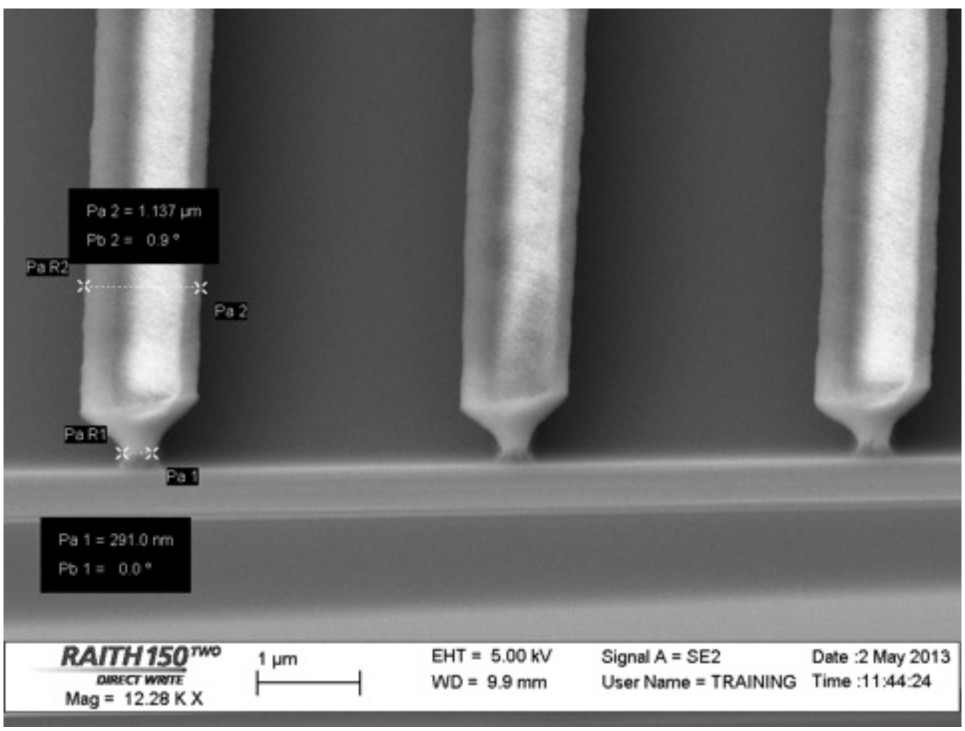
UV Lithography: Development of PMGI/S1811 bilayer process which significantly improves metal lift-off processes

N. Nelson-Fitzpatrick



UV Lithography: Ma-N 1410 negative UV resist

N. Nelson-Fitzpatrick



UV Lithography: S1811 Image reversal

N. Nelson-Fitzpatrick

4.3.3. SAFETY

No injuries to report. Only one incident noted:

- July 2012: a trained and experienced lab member did not follow proper fume hood safety procedures. This resulted in hydrofluoric acid residues having been left behind at multiple workstations within the RAC1 cleanroom. An immediate and thorough response by members of the Fab Team fortunately kept anyone from being injured and contained the damage to the *Olympus* microscope and *Veeco Dektak*, both of which suffered minor damage to the surface finish of their respective wafer chucks. Given the serious nature of the incident, the *Fab Management Team* suspended the member in question for two months and charged the individual's supervisor a total of $400 for the time taken by staff to decontaminate and secure the cleanroom post-incident.

5. LAB MEMBERSHIP

Table 1: UW Faculty Registered as Lab Members as of November 30, 2013*

* Last full month of operations in RAC1 temporary cleanroom

Name	IQC	WIN	Other UW
Jonathan Baugh	✓		
David Cory	✓		
Bo Cui		✓	
Irene Goldthorpe		✓	
Jan Kycia	✓		
Raymond Laflamme	✓		
Zoya Leonenko		✓	
Adrian Lupascu	✓		
Raafat Mansour		✓	
Matteo Mariantoni	✓		
Guoxing Miao	✓		
Omar Ramahi			ECE
Safieddin Safavi-Naeini			ECE
Simarjeet Saini		✓	
Shirley Tang		✓	
Mustafa Yavuz		✓	
John Yeow		✓	
TOTAL:	**7**	**8**	**2**

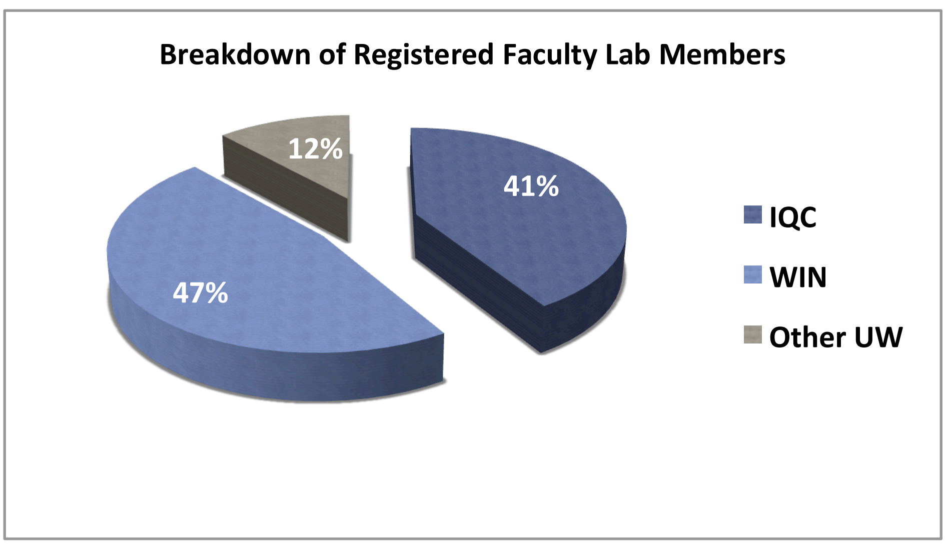
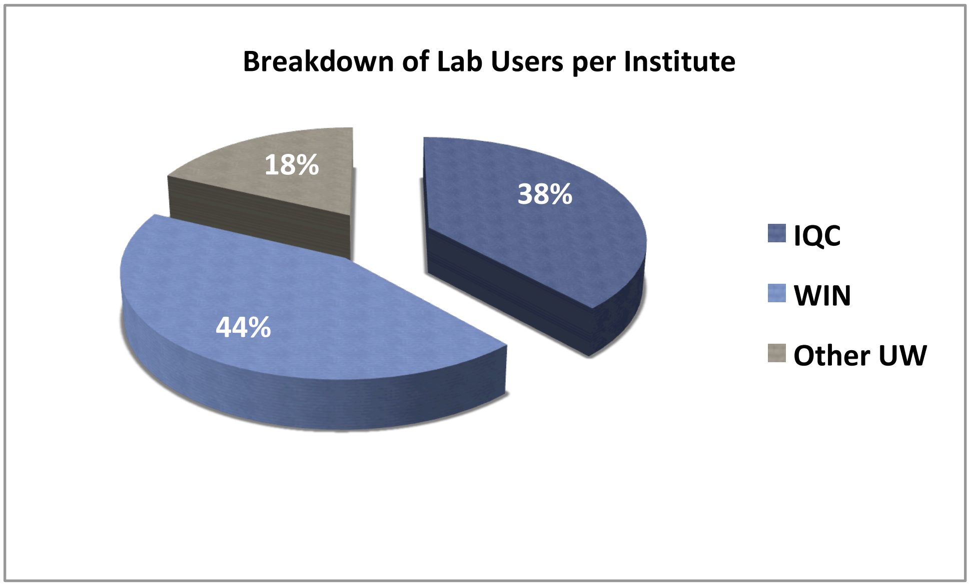
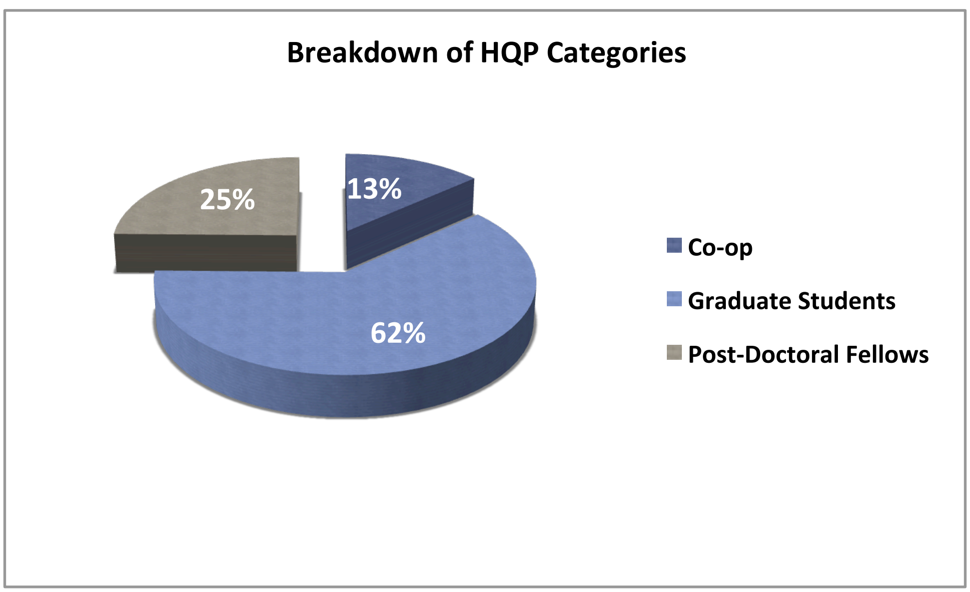


Table 2: Breakdown of Lab Users per Institute as of November 30, 2013*

* Last full month of operations in RAC1 temporary cleanroom

Category	IQC	WIN	Other UW	TOTAL
Co-op Students	9	3		12
Graduate Students	16	27	12	55
Post-Doctoral Fellows	9	9	4	22
TOTAL:	**34**	**39**	**16**	**89**

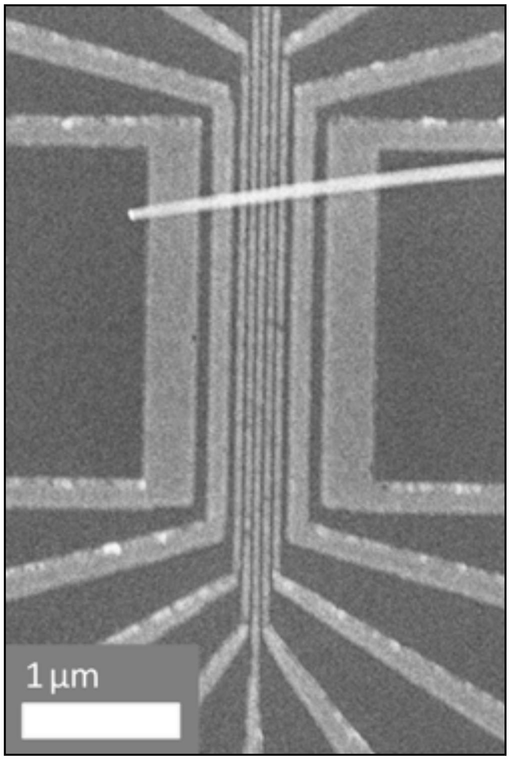


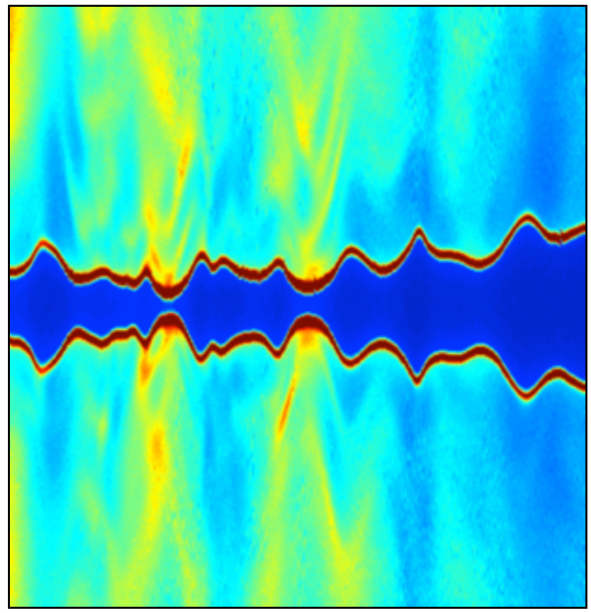


5.1. SAMPLE DEVICES FABRICATED BY LAB MEMBERSHIP

The examples shown in this section represent a small portion of the work carried by the *Quantum NanoFab*'s membership over the period May 2012 to April 2013.

5.1.1. J. BAUGH GROUP





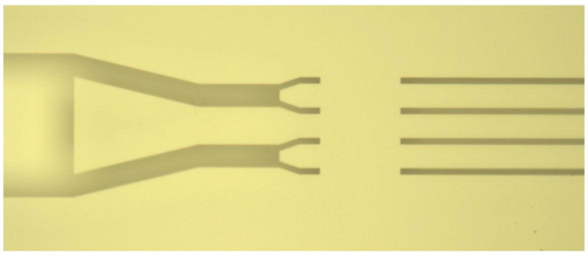
The SEM image shows an InAs nanowire across a series of bottom gates (~25nm wide with a 60nm pitch).

The colourscale plot shows device resistance versus gate voltage where the dark blue region in the middle corresponds to nearly zero resistance, due to proximity effect superconductivity in the nanowire channel. The critical current of this Josephson junction, seen as the red line at the boundary of this region, is modulated by the local gate.

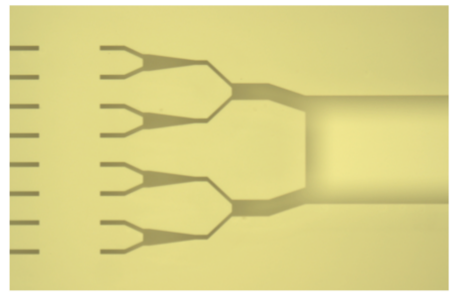
The successful observation of proximity superconductivity in this device opens up many new doors, including our ability to search for Majorana fermions, exotic quasiparticle states that have been proposed for fault tolerant quantum computing.

5.1.2. D. CORY GROUP

Superconducting Microstrip Resonators
Niobium on Sapphire



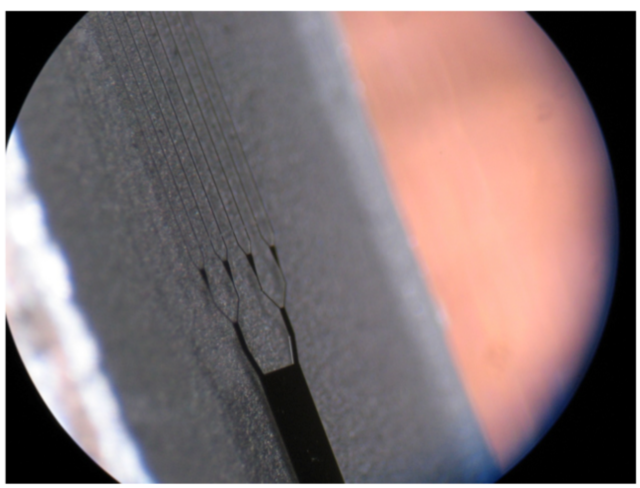
Array of Four Half-wave Resonator



Array of Eight Half-wave Resonator

Smallest Feature =15 um

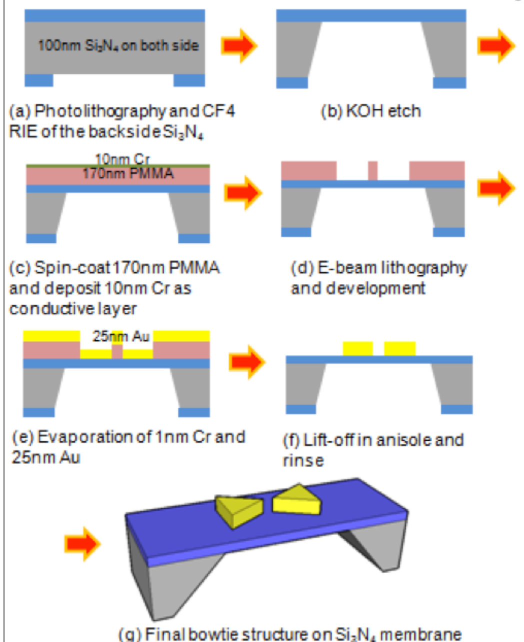
Array of Eight Microstrip Resonator, Nb on Sapphire



5.1.3. B. CUI GROUP

Breakthrough of E-beam Lithography resolution from 10s nm to 3 nm on Si_3N_4 Membrane for SERS sensor

- Jian Zhang, Mehrdad Irannejad and Bo Cui



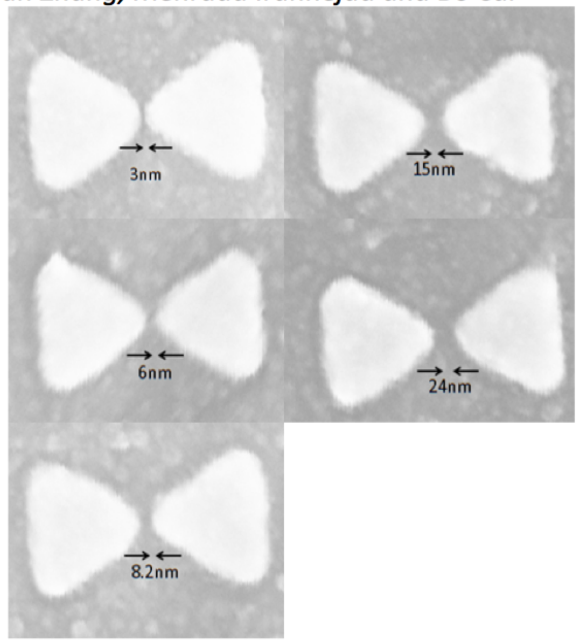
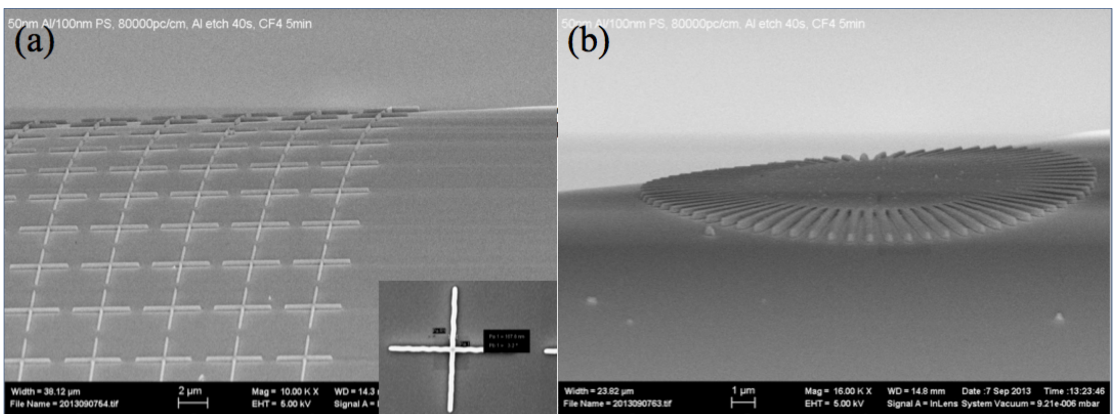


Fig. 1. Schematic of the fabrication process of bowtie nano- antenna on Si_3N_4 membrane

Fig. 2. SEM image of bowtie array exposed on Si_3N_4 membrane.



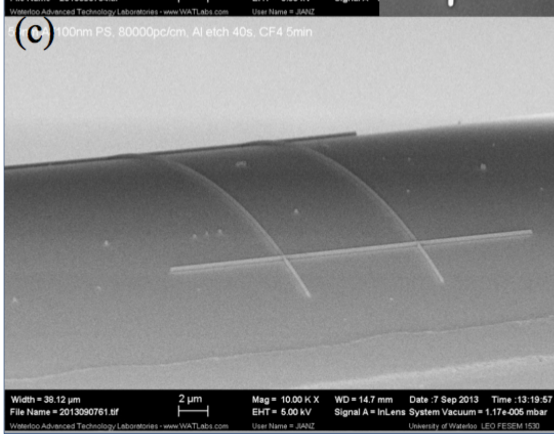


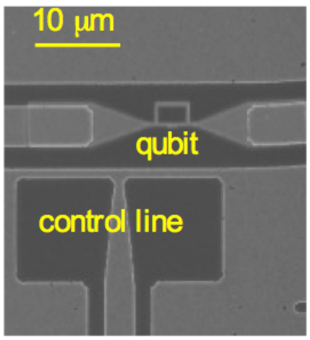
Fig. 7. SEM images of (a) crossbar array with the line width of 167 nm and the depth of 270 nm; (b) pattern of starline CF_4 etched on a fiber; (c) pattern of a circuit CF_4 etched on a fiber.

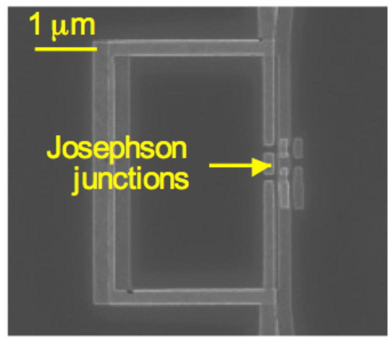
5.1.4. A. LUPASCU GROUP

Qubit based magnetometer

Mustafa Bal

Summary: The SQD group designed and implemented a quantum sensor for magnetometry. The sensor relies on the use of a superconducting flux qubit. The qubit is a ring interrupted by Josephson junctions, operated at temperatures in the tens of miliKelvin range, and controlled using microwave pulses. The magnetometer is useful for detection in the range from tens of kHz to tens of MHz, and it surpasses in sensitivity of other detection methods. The sensitivity reaches 3.3 pT/rt(Hz) for an operation frequency of 10 MHz. (Publication: Nature Communications, 3, 1324, 2012)





Superconducting Microwave Resonators

Martin Otto, Chunqing Deng

Summary: The SQD group have designed and experimentally characterized various types of superconducting microwave resonators which operate at GHz frequencies. Such resonators consist of simple inductor and capacitor circuit elements and provide an accurate method of studying low temperature properties of materials. Quality factor measurements in the range of 10mK – 1K allows for the extraction of the dielectric loss tangent, a figure of merit in characterizing suitable materials for quantum information processing.

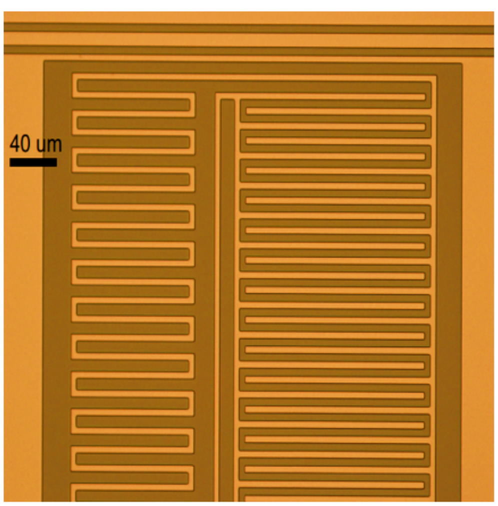


Figure 1: Niobium interdigitated resonator with meander inductor (left) and finger capacitor (right)

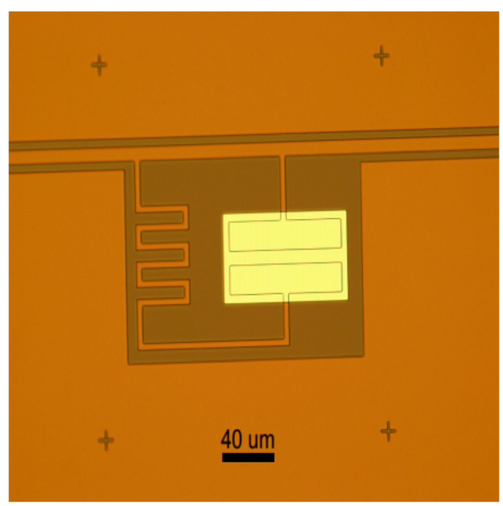
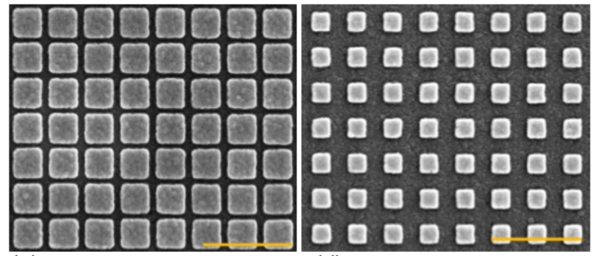


Figure 2: Niobium-Aluminum resonator with meander-line inductor (left) and overlap parallel plate capacitor (right)

Colorful Gold Nano-patch for Sensing

Width \ Index	air	n=1.30	n=1.35	n=1.39
155 nm gold nano-patches				
210 nm gold nano-patches				
230 nm gold nano-patches				
320 nm gold nano-patches				
Gold thin film				
Al mirror				



(c) (d)

"A two-dimensional array of gold nano-patches on a highly reflective mirror is proposed for refractive index sensing based on changes in the reflected colors. Scale bar 1 µm."

M. Khorasaninejad *etal* ""Colorimetric sensors using nano-patch surface plasmon resonators" Nanotechnology 24 (35), 2013.

Plasmonic Nano-Crescent

These nano crescents are fabricated by electron Beam Lithography and liftoff process. Using these nanostructure with were able to enhance nonlinearity from graphene ~1000 times. Scale bar is 200 nm.

M. Khorasaninejad, *et al.* Highly Enhanced Raman Scattering of Graphene using Plasmonic Nano-Structure. Sci. Rep. 3, 2936; DOI: 10.1038/srep02936 (2013).

6. EQUIPMENT BOOKINGS

Table 3: User Equipment Bookings (hours)

2009/10	2010/11	2011/12	2012/13	2013/14*	TOTAL** **since start of operations
235	1073	3551	6153	3985	**14997**

*Fab in operation for only 7 of 12 months during 2013/14 fiscal year

Table 4: Equipment Hours Booked per Faculty Member in 2012/13

Name	IQC	WIN	Other UW
Jonathan Baugh	1481		
David Cory	216		
Bo Cui		553	
Irene Goldthorpe		36	
Jan Kycia	6		
Raymond Laflamme	3		
Adrian Lupascu	1475		
Raafat Mansour		74	
Guoxing Miao	29		
Omar Ramahi			17
Safieddin Safavi-Naeini			598
Simarjeet Saini		1463	
Shirley Tang		191	
Mustafa Yavuz		11	
TOTAL:	**3210**	**2328**	**615**

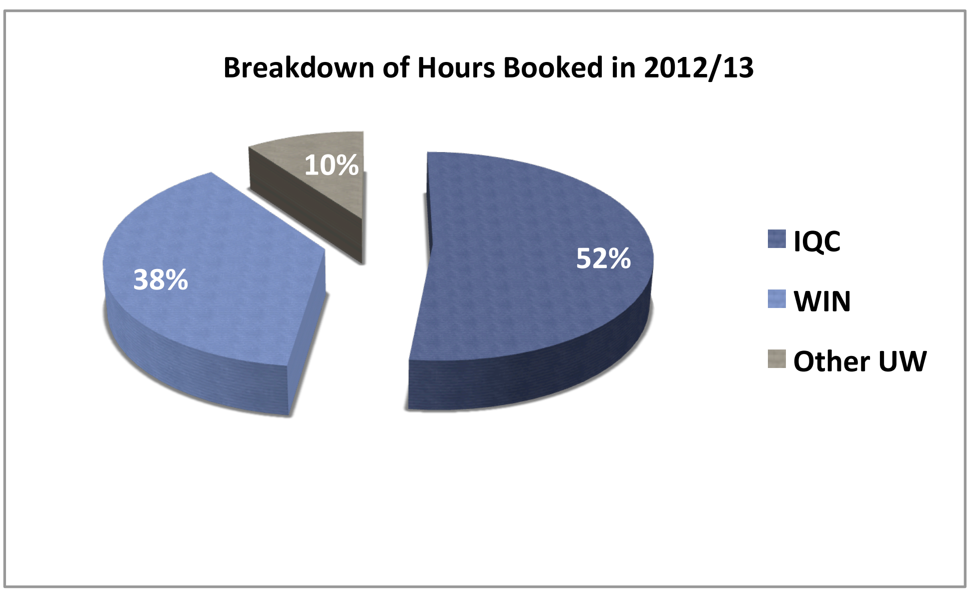
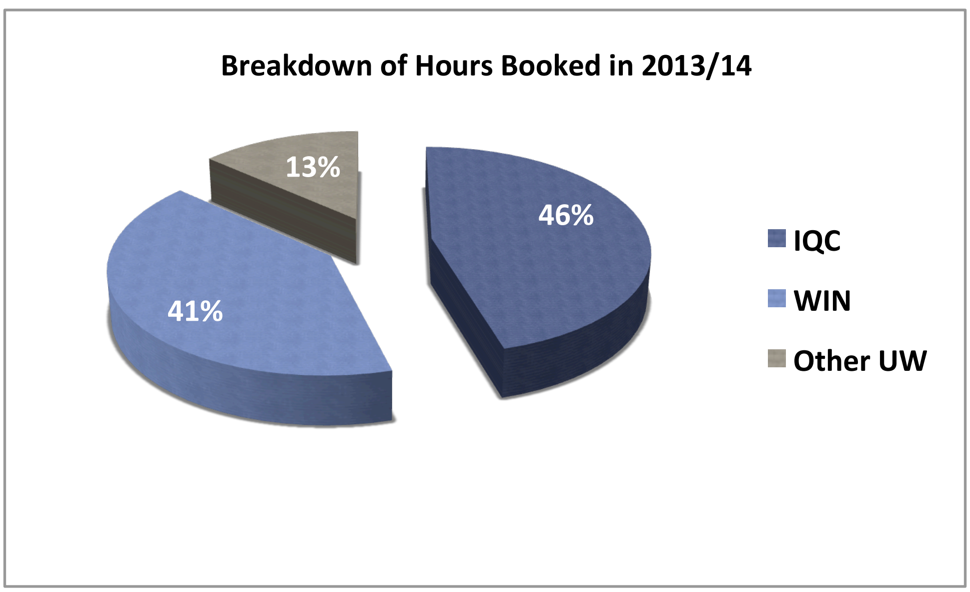


Table 5: Equipment Hours Booked per Faculty Member in 2013/14

Name	IQC	WIN	Other UW
Jonathan Baugh	687		
David Cory	79		
Bo Cui		681	
Irene Goldthorpe		19	
Jan Kycia	18		
Raymond Laflamme	9		
Adrian Lupascu	524		
Raafat Mansour		10	
Matteo Mariantoni	175		
Guoxing Miao	327		
Omar Ramahi			15
Safieddin Safavi-Naeini			521
Simarjeet Saini		852	
Shirley Tang		50	
Mustafa Yavuz		3	
John Yeow		15	
TOTAL:	**1819**	**1630**	**536**



7. EXPENSES & REVENUES

Expenses are divided into direct and indirect costs. Indirect costs were equally covered by IQC and WIN; direct costs were paid out of a combination of CFI-IOF funds and, on an exceptional basis, IQC funds. Facility access fees were collected throughout this reporting period as a function of the fee schedule published on the public portal of the facility website.

Indirect Costs

Table 6: Indirect Costs covered by IQC & WIN *

* These costs are not CFI-IOF admissible and are therefore directly and equally borne by both institutes

Category	IQC	WIN
Salary & Benefits, Director of Operations	50%	50%
Salary & Benefits, Accounting Support ** ** 1 day per week	50%	50%
Salary & Benefits, Information Technology Support ** ** 1 day per week	50%	50%

7.1. 2012/13 FISCAL YEAR

Direct Costs

Table 7: Breakdown of Direct Costs - FY2012/13

Category	Cost	% of total
Salaries & Benefits: (Direct personnel only)	$274,113	69%
Supplies, Maintenance & Repairs: cleanroom, chemicals, process gases, lab equipment repairs	$94,373	24%
Supplies: Bulk nitrogen gas	$27,898	7%
TOTAL ($):	**$396,384**	

NOTES: **A)** On May 15, 2009, UW's *Office of Research* confirmed "*there is no expiration date on the IOF, however funds are expected to be used within 5 years or "within reasonable life expectancy of the CFI equipment".*"

B) As mentioned by this document's author at the WIN Board of Directors meeting held on June 10, 2015, IQC wishes to preserve, as long as reasonably possible, the CFI-IOF funds allocated to the *Quantum NanoFab*. IQC has therefore paid a significant portion of the *Quantum NanoFab*'s operating costs since FY2011/12 (year-by-year breakdown to end FY2014/15 included in Appendix H). IQC aims to initiate discussions with WIN to elaborate a plan for equitable sharing of these costs.

Revenues

A total of 129 invoices were issued over the fiscal period May 1, 2012 to April 30, 2013. The total amount invoiced was $157,915. A breakdown of fab charges per faculty member for this period is included in Appendix I.

Revenues are deposited in a fund 100 operating account dedicated to *Quantum NanoFab* operations. In FY2013/14, revenues were used to purchase service contracts for several critical pieces of equipment as well as spare roughing pumps and other equipment sub-assemblies. These service contracts and spare parts further bolstered the Fab Team's ongoing goal of maximizing equipment uptime to the overall benefit of the Lab Member community.

The balance of CFI-IOF funds granted against CFI project # 11544 continues to be dedicated to the operations of the two IQC & WIN jointly shared facilities. These include:

- The Quantum NanoFab
- The QNC Metrology Facility

These funds remain primarily earmarked for the salaries of technical staff dedicated to the operation & maintenance of both shared facilities.

7.2. 2013/14 FISCAL YEAR

Direct Costs

Table 8: Breakdown of Direct Costs - FY2013/14

Category	Cost	% of total
Salaries & Benefits: HQP dedicated to infrastructure operations & maintenance	$290,309	36%
Supplies, Maintenance & Repairs: cleanroom, chemicals, process gases, equipment spares, service contracts	$486,462	61%
Supplies: Bulk nitrogen gas	$20,494	3%
TOTAL ($):	**$797,285**	

NOTES: **A)** On May 15, 2009, UW's *Office of Research* confirmed "*there is no expiration date on the IOF, however funds are expected to be used within 5 years or "within reasonable life expectancy of the CFI equipment"*."

B) As mentioned by this document's author at the WIN Board of Directors meeting held on June 10, 2015, IQC wishes to preserve, as long as reasonably possible, the CFI-IOF funds allocated to the *Quantum NanoFab*. IQC has therefore paid a significant portion of the *Quantum NanoFab*'s operating costs since FY2011/12 (year-by-year breakdown to end FY2014/15 included in Appendix H). IQC aims to initiate discussions with WIN to elaborate a plan for equitable sharing of these costs.

C) The substantial increase in "Supplies, Maintenance & Repairs" costs during this particular fiscal period are due to the acquisition of:

- Annual support agreement for *Raith 150^{TWO}* E-Beam Litho system ($91k US)
- Annual support agreement for *Oxford Instruments* reactive ion etch (RIE) systems (2) and PECVD/ALD deposition cluster system ($86k US)
- Pump upgrade & spare pump acquisition for *Oxford* ALD deposition system ($69k)

- Spare pump for *Oxford* PECVD deposition system($26k)
- Spare pump shared between both *Oxford* ICP RIE's ($20k)
- BCl_3/Cl_2 gas cabinet upgrade for QNC ($22k)
- 99.999% purity gold pellets for e-beam evaporator ($29k)
- High purity process gases for QNC startup ($20k)
- 99.99% purity platinum for e-beam evaporator ($11k)
- Miscellaneous spare parts and repairs such as RIE wafer clamp ($4k), loadlock spare pump ($6k), wafers for furnace commissioning ($8k) , roughing pump repair ($4k), etc.

Revenues

A total of 90 invoices were issued over the period May 1, 2013 to November 30, 2013. The total amount invoiced was $111,333. A breakdown of fab charges per faculty member for this period is included in Appendix J.

8. ACCESS FEES FOR 2013/14 & INCREASES PLANNED FOR 2014/15

Historical access fees in effect for FY2013/14 are included in Appendix K.

Access fees for the 2013/14 fiscal year were not increased from the previous fiscal year; they remained unchanged since April 1, 2012. Access fees remain highly subsidized by IQC, WIN, the University of Waterloo and the CFI-IOF fund associated with CFI project # 11544. The estimated extent of these subsidies was detailed in the individual monthly invoices sent to Principal Investigators over this period.

Some of our infrastructure had been in operation in the RAC1 temporary facility for 3 to 4 years prior to being moved to QNC. The odds of their suffering potentially expensive repairs with resulting extended downtimes are steadily increasing. As a hedge against these growing probabilities, service contracts have been acquired for five of the facility's most complex and most widely & frequently used pieces of equipment.

The addition of many new pieces of lab equipment in the QNC cleanroom have further increased annual operating costs since many new expensive gases, materials and chemicals are typically used by these machines on a routine basis. In addition, QNC cleanroom operations are more expensive than they were at RAC1 given the QNC's enhanced certification levels and its surface area which is 800% greater than it was at RAC1. These factors contributed to the decision to adjust facility access fees prior to commencement of QNC fab operations.

Final remarks:

As has been the case since temporary operations first started in the RAC1 cleanroom in November 2009, a single access fee structure remains in place for all academic members, regardless of affiliation (IQC, WIN, other academic), and regardless of PI status (junior or senior faculty).

Over the course of FY2014/15, Management intends to define and implement the necessary protocols and procedures needed to permit facility access to other academic institutions, government labs and private sector companies. This will allow the facility to fulfill access requirements dictated by its federal and provincial funding agencies. It will also allow for the generation of much needed additional revenues to fund its expanding operating costs.

As shown in Appendix F, industrial access rates have been set to 3x the academic rates. This is in line with trends observed at other similar institutions, and is subject to future review/adjustment.

9. 2014/15 KEY OBJECTIVES & ACTIVITIES

Some portions of the QNC infrastructure were not 100% ready for commencement of operations on September 2, 2014, the *Quantum NanoFab's* grand opening date. Completion of these final elements remained the Fab Team's main focus after the facility's doors were opened for business. These included the following major objectives:

Building & Cleanroom Infrastructure

- Ensure completion of fandeck (interior) wall repairs
- Complete modifications to gowning room main access door & sliding door assembly
- Install stand-alone temperature monitor in gas bunker 1709
- Complete *Packaging Lab* & *Sample Prep Lab* setups
- Eliminate facility access for all construction trades
- Ensure Process Chilled Water (PCW) resistivity set point maintained at acceptable level prior to powering lab equipment with RF power supplies
- Ensure facility "clean steam" humidification capability tested and enabled prior to start of dry, winter season

- Per safety code requirements, implement protocol for annual verification of fume hood face velocities, monthly inspection of fire extinguishers and monthly testing of emergency safety showers
- Establish content for & activate TV panels located at cleanroom gowning room entrance and along centre aisle within cleanroom
- Establish detailed procedure for safely charging toxic & corrosive gas lines
- Install nitrogen and house vacuum ports to hoods in labs 1508 and 1707
- Work with UW *Plant Operations* to devise a plan & procedure for routinely maintaining cleanroom ventilation infrastructure all while minimizing impact to fab operations

Cleanroom Operations - General

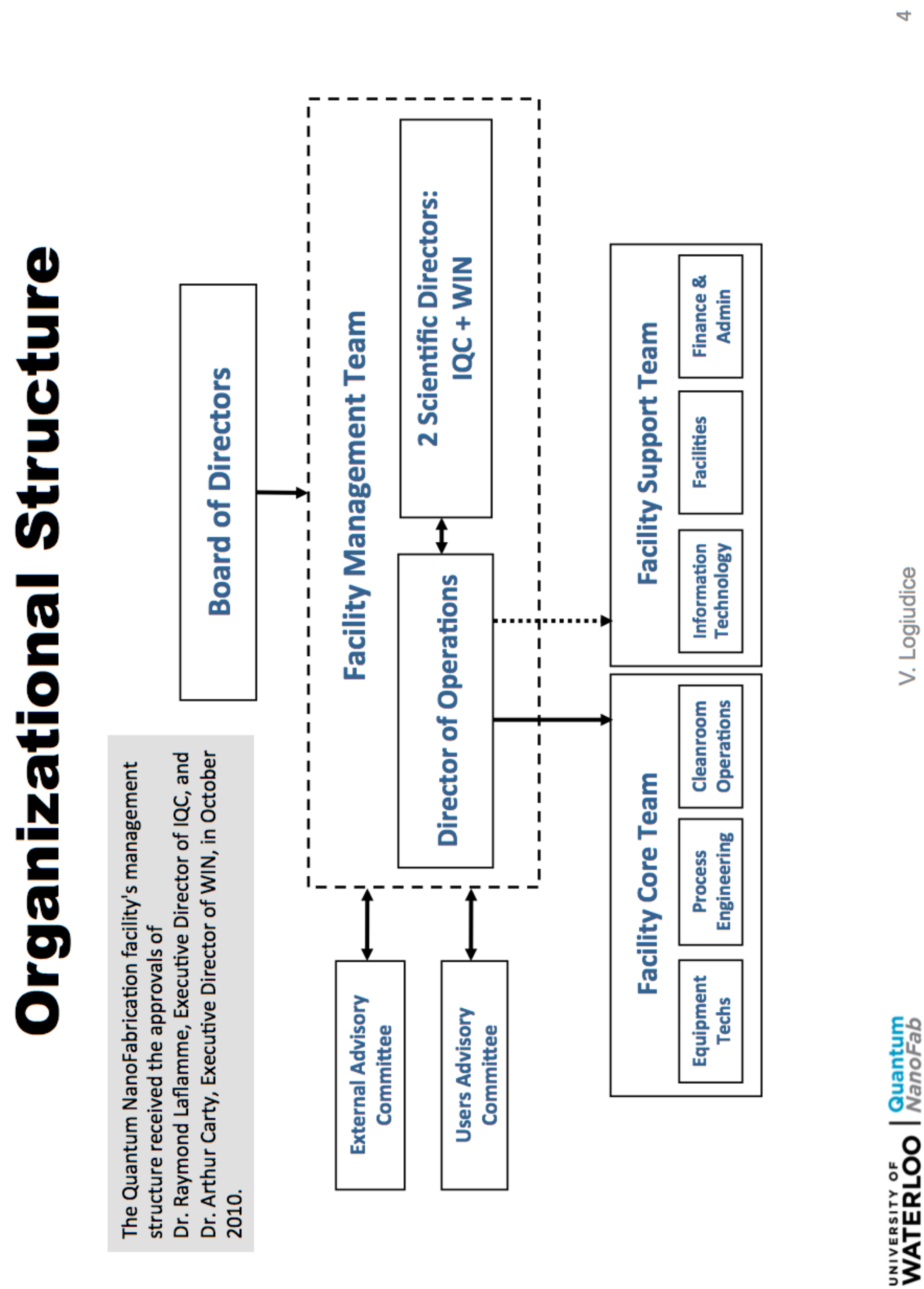
- Install additional chemical storage cabinets
- Acquire chemical transport carts
- Devise & implement plan for keeping fire extinguishers off the floor as required to comply with UW Safety Office guidelines
- Establish plan for cleanroom gowning gear laundering protocol & frequency
- Establish & implement protocol and schedule for ongoing cleaning of cleanroom walls, floors and ceilings
- Establish facility safety inspection plan and commence monthly inspections starting September 2014
- Streamline website to facilitate retrieval of information on public and password-protected portals
- Acquire additional chemical spill kits
- Establish online quiz for "*HF Acid Handling Best Practices*" training module
- Roll-out mechanism for generating new user ID badges and facility access FOB's
- Create job description for new *Nanofabrication Equipment Technologist* position
- Expand facility access policies to allow non-UWaterloo access (including non-UW academic and private sector applicants)
- Establish facility checklist and commence weekly and monthly datalogs
- Establish temporary monthly invoicing mechanism via support from *Badger LMS*
- Roll out *Badger Dashboard* on fab website
- Order additional cleanroom gowning gear

Lab Equipment

- Complete all remaining ESA certifications
- Commission all tools previously available in RAC1 temporary facility on a priority basis:
    - *Oxford* silicon etcher (Si DRIE)

- *Oxford* metal etcher (RIE for metals & III-V materials)
    - *Oxford* ALD/PECVD cluster deposition system
    - *YES* Oxygen plasma etch system
- Commission newly installed equipment including:
    - Rapid Thermal Processor
    - *AJA* Twin-chamber sputter
    - *AJA* Ion mill
    - Four-tube furnace stack
    - Ellipsometers
    - Wet benches
    - Film stress measurement system
    - Packaging Lab equipment

Submitted by: Vito Logiudice P.Eng.
Director of Operations, *Quantum NanoFab*
June 30, 2015


Organizational Structure
The Quantum NanoFabrication facility's management structure received the approvals of
Dr. Raymond Laflamme, Executive Director of IQC, and
Dr. Arthur Carty, Executive Director of WIN, in October 2010.
Board of Directors
Facility Management Team
2 Scientific Directors: IQC + WIN
Director of Operations
External Advisory Committee
Users Advisory Committee
Facility Core Team
Equipment Techs
Process Engineering
Cleanroom Operations
Facility Support Team
Information Technology
Facilities
Finance & Admin
V. Logiudice
4

APPENDIX B: QNC CLEANROOM VIBRATION & ACOUSTIC TEST DATA

SURVEY OF VIBRATION AND ACOUSTIC NOISE, AS-BUILT CONDITION
UNIVERSITY OF WATERLOO QUANTUM-NANO CENTRE
WATERLOO, ONTARIO, CANADA

Prepared by: **Michael Gendreau**
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+1 (415) 570-0350

CGA Project Nr. 05097.02
27 November 2012

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COLIN GORDON ASSOCIATES INC - SPECIALIZING IN ACOUSTIC AND VIBRATION SOLUTIONS
150 NORTH HILL DRIVE, SUITE 15, BRISBANE, CALIFORNIA 94005 USA TEL +1-415-570-0350 FAX +1-415-570-0351
www.colingordon.com

1. Introduction and Executive Summary

Introduction. On 30 October 2012, Michael Gendreau of Colin Gordon Associates conducted an "as built" vibration and noise evaluation of the University of Waterloo Quantum-Nano Centre in Waterloo Ontario. An "as built" evaluation, as defined by international standards organizations, is a test of the environment after the structure is complete and with all or most of the building mechanical equipment installed, operating, and balanced, but before installation of research equipment ("tools"). This state appeared to be the case at the time of our visit, although we understand that air balance may have been affected in some rooms due to ongoing finishing work, fume hood adjustment, etc. Testing was carried out in a selection of vibration and noise sensitive technical areas on all floors, including Metrology, the Clean Fabrication Suite, IQC Labs, and Nano Project Labs, and others.

Executive summary. The data and analysis presented in this report support the following conclusions.

Vibration
The project vibration criteria have been met in all areas. The ground-level laboratories will provide a particularly low-vibration environments, well below the VC-E design criterion, and even below the stringent low-frequency NIST-A criterion. Most upper floor laboratories perform at several grades lower in vibration than required by the criteria. In a few cases, sources of tonal vibration (compressors, fans, transformers) are visible in the vibration signatures of some floors, but not of excessive amplitude.

Acoustic Noise
The measured noise levels are mostly compliant with the design goals. Some of the Metrology laboratories appear to be louder than might be desired, and this appears to be due to local balancing problems (air valves, etc.). The IQC labs are particularly quiet on all floors, as is the Clean Manufacturing Suite, and in particular the e-beam isolation room. Nano and Northeast Project Rooms have higher noise levels as is consistent with and expected in rooms containing fume hoods.

2. Vibration and Noise Criteria

Vibration criteria. Table 1 summarizes the floors studied and the relevant vibration criteria.

Table 1: Summary of Vibration Criteria in Vibration Sensitive areas of UW QNC

Laboratory	Criterion	Floor Level	Structural System
Clean Fabrication Suite	VC-E	1	Waffle Slab
Metrology Suite	VC-E	Grade	Slab-On-Grade
Packaging & Assembly	VC-B	1	Waffle Slab
MBE	VC-B	1	Waffle Slab
Cold Atoms	VC-C	1	Waffle Slab
IQC	VC-D	Grade	Slab-On-Grade
	VC-B	2-4	Waffle Slab
Nano Project Rooms	VC-B	Grade	Slab-On-Grade
		1	Waffle Slab
		3-5	Composite Slab

The criteria in Table 1 refer to the commonly-used vibration criterion (VC) curves, as described in Appendix A. The vibration criteria are valid at start-up, with the building mechanical equipment in place, balanced, and operating.

Noise criteria—generic. For traditional laboratories, a design criterion of NC-45 (with fume hoods) or NC-40 (without fume hoods) is common, but it is not unusual to require much more stringent criteria for very sensitive physics research and nanotechnology work, perhaps on the order of NC-25. Table 2 lists typical noise design criteria (performance criteria are typically 5 points higher) for some common room functions in laboratory buildings.

Table 2: Typical Room Noise Criteria (NC)[1]

Room Function	Recommended NC
Cleanrooms (Class 100)	55 - 60
Laboratories with fume hoods	45 - 50
Laboratories without fume hoods	40 - 45
Sensitive imaging and research labs	25 - 35

Noise criteria specific to QNC project. Early in the project, noise criteria were identified by the University for the Metrology area (represented in KPMB/HDR Drawing Number HQ-10LA dated 10 November 2006), and for other areas in Specification Section 13080 Sound and Vibration Control. The latter, however, only addresses non-technical spaces (seminar, meeting,

[1] This compilation is based on the following references, and others: *ASHRAE HVAC Applications* Chapter 42 Sound and Vibration Control (1991); Howard F. Kingsbury "Review and Revision of Room Noise Criteria" *Noise Control Engineering Journal* 43-3 May-June 1995; American National Standards Institute *Criteria for Evaluating Room Noise* ANSI S12.2-1995; Robin M. Towne et al. "The Changing Sound of Education" *Sound and Vibration* January 1997.

- For interest, we also measured the transfer function across the structural isolation break (SIB) that runs along the corridor B872 just outside rooms B712 through B714. This was done by measuring simultaneously about 1m from the SIB on a line normal to it, and on either side of it. Three separate measurements were made for each of the three standard orthogonal axes, and the data are shown in Figures B10, B11, and B12. The data labeled "plant room side" are measured in the doorway of ESCA lab B713 and the data labeled "lab side" are measured in the corridor. There is attenuation of vibration on the lab side at about 20 Hz and above (as is typical, there is no attenuation at lower frequencies were the large wavelengths propagate primarily in the soil).

- **Level 1 Cold Atoms Labs.** The vibration criterion for these labs is VC-C (12.5 μm/s). Data measured in rooms 1301, 1303, and 1304 are shown in Figures B13, B14, and B15. The vibration amplitudes on this floor easily meet the VC-C criterion, and in fact they also meet the VC-E (3 μm/s) criterion.
- **Level 1 Northeast Project Rooms.** The vibration criterion for these labs is VC-B (25 μm/s). Data measured in room 1509 are shown in Figure B16. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-E (3 μm/s) criterion under ambient conditions.
- **Level 1 Clean Fabrication Suite.** The vibration criterion for the cleanroom structural floor is VC-E (3 μm/s). Data measured at several locations on the structural floor, and in one case on the raised-access floor (RAF), are shown in Figures B17 through B23.
  - Figures B17 through B20 show data measured on the structural floor (B17 and B18) and on the RAF (B19 and B20) at the proposed location of a Karl Suss MA6 mask aligner in Room 1701D. We were asked to compare the MA6 criterion, which is the same as VC-C, with the performance of the structural floor and the RAF, in order to determine if it could be located on the RAF or should be supported from the structural floor on a rigid pedestal. The data show that the structural floor meets the VC-E design criterion (and thus also the VC-C criterion) under ambient and walker conditions. However, the vibration is significantly higher than VC-C on the RAF, especially in the horizontal direction, and especially in the presence of footfall, as would be expected for RAF. It is recommended that the tool be supported on the structural floor, therefore.
  - Figure B21 shows data measured in Room 1701L, which is the vestibule outside the E-beam Lithography isolation room, at the proposed location of a Raith 150^{TWO}. The lab vibration is well below the VC-E criterion. We show the Raith criterion in the plot as well for reference.[3] The Raith criterion is also met, although it is marginally exceeded at 10 Hz, which is due to intermittent tonal vibration (discussed below).
  - Figure B22 shows data measured in Room 1701M, the E-beam Lithography isolation room, at the proposed location of the tool. The lab vibration is well below the VC-E criterion.

---

[3] This criterion is from our archives; the most recent vibration sensitivity information should be verified with the tool manufacturer.

  - Figure B23 shows data measured in Room 1701P, the Testing/Metrology Bay, at the proposed location of an SEM. The lab vibration is well below the VC-E criterion.
  - Intermittent tonal vibration is seen in some of the cleanroom data, primarily at around 10.5 Hz, with some slight variations. This appears to be due to the reciprocating compressor located directly above in the cleanroom mechanical room. Measurements on the base of this compressor show that it generates vibrations at frequencies of just above 5 Hz and harmonics (frequencies that are integer multiples of the base frequency) including the frequency just above 10 Hz seen on the cleanroom floor. While this does not a present cause an exceedance of the criterion, the tonal vibration could be reduced or eliminated by using a smoother-running rotating pump.
- **Level 1 Packaging and Assembly.** The vibration criterion for this lab is VC-B (25 µm/s). Data measured in room 1706 are shown in Figure B24. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-E (3 µm/s) criterion under ambient conditions.
- **Level 2 IQC Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 2301 and 2304 are shown in Figures B25 and B26. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-E (3 µm/s) criterion under ambient conditions.
- **Level 3 IQC Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 3301 and 3304 are shown in Figures B27 and B28. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-E (3 µm/s) criterion under ambient conditions.
- **Level 3 Northeast Project Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 3502 and 3517 are shown in Figures B29 and B30. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-C (12.5 µm/s) criterion under ambient conditions.
  - The vertical vibration indicates tonal sources at 14.75 Hz, 20.0 Hz, and other frequencies. The sources of these tones, which do not exceed the criterion, are discussed below.
- **Level 4 IQC Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 4302A and 4303 are shown in Figures B31 and B32. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-E (3 µm/s) criterion under ambient conditions.
- **Level 4 Northeast Project Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 4506 and 4518A are shown in Figures B33 and B34. The vibration amplitudes on this floor easily meet the VC-B criterion, and they also meet the VC-C (12.5 µm/s) criterion under ambient conditions.
- **Level 5 Northeast Project Labs.** The vibration criterion for these labs is VC-B (25 µm/s). Data measured in rooms 5502, 5512, and 5517 are shown in Figures B35, B36, and B37, respectively. The vibration amplitudes on this floor meet the VC-B criterion.
  - Tonal vibration is seen in the 3rd to 5th floor Northeast Project Labs to varying degrees. Measurements on various sources identified the primary sources as the

5. Presentation and Discussion of Acoustic Noise Data

Noise measurement locations. Space-averaged noise was measured at a selection of technical spaces within the QNC building. The measurement locations are listed in the introduction to Appendix C, and referenced in the summary discussion below for each area, which also includes comments on certain measurement conditions, and the overall noise level measured.

Results. The QNC as-built noise data, which are contained in Appendix C, may be summarized as follows:

- **Basement level IQC Labs.** Noise levels in four basement-level IQC labs were measured and are shown in Figure C1. The levels range from NC-31 (37 dBA) in Room B308 to NC-36 (43 dBA) in Room B303. In all IQC rooms (including those on other floors), there is some low-frequency tonal noise due to the transformers located immediately outside the doors. The isolation is compromised in some cases (i.e., shorting by through-bolts in mounts for ground transformers, shorting in hanger spring support in some hanging transformers); in addition to structure-borne noise, some of the noise appears to radiate through the transformer casing.
- **Basement level Nano Project Rooms.** Noise levels in two basement-level Nano Project Rooms were measured and are shown in Figure C2. The levels range from NC-40 (47 dBA) in Room B537 to NC-50 (56 dBA) in Room B533. In B533 some of the ceiling tiles were out of place, which will tend to allow increased noise levels, and in addition this room contains an operating fume hood (there is no fume hood in B537).
- **Basement level Metrology Labs.** Noise levels in three basement-level Metrology labs were measured and are shown in Figure C3. The levels range from NC-30 (38 dBA) in Room B701 to NC-52 (58 dBA) in Room B707. Room B701 (PLD Lab) meets the NC-40 criterion for PLD. Rooms B707 and B711 both exceed their criterion, of NC-40 and NC-30, respectively. In B707 the high-frequency noise, at least, appears to be due to a balance problem: the southeast supply diffuser (or five) appears to be noisier than the others.
- **Level 1 Cold Atoms Labs.** Noise levels in three Level 1 Cold Atoms labs were measured and are shown in Figure C4. The levels range from NC-31 (39 dBA) in Room 1303 to NC-37 (42 dBA) in Room 1301. As with the suite below, there is some transformer noise, especially at 125 Hz, but in any case these levels are fairly low.
- **Level 1 Northeast Project Lab.** Noise levels in a Level 1 Northeast Project lab were measured and are shown in Figure C5. The level in room 1509, which has several large operating fume hoods, is NC-50 (56 dBA).
- **Level 1 Clean Fabrication Suite, and Packaging and Assembly.** Noise levels in four bays in the Class 100 cleanroom and one in the Package and Assembly room were measured and are shown in Figure C6. The cleanroom noise levels range from NC-30 (35 dBA) in Bay 1701M to NC-46 (51 dBA) in Bay 1701P. These are some of the lowest noise levels the author has measured in a Class 100 cleanroom. Room 1706 (Package and Assembly), which is outside the cleanroom and contains operating fume hoods, meets NC-42 (46 dBA).

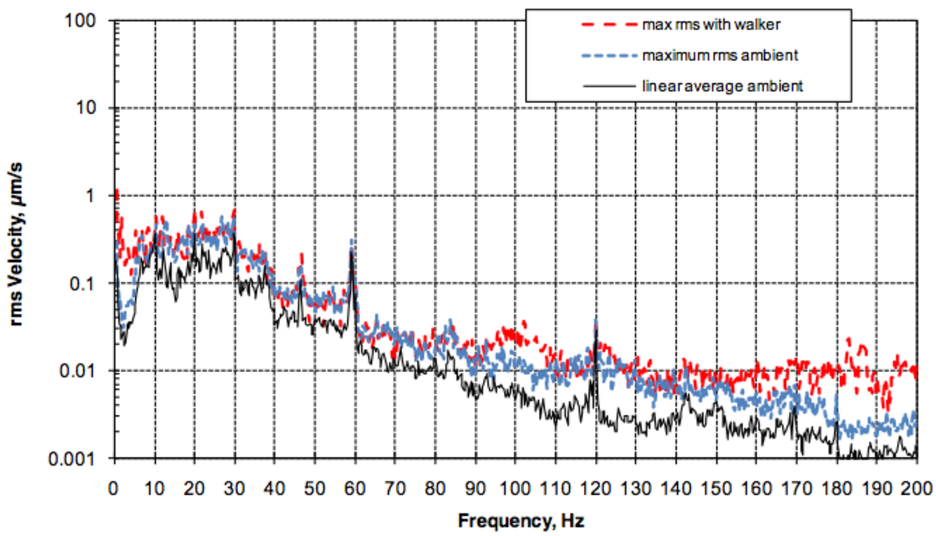
APPENDIX B INDIVIDUAL VIBRATION TEST DATA RECORDS

Key to figures.

Figure	Room Number	Name	Location in Room
B1	B301	IQC	center
B2	B303	IQC	center
B3	B304	IQC	center
B4	B308	IQC	center
B5	B533	Nano Project Room	center
B6	B537	Nano Project Room	center
B7	B701	Metrology (PLD)	center
B8	B707	Metrology (FE SEM)	center
B9	B711	Metrology (FIB)	center
B10	B713/B872	SIB (ESCA to Quiet Corridor), V	
B11	B713/B872	SIB (ESCA to Quiet Corridor), NS	
B12	B713/B872	SIB (ESCA to Quiet Corridor), EW	
B13	1301	Cold Atoms Lab	center (mid-bay)
B14	1303	Cold Atoms Lab	center (mid-bay)
B15	1304	Cold Atoms Lab	center (mid-bay)
B16	1509	Northeast Project Room	center (mid-bay)
B17	1701D	Cleanroom, Wet Lithography, SF, V	tool location
B18	1701D	Cleanroom, Wet Lithography, SF, EW	tool location
B19	1701D	Cleanroom, Wet Lithography, RAF, V	tool location
B20	1701D	Cleanroom, Wet Lithography, RAF, EW	tool location
B21	1701L	Cleanroom, E-Beam Lithography	tool location
B22	1701M	Cleanroom, E-Beam Lithography	tool location
B23	1701P	Cleanroom, Testing/Metrology	SEM location
B24	1706	Packaging and Assembly	center
B25	2301	IQC Lab	center (mid-bay)
B26	2304	IQC Lab	center
B27	3301	IQC Lab	center (mid-bay)
B28	3304	IQC Lab	mid-bay closest to building edge
B29	3502	Northeast Project Lab	mid-bay
B30	3517	Northeast Project Lab	mid column line
B31	4302A	IQC Lab	mid-bay
B32	4303	IQC Lab	mid-bay
B33	4506	Northeast Project Lab	mid-bay
B34	4518A	Northeast Project Lab	mid-bay
B35	5502	Northeast Project Lab	center (mid-bay)
B36	5512	Northeast Project Lab	center (mid-bay)

Figure B17: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701D, Mask Aligner Room Structural Floor, Tool Location,
Vertical, Linear Average Ambient and Maximum RMS with Walker

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



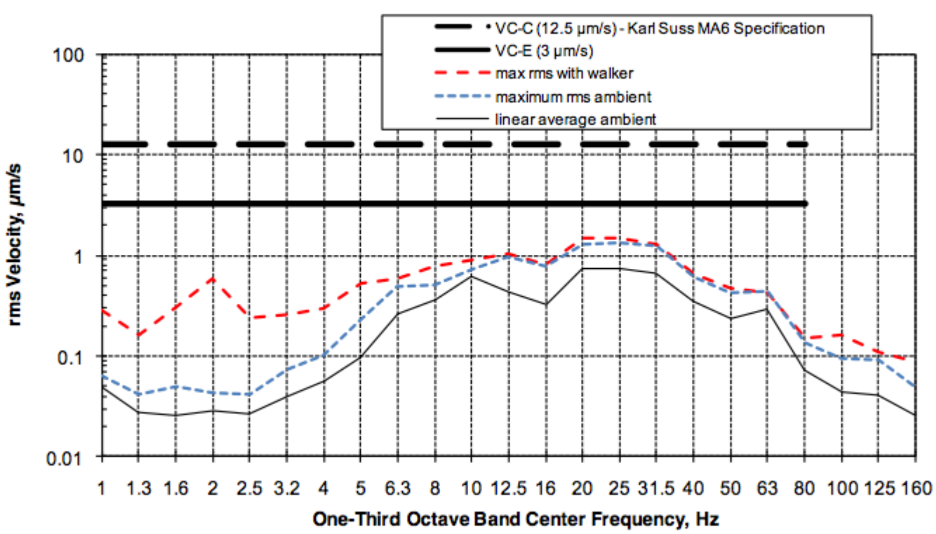


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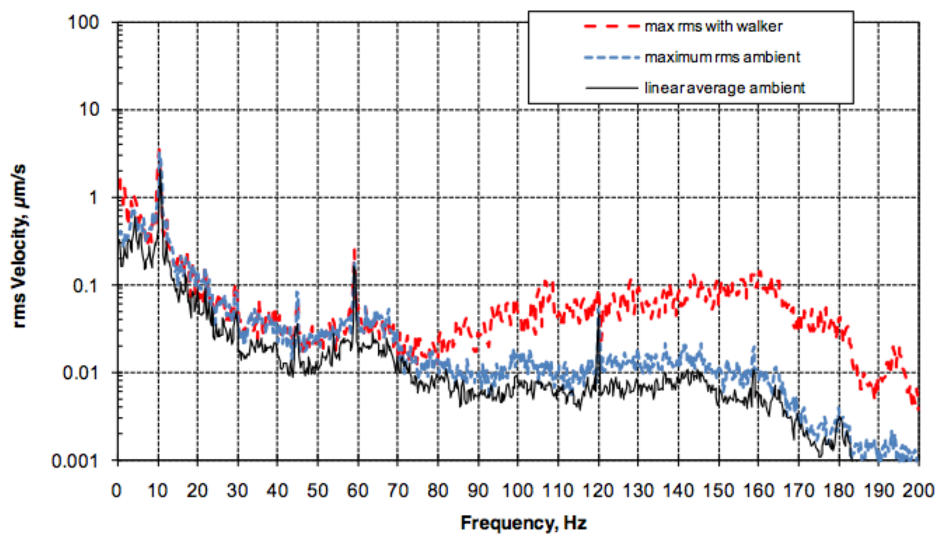
Figure B18: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701D, Mask Aligner Room Structural Floor, Tool Location, Horizontal (EW), Linear Average Ambient and Maximum RMS with Walker

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



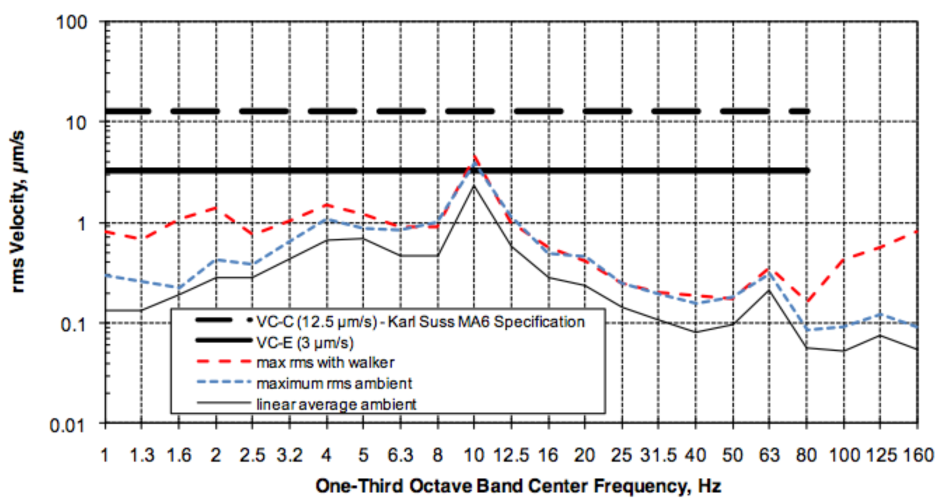


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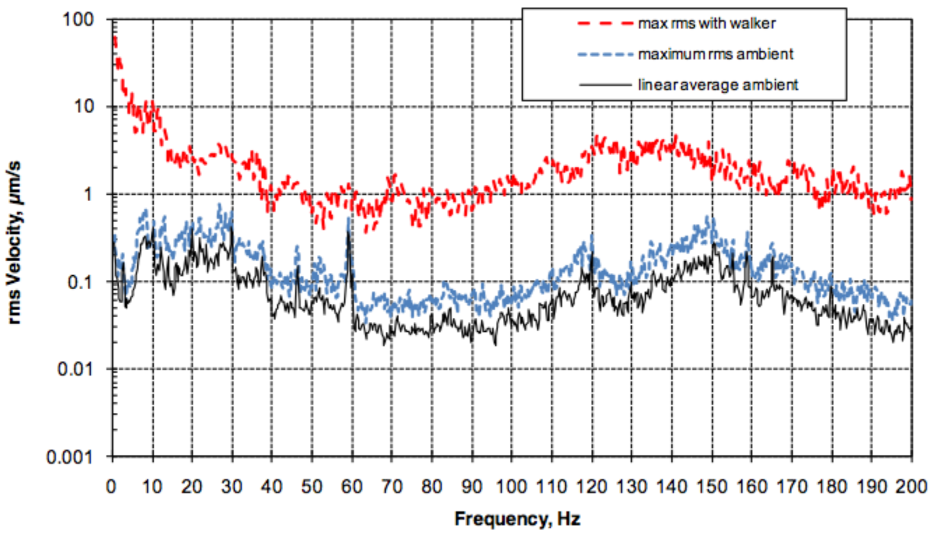
Figure B19: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701D, Mask Aligner Room Raised-Access Floor, Tool Location, Vertical, Linear Average Ambient and Maximum RMS with Walker

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



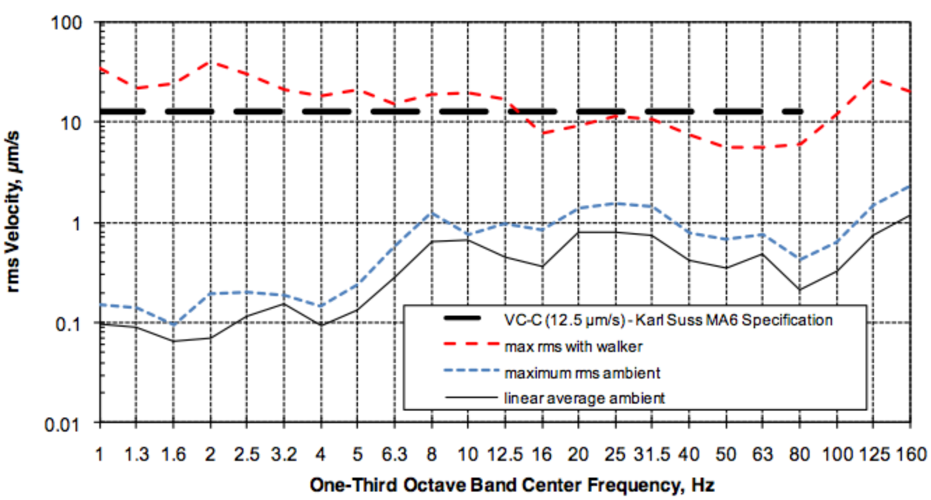


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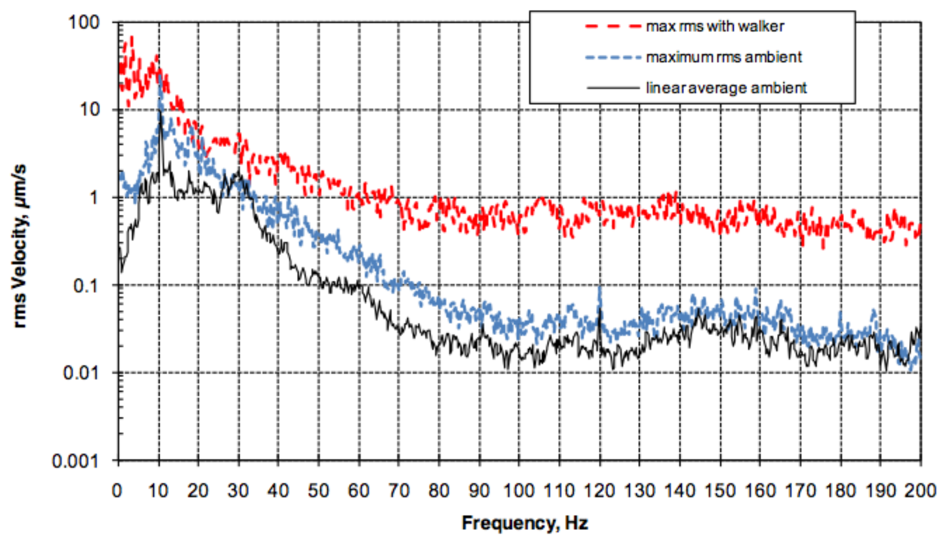
Figure B20: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701D, Mask Aligner Room Raised-Access Floor, Tool Location,
Horizontal (EW), Linear Average Ambient and Maximum RMS with Walker

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



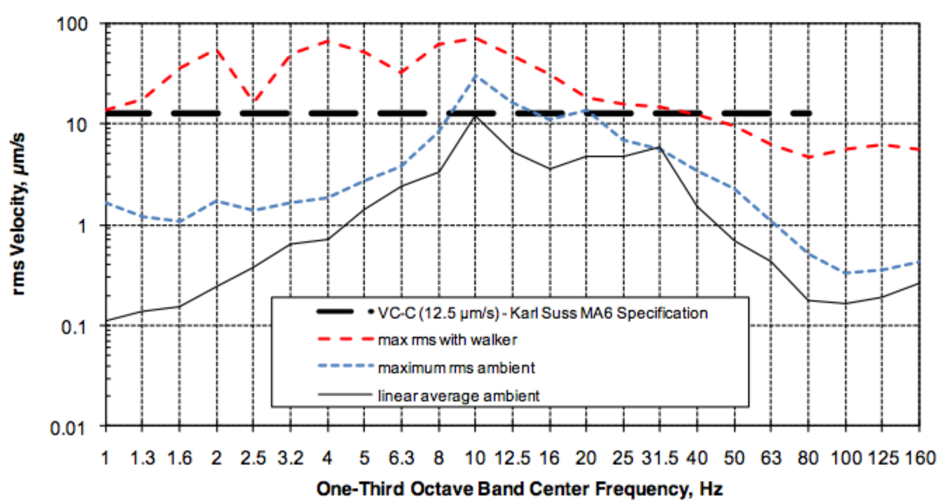


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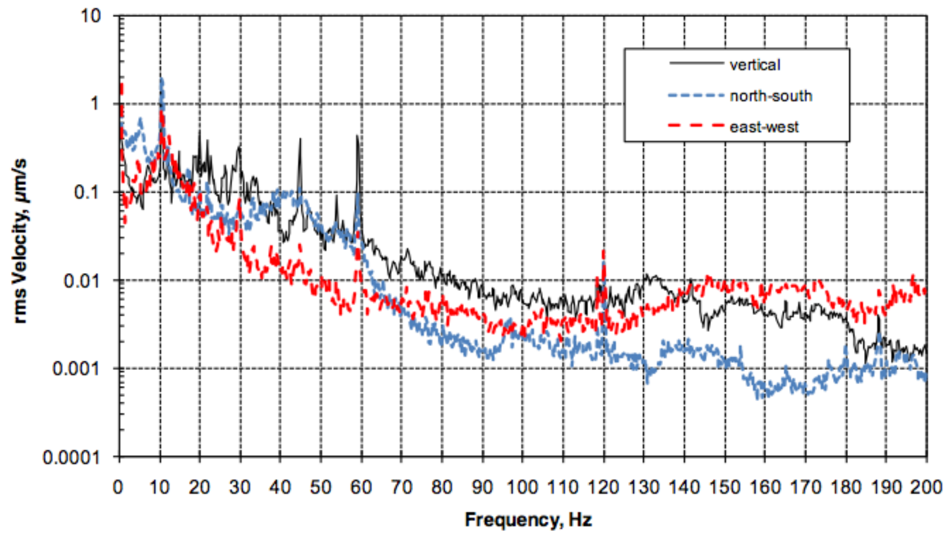
Figure B21: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701L, E-Beam Vestibule, Tool Location, Triaxial, Linear Average
Ambient

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



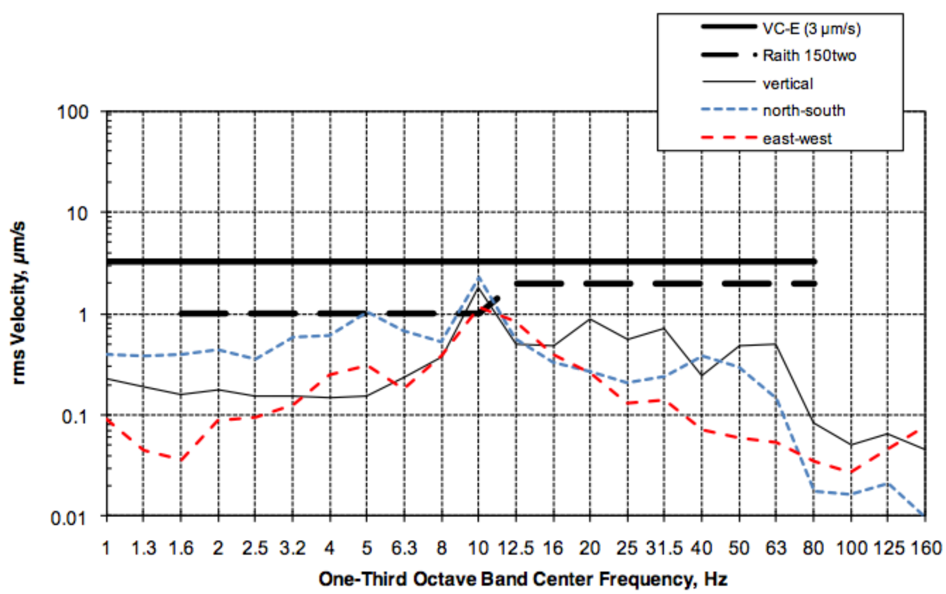


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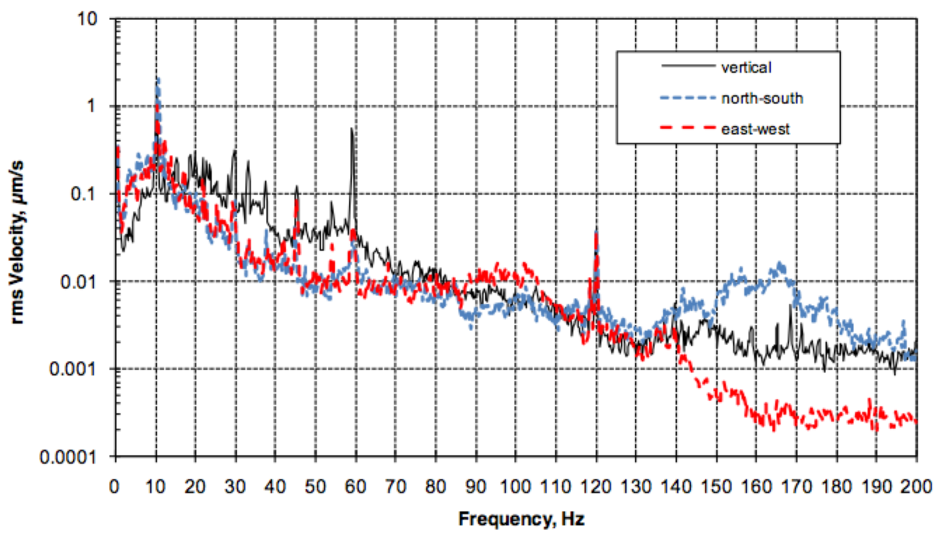
Figure B22: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701M, E-Beam Isolation Room, Tool Location, Triaxial, Linear Average Ambient

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



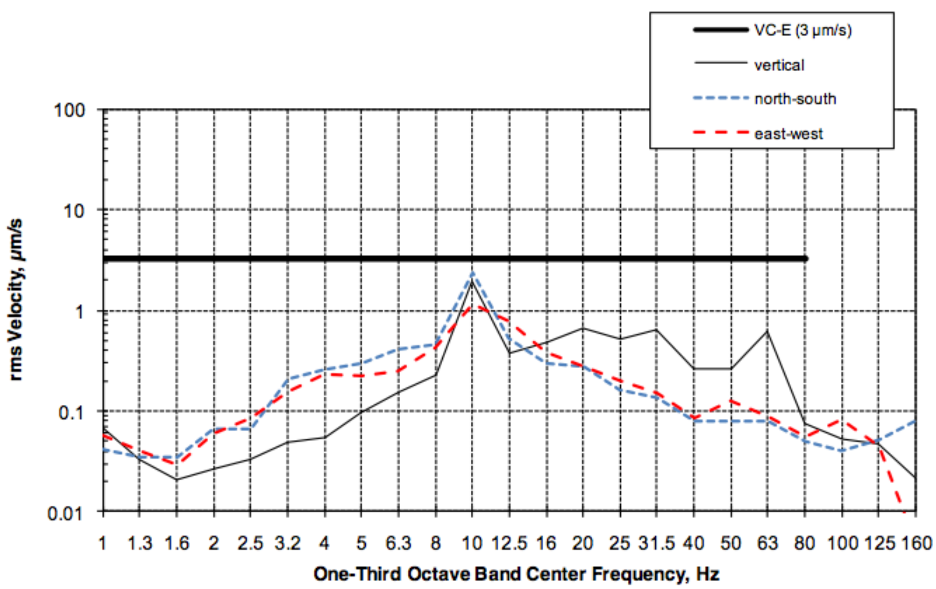


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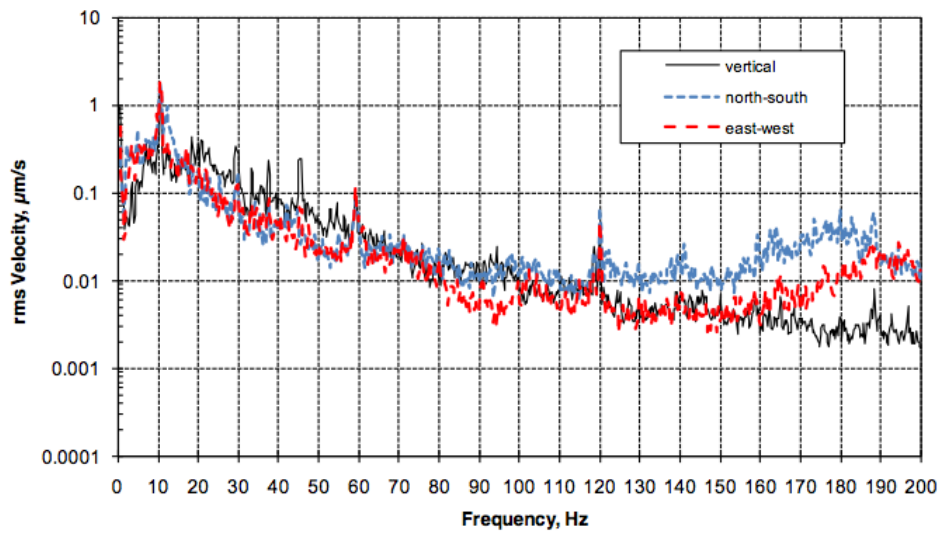
Figure B23: QNC Waterloo As-Built Evaluation - 30 October 2012
Cleanroom 1701P, Metrology Room, Tool Location, Triaxial, Linear Average
Ambient

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



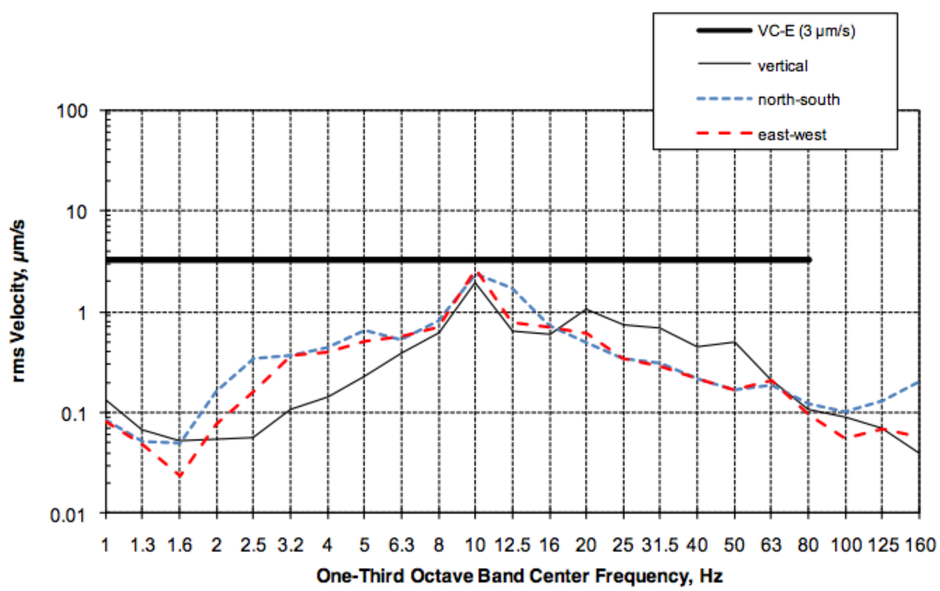


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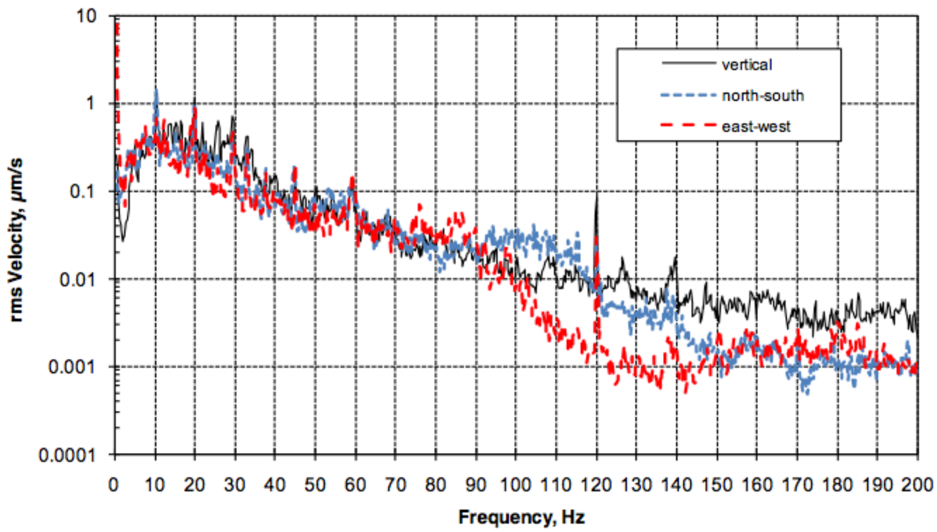
Figure B24: QNC Waterloo As-Built Evaluation - 30 October 2012
Room 1706, Mid-Room, Triaxial, Linear Average Ambient

a) Narrowband (Bandwidth = 0.375 Hz) Velocity



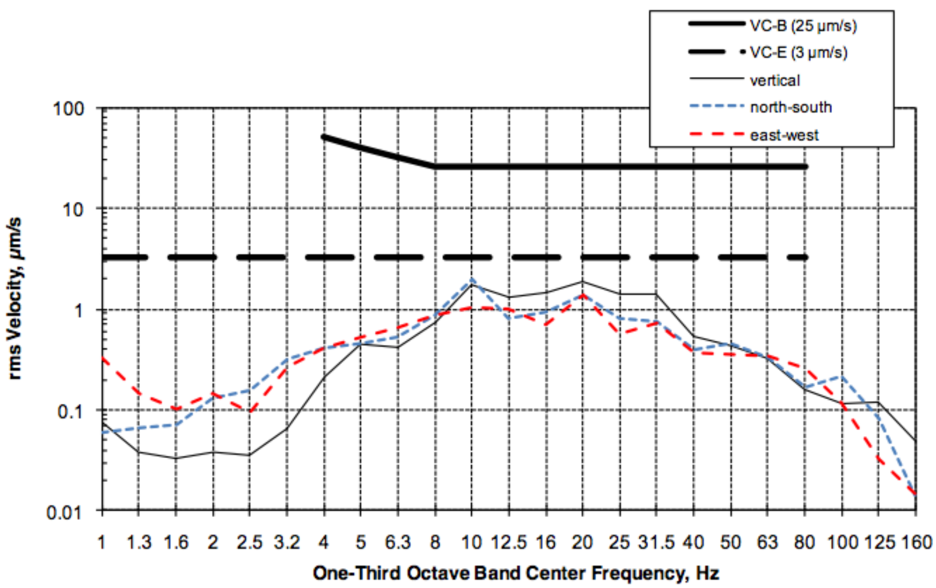


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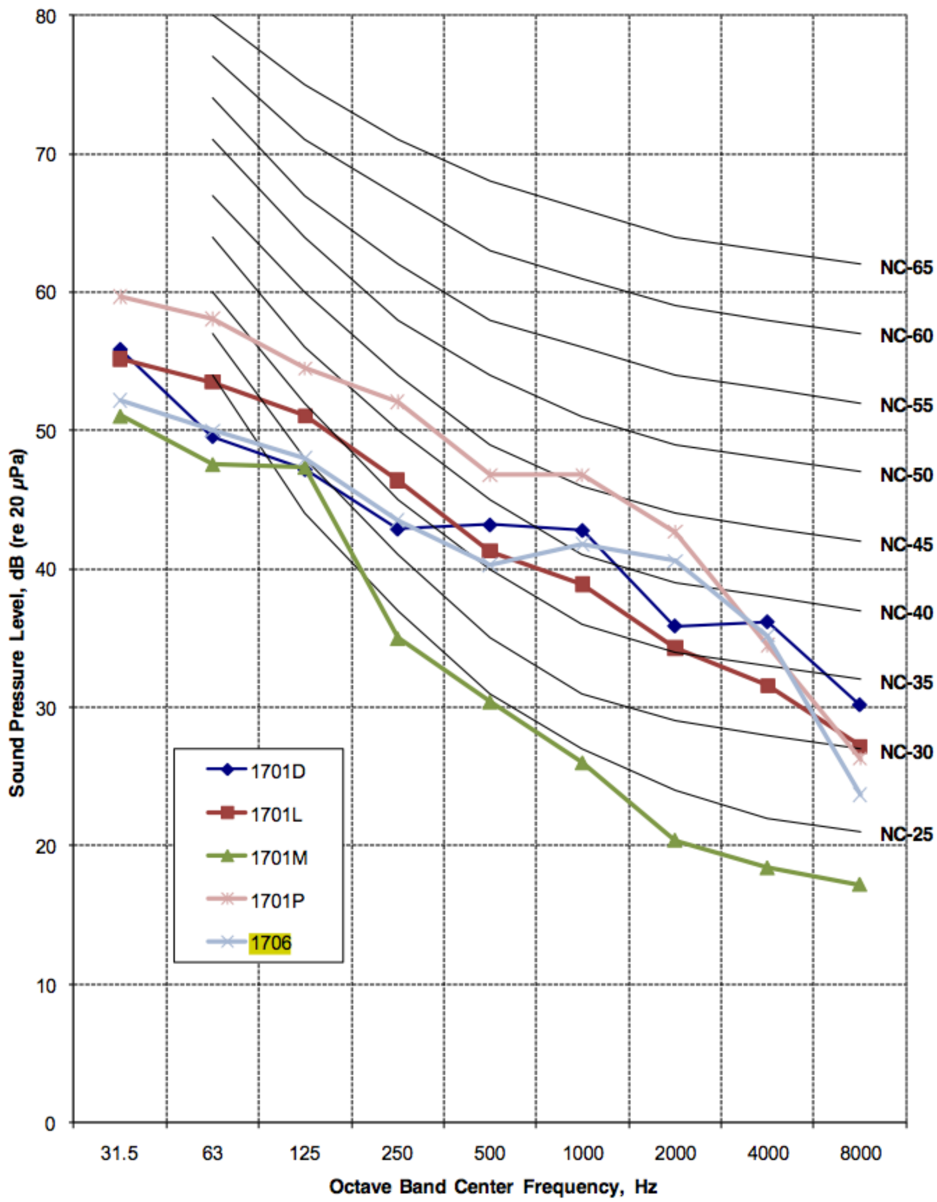
Figure C6: University of Waterloo QNC – 30 October 2012
Octave Band Sound Pressure Levels in Clean Fabrication Suite, 30s L_{eq}



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APPENDIX C: QNC CLEANROOM PARTICLE COUNT TEST DATA: PRE-FIT-OUT

TEST AND CERTIFICATION

OF

UNIVERSITY OF WATERLOO

QUANTAM - NANO CENTER CLEANROOM

DECEMBER 19- 20, 2012

TEST PERFORMED BY:	BRUCE C. PEAT, GENERAL MANAGER CHRIS CLAEYS, SERVICE MANAGER H.E.P.A. FILTER SERVICES INC.
TEST EQUIPMENT USED:	TSI HOTWIRE ANEMOMETER MODEL NO. 8384A SERIAL NO. 98120363 SERIAL NO. 00060057 SHORTRIDGE AIR DATA MULTIMETER MODEL NO. ADM-850 SERIAL NO. M98973 MET ONE PARTICLE COUNTER MODEL NO.3313 SERIAL NO. 040601012 MODEL NO. A2408 SERIAL NO. 970831115

H·E·P·A

TEST AND CERTIFICATION
UNIVERSITY OF WATERLOO QUANTUM-NANO CENTER CLEANROOM

PARTICLE COUNTS PER ISO 14644-1

Particle counts have been taken at rest condition with count locations 36 inches from floor level. Three counts have been taken at each location with a total intake of 1 cubic meter. Counts have been averaged to give a statistically significant result. Counts have been recorded at 0.3, 0.5 and 5.0 micron particle size.

ISO Class 5 Specifications:

10,200 particles at 0.3 micron, 3,520 particles at 0.5 micron, 832 particles at 1.0 micron
29 particles at 5.0 micron.

ISO Class 6 Specifications:

102,000 particles at 0.3 micron, 35,200 particles at 0.5 micron, 8,320 particles at 1.0 micron
293 particles at 5.0 micron.

Room Location	ISO Class	0.3 micron	0.5 micron	1.0 micron	5.0 micron
Testing Metrology					
Rm 1701P					
Location 1	5	61	0	0	0
Location 2		68	0	0	0
Location 3		59	0	0	0
Location 4		62	0	0	0
Location 5		51	0	0	0
Location 6		57	0	0	0
Location 7		49	0	0	0
Location 8		38	0	0	0
E-Beam Lithography 1701M					
Location 1	5	89	2	0	0
Location 2		102	2	0	0
Location 3		116	2	0	0
Location 4		94	0	0	0

TEST AND CERTIFICATION
UNIVERSITY OF WATERLOO QUANTUM-NANO CENTER CLEANROOM

PARTICLE COUNTS PER ISO 14644-1

Room Location	ISO Class	0.3 micron	0.5 micron	1.0 micron	5.0 micron
E-Beam Lithography 1701L					
Location 1	5	41	2	0	0
Location 2		53	0	0	0
Location 3		56	0	0	0
Location 4		14	0	0	0
Film Deposition 1701J					
Location 1	6	23	0	0	0
Location 2		164	105	23	0
Location 3		506	164	94	12
Location 4		528	306	164	0
Location 5		1589	906	121	12
Hot Process 1701F					
Location 1	6	388	270	212	0
Location 2		659	400	329	0
Location 3		553	364	306	0
Location 4		1000	617	517	0
Wet Lithography 1701D					
Location 1	6	2648	1989	1706	129
Location 2		3860	1094	753	12
Location 3		788	447	412	0
Location 4		823	1400	1188	47

H·E·P·A

TEST AND CERTIFICATION
UNIVERSITY OF WATERLOO QUANTUM-NANO CENTER CLEANROOM

PARTICLE COUNTS PER ISO 14644-1

Room Location	ISO Class	0.3 micron	0.5 micron	1.0 micron	5.0 micron
Gown Room 1701A					
Location 1	6	2942	1989	1706	129
Location 2		1895	1094	753	12
Location 3		812	447	412	0
Location 4		2118	1400	1188	47
Main Clean Aisle					
Location 1	6	4813	2177	423	105
Location 2		2766	976	141	35
Location 3		4001	2424	412	176
Location 4		3184	812	503	118
Wipe Down 1704					
Location 1	6	2318	1459	1153	12
Location 2		3916	987	714	18

All rooms meet the ISO specification for the individual ISO Class

H·E·P·A

Cleanroom Post-Construction Air Quality and Airflow Report

ADVANCE TEC
University of Waterloo
Nano Technology Cleanroom

SET3 Account Representative	Russ Schiebel; Sterile Environment Technologies, Inc. (SET3)
Phone	(888) 935-0620 x325
Email	rschiebel@set3.com

Cleaning Dates	6/11/2014 – 6/14/2014
Rooms/Buildings Serviced	Cleanroom
ISO 14644 Class Levels	ISO Class 5 and 6
Services Performed	Cleanroom Post Construction Cleaning and Certification
SET3 Project Manager	Joshua Loman

ISO Classification of Cleanrooms

ISO 14644 classification for cleanrooms is based on the formula:

$$Cn = 10N\ (0.1 / D)\ 2.08$$

Where

- Cn = maximum permitted number of particles per cubic meter equal to or greater than the specified particle size, rounded to whole number
- N = is the ISO class number, which must be a multiple of 0.1 and be 9 or less
- D = is the particle size in micrometers

Maximum Concentration Limits (particles/m^3 of air)

ISO 14644-1 Table Maximum Allowed Number of Particles per Cubic Meter by Micrometer Size						
Class	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1 µm	5 µm
ISO 1	10	2				
ISO 2	100	24	10	4		
ISO 3	1,000	237	102	35	8	
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	29
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7				352,000	83,200	2,930
ISO 8				3,520,000	832,000	29,300
ISO 9				35,200,000	8,320,000	293,000

An ISO 1 cleanroom has the lowest levels of contamination, while an ISO 9 has the highest allowable level. To give a perspective, the ambient air outside in a typical urban environment might contain as many as 35,000,000 particles per cubic meter, 0.5 um and larger in diameter, corresponding to an ISO class 9 cleanroom.

Cleanroom class comparison (ISO v/s Federal Std. 209)

ISO is based on metric measurements whereas Federal Standard 209 is based on imperial measurements. The classes, according to ISO14644, are in terms of class levels 3, 4, 5… of airborne particulate cleanliness corresponding to 1, 10, 100… class Fed 209 standards. A Class 5 means that less than 3,520 particles (0.5 microns in size) are present per cubic meter, which equals 100 particles per cubic foot.

FS 209E	ISO 14644-1
NA	1
NA	2
1	3
10	4
100	5
1,000	6
10,000	7
100,000	8
NA	9

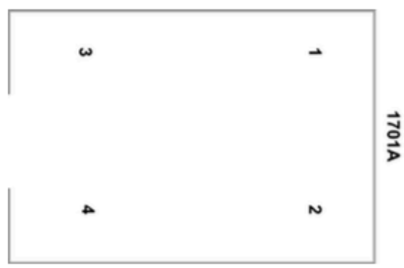
***In United States, Federal Standard 209E (FED-STD-209E) was used until the end of November 2001 to define the requirements for cleanrooms. On November 29, 2001, these standards were superseded by the publication of ISO specification 14644.**

The main differences between Federal Standard 209E and ISO 14644-1 (Testing Standards) are:

- ISO 14644 Establishes 0.1um as the "Standard" Diameter
- ISO 14644 Creates 3 New Cleanliness Classes-
    - 2 "Cleaner" classes (ISO class 1 and ISO class 2) than Federal Standard 209E
    - 1 "Dirtier" Class (ISO Class 9) which is allows more particulate than Fed Standard 209E class 100,000
- Allows for discarding of "Outliers" – whereas Federal Standard 209E did not.

Findings:

AIR PARTICLE COUNTS



ument Model: HANDHELD 3016
ument Serial #: 100802025
icle Data: Cumulative
a Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
/2014 10:48:05	1701A-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
/2014 10:49:28	1701A-02	706.3	0.0	0.0	0.0	0.0	0.0	60	0.003
/2014 10:50:52	1701A-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
/2014 10:52:18	1701A-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	176.6	0.0	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	706.3	0.0	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	353.1	0.0	0.0	0.0	0.0	0.0	0.0	0.000

1701B

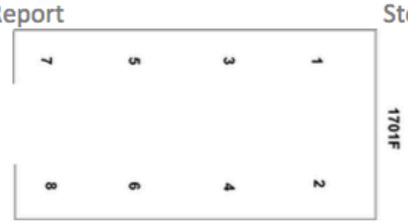
Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 11:16:33	1701B-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:17:50	1701B-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:19:10	1701B-03	2472.0	706.3	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:20:31	1701B-04	706.3	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:21:50	1701B-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	635.7	141.3	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	2472.0	706.3	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	1071.1	315.9	0.0	0.0	0.0	0.0	0.0	0.000

1701D

Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 10:54:10	1701D-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:55:25	1701D-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:56:40	1701D-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:57:54	1701D-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:59:07	1701D-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:00:20	1701D-06	353.1	353.1	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:01:40	1701D-07	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:02:54	1701D-08	1059.4	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	176.6	44.1	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	1059.4	353.1	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	377.5	124.9	0.0	0.0	0.0	0.0	0.0	0.000

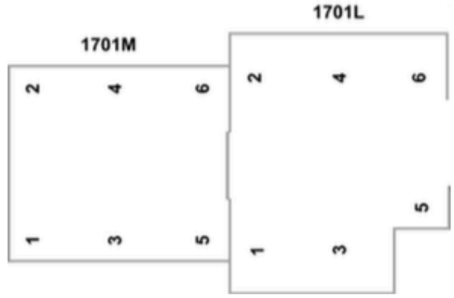


Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 11:04:24	1701F-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:05:36	1701F-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:06:51	1701F-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:08:02	1701F-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:09:40	1701F-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:11:12	1701F-06	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:12:28	1701F-07	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 11:13:48	1701F-08	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	0.0	0.0	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000

Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 10:35:23	1701J-01	353.1	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:37:53	1701J-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:39:14	1701J-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:40:29	1701J-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:41:46	1701J-05	706.3	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:43:04	1701J-06	1059.4	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:45:08	1701J-07	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:46:25	1701J-08	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	264.9	0.0	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	1059.4	0.0	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	411.4	0.0	0.0	0.0	0.0	0.0	0.0	0.000



Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 10:26:30	1701L-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:28:06	1701L-02	1765.7	1412.6	353.1	0.0	0.0	0.0	60	0.003
6/14/2014 10:29:26	1701L-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:30:46	1701L-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:32:13	1701L-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:33:28	1701L-06	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	294.3	235.4	58.9	0.0	0.0	0.0	60.0	0.003
	Maximum	1765.7	1412.6	353.1	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	720.9	576.7	144.2	0.0	0.0	0.0	0.0	0.000

Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 10:17:36	1701M-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:18:57	1701M-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:20:14	1701M-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:21:28	1701M-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:22:41	1701M-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:24:56	1701M-06	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	0.0	0.0	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000

Instrument Model: HANDHELD 3016
Instrument Serial #: 100802025
Particle Data: Cumulative
Data Duration: 6/14/2014 10:05:36 to 6/14/2014 11:26:57

Timestamp	Location (Name)	0.3 micron (p/m^3)	0.5 micron (p/m^3)	1.0 micron (p/m^3)	3.0 micron (p/m^3)	5.0 micron (p/m^3)	10.0 micron (p/m^3)	Sample Time (s)	Sample Volume (m^3)
6/14/2014 10:05:36	1701P-01	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:07:16	1701P-02	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:09:07	1701P-03	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:10:20	1701P-04	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:11:39	1701P-05	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:12:55	1701P-06	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:14:09	1701P-07	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
6/14/2014 10:15:22	1701P-08	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Average	0.0	0.0	0.0	0.0	0.0	0.0	60.0	0.003
	Maximum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	60	0.003
	Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000

***PARTICLE COUNT LEVELS FOR CLASS 5 and 6 AREAS: PASSED**

LIGHTHOUSE
WORLDWIDE SOLUTIONS
Technology That Counts!

Certificate of Calibration

RMA#:	**US-27929**	**Date Calibrated:**	**5/23/2014**
Model#:	**Handheld 3016**	**Calibration Due:**	**5/23/2015**
Serial Number:	**100802025**	**Sensor Block ID:**	**100802-061**

Equipment Description: **Handheld Particle Counter**

The instrument conforms to the specified tolerances for each listed channel size. The channel size calibration has been accomplished by methods defined in the applicable sections of both JIS B 9921 and ISO 21501-4:2007(E). The accuracy of the standards and equipment used in the calibration are traceable to the National Institute of Standards and Technology or have been derived from acceptable values of natural and physical constants. A record of all work performed is maintained by Lighthouse Worldwide Solutions. All work performed is in accordance with Lighthouse Worldwide Solutions, Quality Manual P/N 714252800-1 and ANSI Z-540. Reproduction of this certificate and accompanying documentation is prohibited without the expressed written permission of Lighthouse Worldwide Solutions.

Channel 1: Accuracy Peak Size ± 20%
Channel 2 and above: Accuracy Peak Size ± 10%

Calibration was performed under the following controlled conditions

Temperature of **73.0 °F** Relative Humidity of: **38.0 %** Flow Rate **0.1 CFM**

Test Equipment:

Flow Meter:	**121374**	Calibration Due Date:	**2/10/2015**
DMM:	**80590372**	Calibration Due Date:	**4/10/2015**
MCA:	**0445**	Calibration Due Date:	**8/21/2014**

Spheres: Nominal Size	Lot Number	Channel	**Threshold Voltages:** in Millivolts
0.30	**41699**	**1**	**43**
0.50	**42468**	**2**	**356**
1.00	**40060**	**3**	**913**
3.00	**42363**	**4**	**2563**
5.00	**43188**	**5**	**3383**
10.00	**43005**	**6**	**3925**

Signed *Gordon Glathar* Date: 5/23/2014
Gordon Glathar

Lighthouse Worldwide Solutions

BALAZS™ nanoanalysis
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MR VITO LOGIUDICE
UNIVERSITY OF WATERLOO
200 UNIVERSITY AVENUE WEST
WATERLOO ON N2L 3G1

Phone: (519) 888-4567
Fax: (519) 888-7610

Work Order:	14-04186
Report Date:	11-Jul-14
Order Date:	9-Jul-14
P.O.:	201756
Release:	
Approved By:	Warren York
Title:	SEM-EDS/XRF ANALYST ADVANCED MATERIALS LAB

BALAZS™ TEST RESULTS

If you have any questions regarding the results, please call Victor Chia at (510) 624-4011

1. SEM/EDS Analysis of Particles Collected from Port 1

Sample Description: A petri dish with "black" particles removed from a UPW flow meter was received for SEM/EDS analysis. The purpose of this analysis is to perform SEM/EDS on the particles in order to determine the elemental composition.

Instrumentation: All analysis was performed with a Zeiss EVO-50 SEM with integrated IXRF EDS. A SEM image, EDS spectrum and EDS concentration data from each analysis area is included at the end of this report (Pages 6-9).

Analysis: First a group of the particles was removed from the petri dish. Next an EDS analysis was performed on several of the particles collected. Two representative particles were retained for reporting purposes. All EDS analysis was performed with a 20kV incident beam with an analysis depth of 1-10 μm. All results were quantified by the EDS software with a ZAF matrix type calculation and a pure 99.99% standard of each element. ZAF calculations eliminate all extraneous results from fluorescence and other background noise causing phenomenon. The ZAF matrix also lines up each peak based on a standard with known peak orientation for each element.

Discussion: The particles appear to be comprised of one or more compounds/alloys. Some of the elements identified in the particles are in ratios which are common to an iron alloy such as stainless steel (Fe, Cr, Ni, Mn, Mo etc). Please let us know if we can be of further assistance.

2. ICP-MS, IC, TOC and Bacteria data on pages 2-5

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Air Liquide Electronics U.S. LP
46409 Landing Parkway, Fremont CA 94538
Telephone (510) 624-4000 Fax (510) 657-2292

MR VITO LOGIUDICE
UNIVERSITY OF WATERLOO
P.O.: 201756
Release:

Report Date: 11-Jul-14
Order Date: 07/09/2014
Work Order: 14-04186
Approved By: Warren York

Sample: 1022175 [PORT 1] **Date Sampled: 7/8/2014**

Component	Units	Detection Limit	Result Value
W0174-UPW-N-R-C 30 Elements Low Level in UPW by ICP-MS			
Aluminum (Al) / 1	ppt (ng/L)	2	*
Antimony (Sb) / 1	ppt (ng/L)	2	*
Arsenic (As) / 1	ppt (ng/L)	3	*
Barium (Ba) / 1	ppt (ng/L)	0.5	*
Bismuth (Bi) / 1	ppt (ng/L)	1	*
Boron (B) / 1	ppt (ng/L)	50	58
Cadmium (Cd) / 1	ppt (ng/L)	3	*
Calcium (Ca) / 1	ppt (ng/L)	20	*
Chromium (Cr) / 1	ppt (ng/L)	3	*
Cobalt (Co) / 1	ppt (ng/L)	0.5	*
Copper (Cu) / 1	ppt (ng/L)	2	*
Gallium (Ga) / 1	ppt (ng/L)	1	*
Germanium (Ge) / 1	ppt (ng/L)	3	*
Iron (Fe) / 1	ppt (ng/L)	10	*
Lead (Pb) / 1	ppt (ng/L)	1	*
Lithium (Li) / 1	ppt (ng/L)	1	*
Magnesium (Mg) / 1	ppt (ng/L)	2	*
Manganese (Mn) / 1	ppt (ng/L)	2	*
Mercury (Hg) / 1	ppt (ng/L)	20	*
Molybdenum (Mo) / 1	ppt (ng/L)	4	*
Nickel (Ni) / 1	ppt (ng/L)	2	*
Potassium (K) / 1	ppt (ng/L)	10	*
Silver (Ag) / 1	ppt (ng/L)	1	*
Sodium (Na) / 1	ppt (ng/L)	5	*
Strontium (Sr) / 1	ppt (ng/L)	0.5	*
Tin (Sn) / 1	ppt (ng/L)	3	*
Titanium (Ti) / 1	ppt (ng/L)	2	*
Tungsten (W) / 1	ppt (ng/L)	5	*
Vanadium (V) / 1	ppt (ng/L)	1	*
Zinc (Zn) / 1	ppt (ng/L)	5	*
W0121-UPW-N-R-C Anions by IC (UltraPure)			
Fluoride (F-) / 1	ppb (µg/L)	0.03	*
Chloride (Cl-) / 1	ppb (µg/L)	0.02	*
Nitrite (NO2-) / 1	ppb (µg/L)	0.02	*
Bromide (Br-) / 1	ppb (µg/L)	0.02	*
Nitrate (NO3-) / 1	ppb (µg/L)	0.02	*

BALAZS™ nanoAnalysis
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Telephone (510) 624-4000 Fax (510) 657-2292

MR VITO LOGIUDICE
UNIVERSITY OF WATERLOO
P.O.: 201756
Release:

Report Date: 11-Jul-14
Order Date: 07/09/2014
Work Order: 14-04186
Approved By: Warren York

Sample: 1022175 [PORT 1] **Date Sampled:** **7/8/2014**

Component	Units	Detection Limit	Result Value
Phosphate (HPO4=) / 1	ppb (µg/L)	0.02	*
Sulfate (SO4=) / 1	ppb (µg/L)	0.05	*
W0127-UPW-N-R-C Single Ion by IC (NH4)			
Ammonium (NH4+) / 1	ppb (µg/L)	0.02	*
W0106-UPW-N-R-C Total Organic Carbon			
Total Oxidizable Carbon (TOC) / 1	ppb (µg/L)	5	6
W0102-UPW-N-I-C Bacteria-ASTM Method-48 Hr Incubation			
Bacteria/100mL / 1	cfu	1	*
W0115-UPW-N-R SEM/EDS Instrument Time/Hr			
Comment / 1			See report

* = Analysis revealed that the element was not found at or above the detection limit.

BALAZS™ nanoanalysis
Air Liquide Electronics U.S. LP
46409 Landing Parkway, Fremont CA 94538
Telephone (510) 624-4000 Fax (510) 657-2292

MR VITO LOGIUDICE
UNIVERSITY OF WATERLOO

P.O.: 201756

Release:

Report Date: 11-Jul-14
Order Date: 07/09/2014
Work Order: 14-04186
Approved By: Warren York

Sample: 1022176 [PORT 3] **Date Sampled: 7/8/2014**

Component	Units	Detection Limit	Result Value
W0174-UPW-N-R-C 30 Elements Low Level in UPW by ICP-MS			
Aluminum (Al) / 1	ppt (ng/L)	2	*
Antimony (Sb) / 1	ppt (ng/L)	2	*
Arsenic (As) / 1	ppt (ng/L)	3	*
Barium (Ba) / 1	ppt (ng/L)	0.5	*
Bismuth (Bi) / 1	ppt (ng/L)	1	*
Boron (B) / 1	ppt (ng/L)	50	67
Cadmium (Cd) / 1	ppt (ng/L)	3	*
Calcium (Ca) / 1	ppt (ng/L)	20	*
Chromium (Cr) / 1	ppt (ng/L)	3	*
Cobalt (Co) / 1	ppt (ng/L)	0.5	*
Copper (Cu) / 1	ppt (ng/L)	2	*
Gallium (Ga) / 1	ppt (ng/L)	1	*
Germanium (Ge) / 1	ppt (ng/L)	3	*
Iron (Fe) / 1	ppt (ng/L)	10	*
Lead (Pb) / 1	ppt (ng/L)	1	*
Lithium (Li) / 1	ppt (ng/L)	1	*
Magnesium (Mg) / 1	ppt (ng/L)	2	*
Manganese (Mn) / 1	ppt (ng/L)	2	*
Mercury (Hg) / 1	ppt (ng/L)	20	*
Molybdenum (Mo) / 1	ppt (ng/L)	4	*
Nickel (Ni) / 1	ppt (ng/L)	2	*
Potassium (K) / 1	ppt (ng/L)	10	*
Silver (Ag) / 1	ppt (ng/L)	1	*
Sodium (Na) / 1	ppt (ng/L)	5	*
Strontium (Sr) / 1	ppt (ng/L)	0.5	*
Tin (Sn) / 1	ppt (ng/L)	3	*
Titanium (Ti) / 1	ppt (ng/L)	2	*
Tungsten (W) / 1	ppt (ng/L)	5	*
Vanadium (V) / 1	ppt (ng/L)	1	*
Zinc (Zn) / 1	ppt (ng/L)	5	*
W0121-UPW-N-R-C Anions by IC (UltraPure)			
Fluoride (F-) / 1	ppb (µg/L)	0.03	*
Chloride (Cl-) / 1	ppb (µg/L)	0.02	*
Nitrite (NO2-) / 1	ppb (µg/L)	0.02	*
Bromide (Br-) / 1	ppb (µg/L)	0.02	*
Nitrate (NO3-) / 1	ppb (µg/L)	0.02	*

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Component	Units	Detection Limit	Result Value
Phosphate (HPO4=) / 1	ppb (µg/L)	0.02	*
Sulfate (SO4=) / 1	ppb (µg/L)	0.05	*
W0127-UPW-N-R-C Single Ion by IC (NH4)			
Ammonium (NH4+) / 1	ppb (µg/L)	0.02	*
W0106-UPW-N-R-C Total Organic Carbon			
Total Oxidizable Carbon (TOC) / 1	ppb (µg/L)	8	*
W0102-UPW-N-I-C Bacteria-ASTM Method-48 Hr Incubation			
Bacteria/100mL / 1	cfu	1	*

* = Analysis revealed that the element was not found at or above the detection limit.

UNIVERSITY OF WATERLOO | Quantum NanoFab

Facility Access Fees

Tool Type	Tool Name	Academic Rate	Industrial Rate
E-beam Lithography	RAITH 150TWO	$ 60	$ 180
Mask Aligner	SUSS-MA6 front/back	$ 35	$ 105
HMDS oven	YES-HMDS	$ 25	$ 75
semi-auto spin/bake	BREWER-UVspinbake	$ 30	$ 90
PR spin/bake station	BREWER-Ebeamspinbake	$ 35	$ 105
PR spin/bake station	REYNOLDSTECH-twincoater	$ 25	$ 75
atmospheric oven	FISHER-oven	$ 15	$ 45
E-beam evaporator	INTLVAC-Ebeam	$ 35	$ 105
ALD & PECVD	OXFORD-ALD/PECVD cluster	$ 50	$ 150
Automated sputter	PLASSYS-Nb sputter	$ 40	$ 120
oxidation/anneal furnace	TYSTAR1-atm	$ 40	$ 120
LPCVD Nitride furnace	TYSTAR2-nitride	$ 45	$ 135
LPCVD Poly furnace	TYSTAR3-Poly & SiC	$ 45	$ 135
LPCVD LTO furnace	TYSTAR4-LTO	$ 45	$ 135
Sputter	AJA-2-chamb, loadlocked	$ 40	$ 120
atmospheric RTA/RTP	ALLWIN-RTP	$ 40	$ 120
ICPRIE - Cl chemistries	OXFORD-metalRIE	$ 45	$ 135
ICPRIE - F chemistries	OXFORD-Si deep RIE	$ 45	$ 135
Ashing RIE	YES-ash	$ 25	$ 75
Ion mill 6" wafer	AJA-ionmill	$ 45	$ 135
Cont. ang. goniometer	RAMEHART-contactangle	$ 15	$ 45
LWD opt microscope	OLYMPUS-scope3	$ 15	$ 45
Dicing saw	DISCO-saw	$ 40	$ 120
wirebond pull tester	WESTBOND-pulltest	$ 10	$ 30
Semi-auto wirebond	WESTBOND-wirebond1	$ 40	$ 120
multimode wirebond	WESTBOND-wirebond2	$ 40	$ 120
Flip chip die bonder	TRESKY-diebond	$ 45	$ 135
diamond scribe tool	OEG-scriber	$ 30	$ 90
epoxy dispenser robot	NORDSON-epoxy	$ 15	$ 45
H plasma cleaner	LFC-plasmaclean	$ 30	$ 90
epoxy cure oven	Cureoven	$ 15	$ 45
wafer cleaner	ULTRON-cleaner	$ 20	$ 60
reflectometer	FILMETRICS-F40	$ 10	$ 30
reflectometer -auto	FILMETRICS-F50	$ 10	$ 30
wafer microscope	OLYMPUS-scope1	$ 20	$ 60
wafer microscope	OLYMPUS-scope2	$ 20	$ 60

QuantumNanoFabFees_rev_7.xlsx Rates in effect as of September 1, 2014 1/2

Facility Access Fees

Tool Type	Tool Name	Academic Rate	Industrial Rate
stylus profilometer	VEECO-profilometer	$ 20	$ 60
auto. 4-point probe	CDE-4pp	$ 20	$ 60
stress meas. tool	TOHO-stress	$ 30	$ 90
ellipsometer	WOOLLAM-ellip	$ 40	$ 120
Wetbench - Acids	ACIDBASEnonHF	$ 25	$ 75
Wetbench - HF	HFACID	$ 25	$ 75
Wetbench - solvents	SOLVENT1	$ 25	$ 75
Wetbench - solvents	SOLVENT2	$ 25	$ 75
Wetbench - RCA clean	RCACLEAN	$ 25	$ 75
Wetbench - KOH	REYNOLDSTECH-bulkSi	$ 40	$ 120
Wetbench - Piranha	PIRANHA	$ 25	$ 75
Wetbench - UV dev	DEVELOPUV	$ 25	$ 75
Wetbench - EBL dev	DEVELOPEBL	$ 25	$ 75

Additional Fees:

1) For Academic Users, cleanroom consumables costs are recovered via a charge of $1.84 per each equipment "enable" within Badger.

   For Industrial Users, the cleanroom consumables fee is $5.52 per equipment enable.

2) For Academic Users, equipment training is completed by facility staff and is charged at $25 per hour.

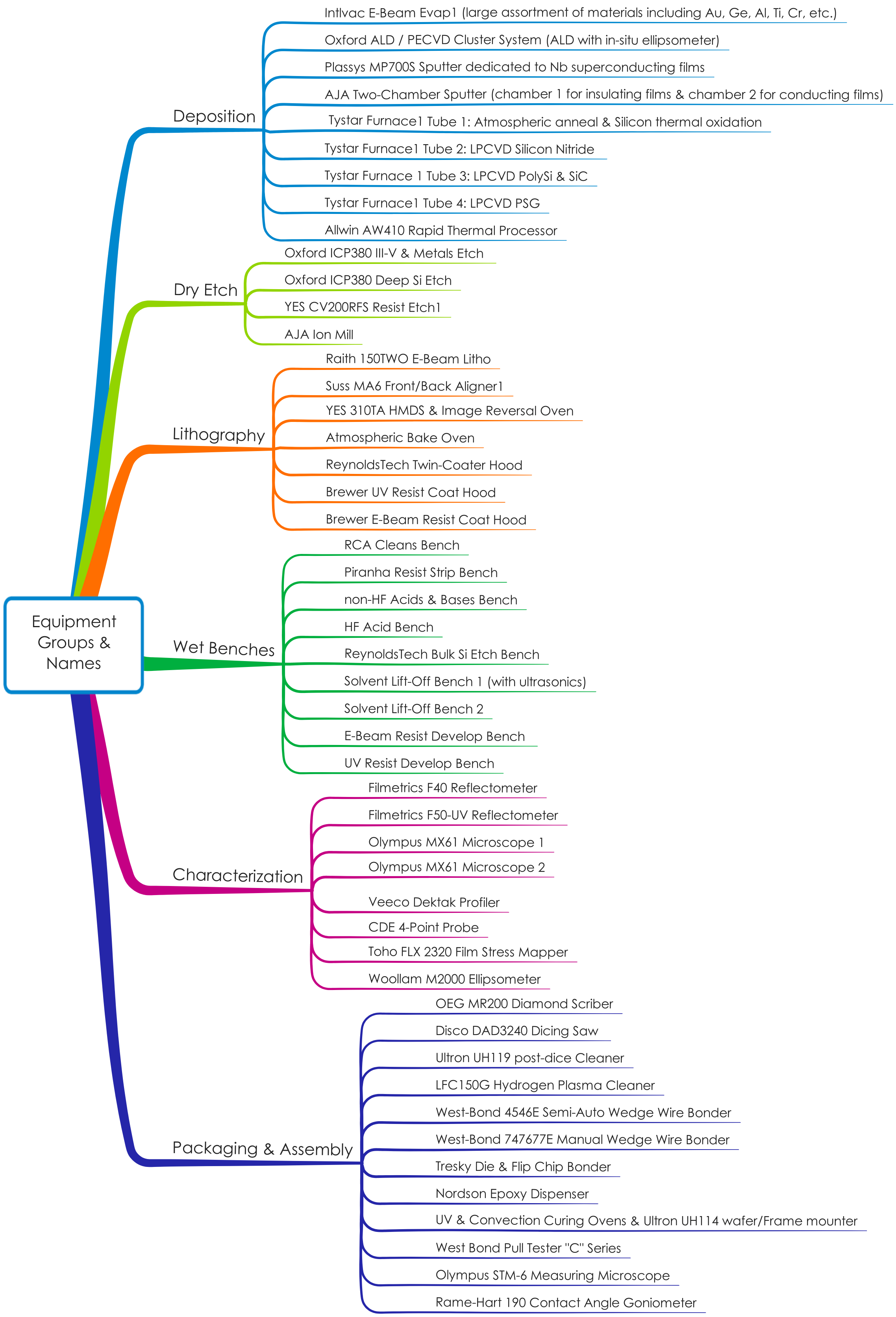
   For Industrial Users, equipment training is charged at $75 per hour.

3) For Academic Users, general support provided by facility staff is charged at $50 per hour.

   For Industrial Users, general support is charged at $150 per hour.

QuantumNanoFabFees_rev_7.xlsx   Rates in effect as of September 1, 2014   2/2

APPENDIX G: FAB EQUIPMENT LIST



APPENDIX H: YEAR-BY-YEAR FINANCIAL SUMMARY OF FAB OPERATIONS

Annual Report - Clean Room Financial Summary

	FISCAL YEAR ENDING APRIL 30				
INVOICING	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Invoice Total Value for Year	$86,583	$157,915	$111,333	$80,860	**$436,691**
Funds Received for Year (into Fab Operating Fund 100)	$66,638	$120,084	$106,072	$59,806	**$352,600**
Number of Invoices Issued to Users	86	129	90	86	**391**
SALARY EXPENSES					
Technician Salary and Benefits paid by IQC	80,610	247,500	181,313	204,799	714,222
Technician Salary and Benefits on CFI-IOF (Fund 105) (no Metrology technicians)	142,035	26,613	106,901	158,639	434,188
CleanRoom Salary and Benefits on Fab Operating (Fund 100)			2,095	2,274	4,369
TOTAL	**222,645**	**274,113**	**290,309**	**365,712**	**1,152,779**
SUPPLIES, MAINTENANCE AND EQUIPMENT EXPENSES					
Supplies/Equipment/Maintenance paid by IQC	34,935	28,546	0	0	63,481
Supplies/Equipment/Maintenance on CFI-IOF (Fund 105)	34,232	65,827	88,654	160,789	349,502
Supplies/Equipment/Maintenance on Fab Operating (Fund 100)			397,828	141,590	539,418
TOTAL	**69,167**	**94,373**	**486,482**	**302,379**	**952,401**
PRAXAIR EXPENSES					
Praxair paid by IQC	16,113	14,351	10,206	0	40,670
Praxair on CFI-IOF (Fund 105)	16,113	13,547	10,287	0	39,947
Praxair on Operating (Fund 100)			0	**0**	0
TOTAL	**32,226**	**27,898**	**20,494**	**0**	**80,618**
GRAND TOTAL	**324,038**	**396,384**	**797,285**	**668,091**	**2,185,798**

SPENDING BY GRANT	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Paid by IQC	131,658	290,397	191,519	204,799	**818,373**
Spending on CFI-IOF (fund 105) no metrology nor director salary	192,380	105,987	205,842	319,428	**823,637**
Spending on Operating (Fund 100)	0	0	399,923	143,864	**543,787**
GRAND TOTAL	**324,038**	**396,384**	**797,285**	**668,091**	**2,185,798**

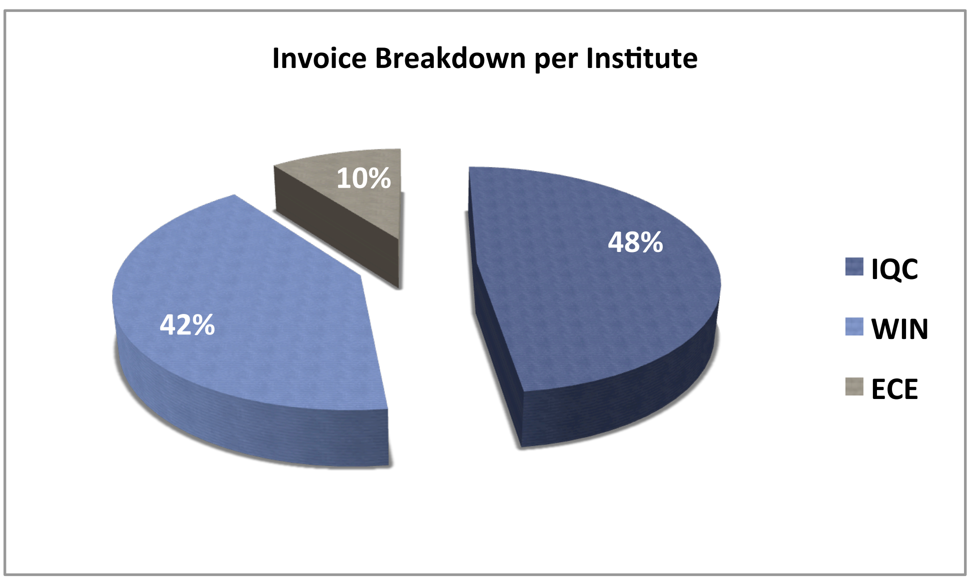
***** Salaries do NOT include metrology lab technician salaries paid on CFI-IOF nor director salary and benefits***

****** IQC aims to verify/confirm these figures prior to discussions with WIN***

APPENDIX I: FAB FEES INVOICED PER FACULTY MEMBER IN 2012/13

Table 9: Total Fab Fees Invoiced per Faculty Member in 2012/13

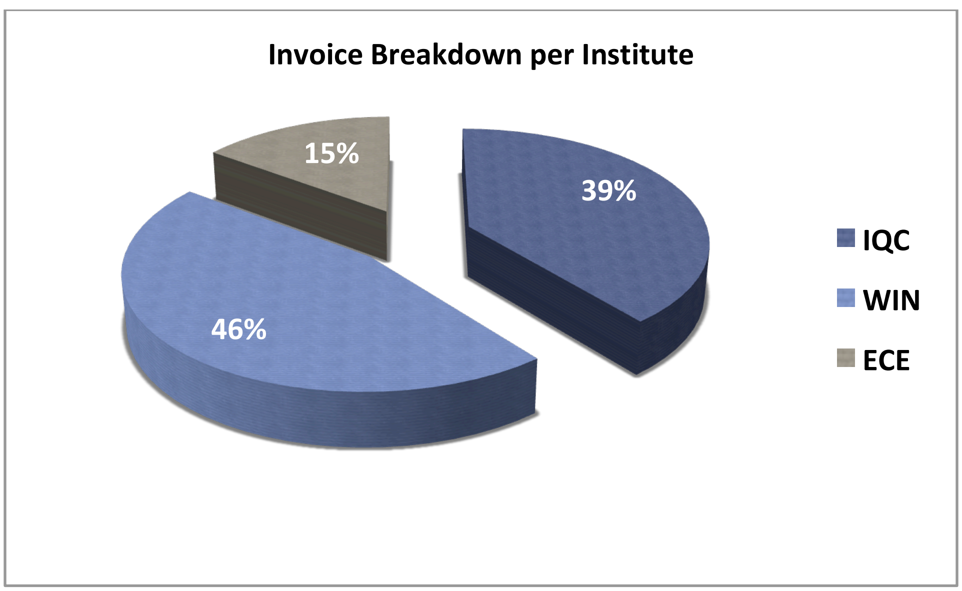
Name	IQC	WIN	UW (ECE)
Jonathan Baugh	$35,684		
David Cory	$4,583		
Bo Cui		$21,768	
Irene Goldthorpe		$863	
Jan Kycia	$342		
Raymond Laflamme	$116		
Zoya Leonenko			
Adrian Lupascu	$33,594		
Raafat Mansour		$3,209	
Guoxing Miao	$1,359		
Omar Ramahi			$963
Safieddin Safavi-Naeini			$15,444
Simarjeet Saini		$34,567	
Andrei Sazonov			
Shirley Tang		$4,712	
Mustafa Yavuz		$713	
TOTAL:	**$75,677**	**$65,832**	**$16,407**



APPENDIX J: FAB FEES INVOICED PER FACULTY MEMBER IN 2013/14

Table 10: Total Fab Fees Invoiced per Faculty Member in 2013/14

Name	IQC	WIN	UW (ECE)
Jonathan Baugh	$17,437		
David Cory	$1,570		
Bo Cui		$25,155	
Irene Goldthorpe		$376	
Jan Kycia	$709		
Raymond Laflamme	$260		
Adrian Lupascu	$10,174		
Raafat Mansour		$348	
Matteo Mariantoni	$5,440		
Guoxing Miao	$8,157		
Omar Ramahi			$552
Safieddin Safavi-Naeini			$16,016
Simarjeet Saini		$23,451	
Shirley Tang		$1,065	
Mustafa Yavuz		$99	
Mustafa Yavuz		$827	
TOTAL:	**$43,746**	**$51,322**	**$16,568**



APPENDIX K: FACILITY ACCESS FEES IN EFFECT FROM MAY 2012 TO NOV 2013

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Facilty Access Fees

Please Note:

Access rates are heavily subsidized by the following organizations:

- Innovation Canada (CFI)
- The Institute for Quantum Computing (IQC)
- The Waterloo Institute for Nanotechnology (WIN)
- The University of Waterloo

Rates will be adjusted in the future to ensure long-term sustainability of operations.
A minimum 3-month notice will be given prior to new rates coming into effect.

Equipment Groups & Hourly Fees per Equipment Group **

** Changes to access rates will be announced 3 months in advance of their coming into effect

		E-Beam Lithography	Optical Lithography	Dry Etch	Deposition	Wet Processes	Ox-Diff, Anneal & Doping	Characteri-zation & Testing	Assembly & Packaging	NOTES:
		Raith 150TWO e-beam writer	Suss MA6 front/back aligner	Oxford ICP380 RIE - Chlorine	Oxford PECVD / ALD cluster	Solvent Fumehood		Dektak 150 profiler & film stress mea-surement		1) Fees shown are per person granted access, not per faculty member.
			YES-310TA HMDS vapour prime oven	Oxford ICP380 DRIE (dedicated to Si etch)	IntlVac Nanochrome II evaporator	Non-HF Acid Fumehood		Olympus MX61 microscope		2) Access rates are low as we are not equipped to implement monthly or quarterly caps at this time. This will be revisited in the future.
			YES-CV200RFS plasma asher			HF Acid Fumehood		Filmetrics F50-UV film mapper		3) There is no cap on special material costs (ex: Au, Pt, Ge or specialty chemicals) which are charged separately. The cost of routine process gases and chemicals (ex: routine resists and acids) is included in the rates shown.
			Spin-coat fumehood							4) The lab access fee covers the cost of cleanroom gloves, wipes, apparel, etc.
Equipment Use Fee (charged separately):	Rate, per hour:	$40.00	$25.00	$30.00	$30.00	$5.00	not available	NO CHARGE	not available	NO Cap
Lab Access Fee (charged separately):	Charged per person, per equipment booking:	$1.00								NO Cap
Hands-on Training Fee (charged separately):	Charge per hour:	$25 (plus cost of hrly equipment reservation during training & qualification sessions)								NO Cap
General Support Fee (charged separately):	Charge per hour:	$50 (for help running equipment, process development, etc.)								NO Cap

Rates in effect as of April 1, 2012

QuantumNanoFabFees_rev_5.xlsx