Quantum NanoFab Users Advisory Committee

Agenda

1. Infrastructure past & present: we've come a long way
2. Fab Operations: General overview
   - Highlights from Fiscal Year 2016/17 & updates to Nov 30 '17
   - TQT shared infrastructure: Benefitting from generous funding
   - Financial update to end FY 2016/17
   - June 2017 Lab User survey results
   - Key objectives 2018
3. Discussion
   - Questions
   - Concerns
   - Suggestions
   - Additional items?

Questions during the presentation are welcome

We've come a long way . . .

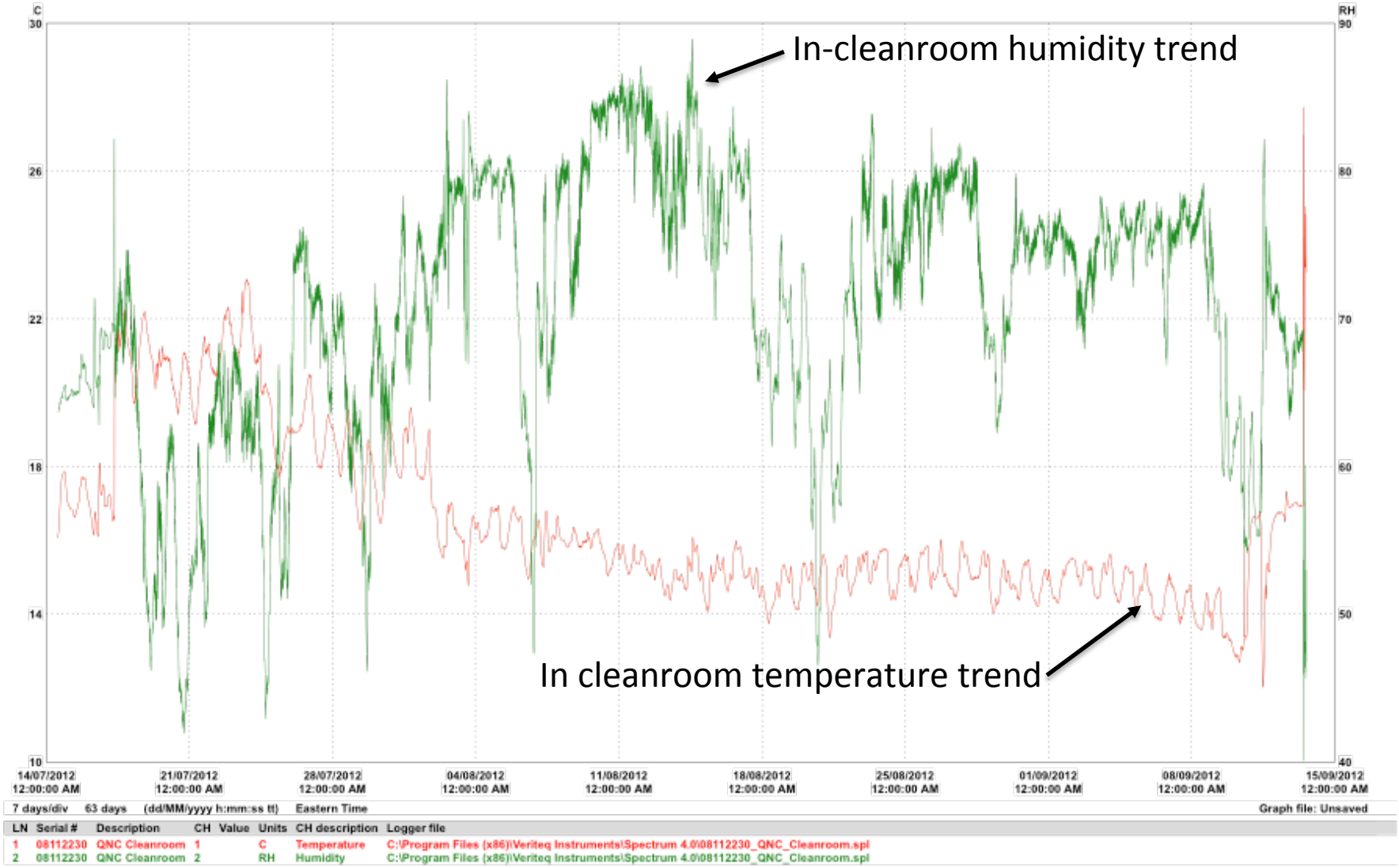
Issues identified well before pre-occupancy (but not properly addressed) resulted in significant delays years later

Hidden corner deep inside the cleanroom @ ceiling (20ft above ground level, above intermediate grid)

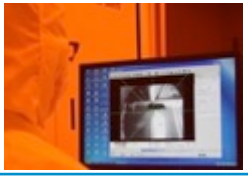
Final Fit-Out & Tool installation activities in full swing

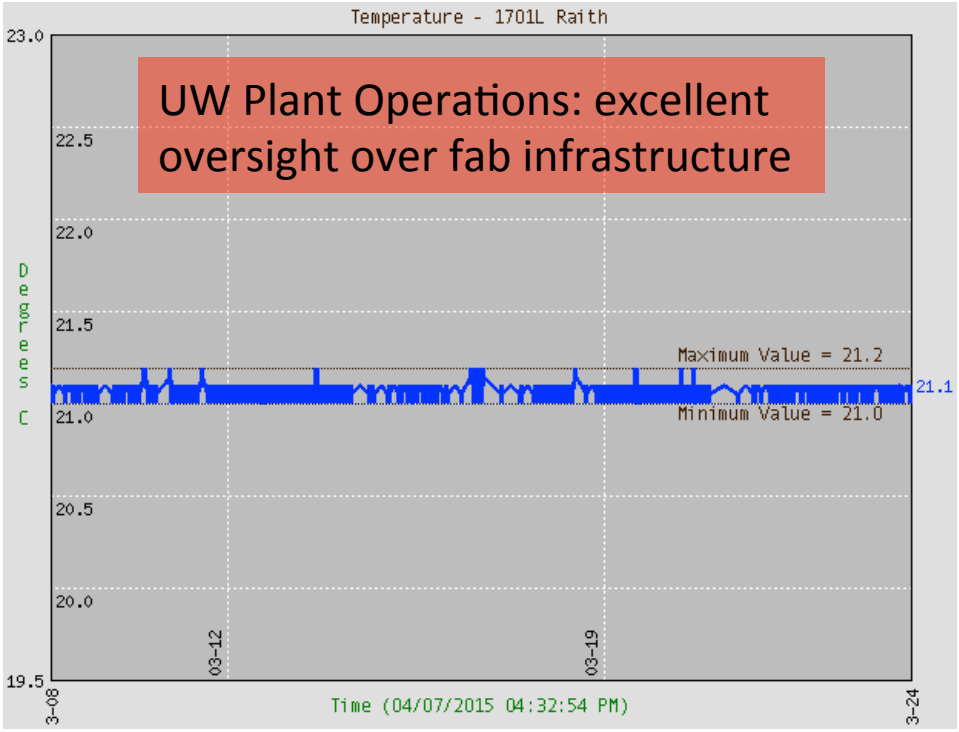
Environmental controls: crucial but difficult to master

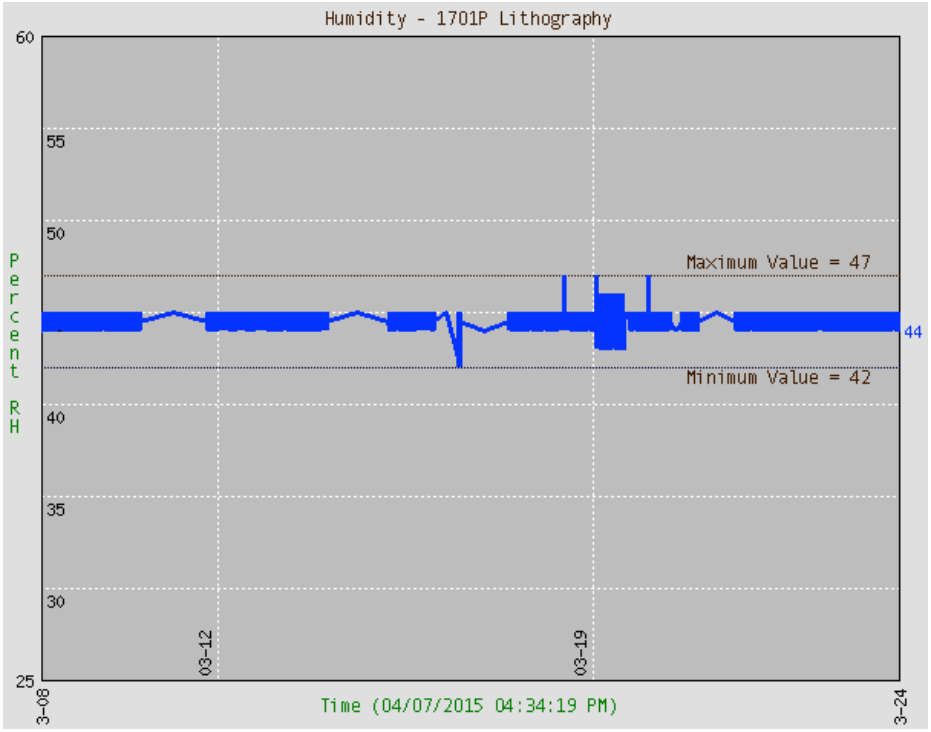
Pre-occupancy: Summer 2012



Environmental controls today: excellent







JEOL JBX-6300FS Direct Write E-Beam Lithography System

	ITEMS		Conditions	Measurements	Specification	Results	
1	Minimum line width	Measurement at field center	Acc. Volt: 100kV	At field center	8nm or less	X: 8.0 nm	Y: 8.0 nm
2	Mask writing performance	1) Field stitching accuracy	Acc. Volt: 100kV	Pattern position measurement (LEICA IPRO)	+/- 20nm or less	Min: -8.5 nm	Max: 8.3 nm
3	Direct writing performance	1) EB-EB overlay accuracy	Acc. Volt: 100kV	Pattern position measurement (LEICA IPRO)	+/- 20nm or less	Min: -2.2 nm	Max: 9.2 nm
		2) Field stitching accuracy			+/- 20nm or less	Min: -6.2 nm	Max: 9.2 nm

Particle counts: consistently excellent

Data from measurements taken on April 7, 2017

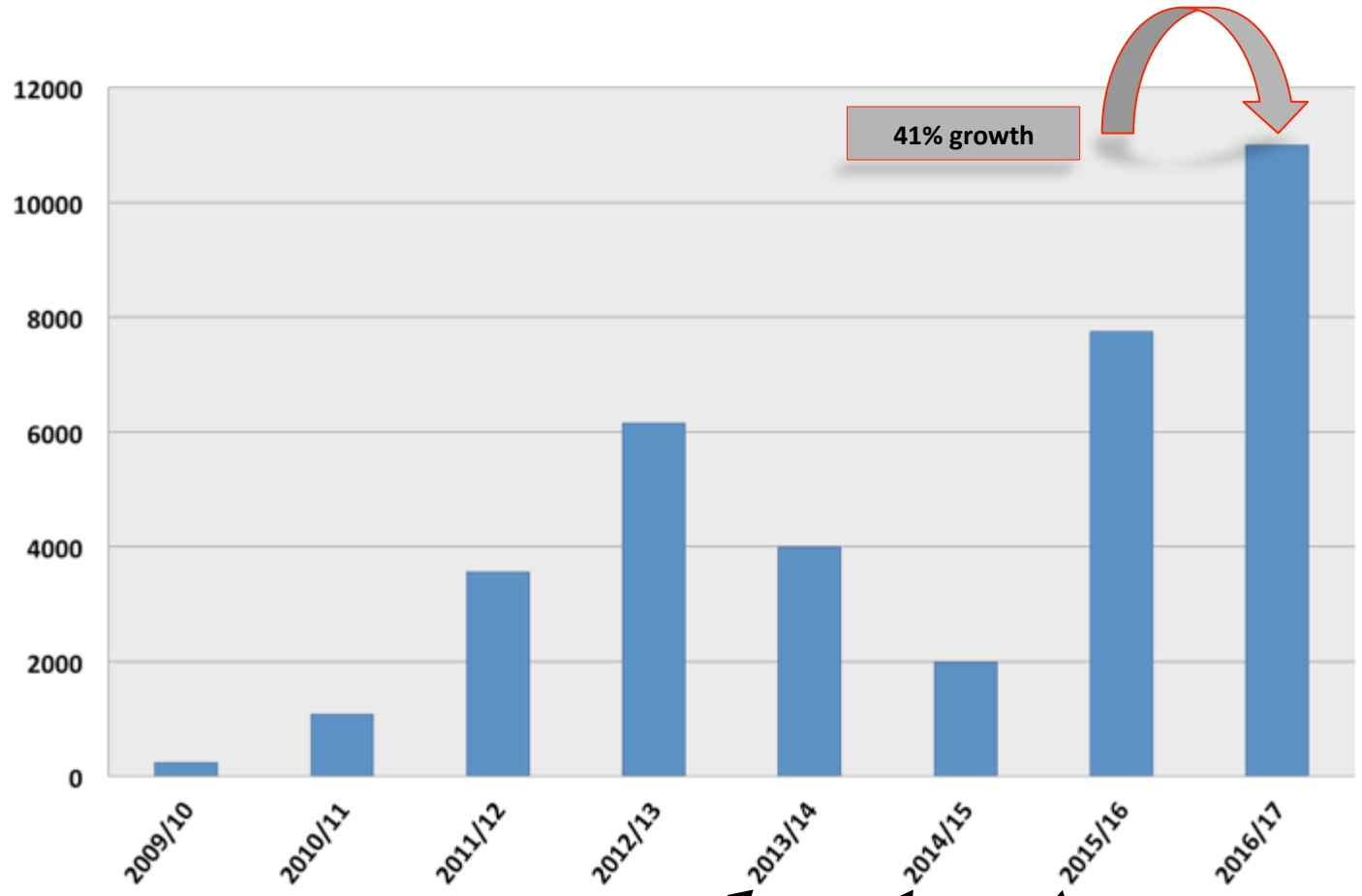
Sampling time: 60 sec Sampling locations per module: 3 (average counts shown)

Module	Particle Size				People present during count?
	0.3 um	0.5 um	1 um	5 um	
UV Litho Bay	23	0	0	0	yes
E-Beam Litho Bay 1 (Raith)	0	0	0	0	no
E-Beam Litho Bay2 (JEOL)	0	0	0	0	yes
Specification: max particles/m3 class 10 (ISO 4):	**1020**	**352**	**83**	**n/a**	
Dry Etch & PVD/ALD/PECVD Bay	2248	282	188	106	yes
Etch & Furnace Bay	59	5	12	0	no
Dep & Chemical Process Bay	164	70	12	0	no
Specification: max particles/m3 class 100 (ISO 5):	**10200**	**3520**	**832**	**29**	

Key highlights: Fiscal year ending Apr 30 ’17

- **Safety:** No injuries to report; ongoing monthly inspections
- **People:**
  - Lino Eugene hired as *Senior E-Beam Litho Scientist* (CFREF-TQT funded)
  - Nathan Nelson-Fitzpatrick promoted to *Process Engineering Manager*
  - Two ongoing Co-op student positions filled since mid-2016 (IQC funded)
- **Operations**:
  - Expansion of full hours of operation: 8am to 10pm, 7 days per week
  - Extensive JEOL EBL training module
  - Growing number of qualified JEOL EBL users including Jean Lapointe with NRC
  - “Shuttle car” for fab users based in RAC1 & RAC2 (funded by D. Cory)
- **Process developments in past six months**:
  - Characterized ITO thin film deposition recipe
  - EBL: Process for minimizing substrate charging
  - MEMS process development: Comb Drive

Hours of equipment use invoiced per fiscal year



2013/14: RAC1 cleanroom in operation for only 7 months

2014/15: QNC cleanroom in operation for only 8 months & long learning curve for new access protocol

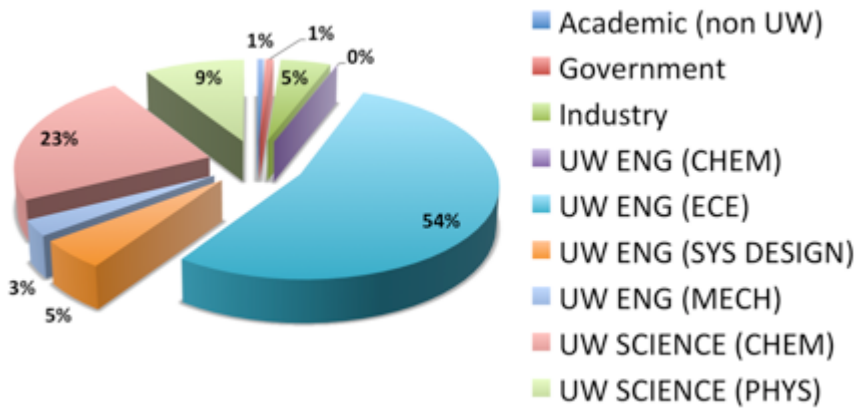
2015/16: First full year of QNC operations

Lab Membership & Hours of use per PI

for FY 2016/17 ending April 30, 2017

- 43 Active PI's in the past fiscal year
- 49 PI's registered since 2014
  - Over 130 distinct projects
  - Over 200 registered lab members

Breakdown of Facility Users



Name	Faculty/Dept	IQC	WIN	Other
Choi, Kyung	UW SCIENCE / PHYS	34		
Day-Hamilton, Tobi (IQC Tiny Flag work)	UW SCIENCE / PHYS	57		
Lupascu, Adrian	UW SCIENCE / PHYS	121		
Budakian, Raffi	UW SCIENCE / PHYS	262		
Mariantoni, Matteo	UW SCIENCE / PHYS	538		
Tsen, Wei	UW SCIENCE / CHEM	224		
Cory, David	UW SCIENCE / CHEM	274		
Baugh, Jonathan	UW SCIENCE / CHEM	1826		
Pawliszyn, Janusz	UW SCIENCE / CHEM		13	
Schipper, Derek	UW SCIENCE / CHEM		7	
Sciaini, German	UW SCIENCE / CHEM		189	
Tang, Shirley	UW SCIENCE / CHEM		13	
Mayer, Michael	UW ENG MECH			134
Yavuz, Mustafa	UW ENG MECH		173	
Wong, Alexander	UW ENG / SYS DES			20
Yeow, John	UW ENG / SYS DES		408	
Abdel-Rahman, Eihab	UW ENG / SYS DES		139	
Miao, Guo-Xing	UW ENG / ECE	37		
Kim, Na Young	UW ENG / ECE	226		
Reimer, Michael	UW ENG / ECE	266		
Bajcsy, Michal	UW ENG / ECE	296		
Wilson, Christopher	UW ENG / ECE	722		
Ban, Dayan	UW ENG / ECE		1569	
Cui, Bo	UW ENG / ECE		1247	
Goldthorpe, Irene	UW ENG / ECE		9	
Karim, Karim	UW ENG / ECE		6	
Majedi, Hamed	UW ENG / ECE		40	
Mansour, Raafat	UW ENG / ECE		469	
Safavi-Naeini, Safieddin	UW ENG / ECE			897
Saini, Simarjeet	UW ENG / ECE		37	
Wasilewski, Zbig	UW ENG / ECE		3	
Wong, William	UW ENG / ECE		80	
Gostick, Jeff	UW ENG / CHEM			4
Tsui, Ting	UW ENG / CHEM		2	
Applied Nanotools	OTHER INDUSTRY			178
Knights, Andy (Ranovus)	OTHER INDUSTRY			6
Maheshwari, Vivek (Medella Health)	OTHER INDUSTRY			230
Roy, Jason (Chip Delayering)	OTHER INDUSTRY			3
Teklemariam, Grum (High Q Technologies)	OTHER INDUSTRY			86
Lapointe, Jean (NRC)	OTHER GOVERNMENT			82
Dolgaleva, Ksenia (U Ottawa)	OTHER ACADEMIC non UW			8
Lindsay, Ian (U Bristol UK)	OTHER ACADEMIC non UW			12
Aitchison, Stewart (U of T)	OTHER ACADEMIC non UW			43

Substantial growth in new users over past 7 months

Lab Membership (PI's) as of November 30, 2017

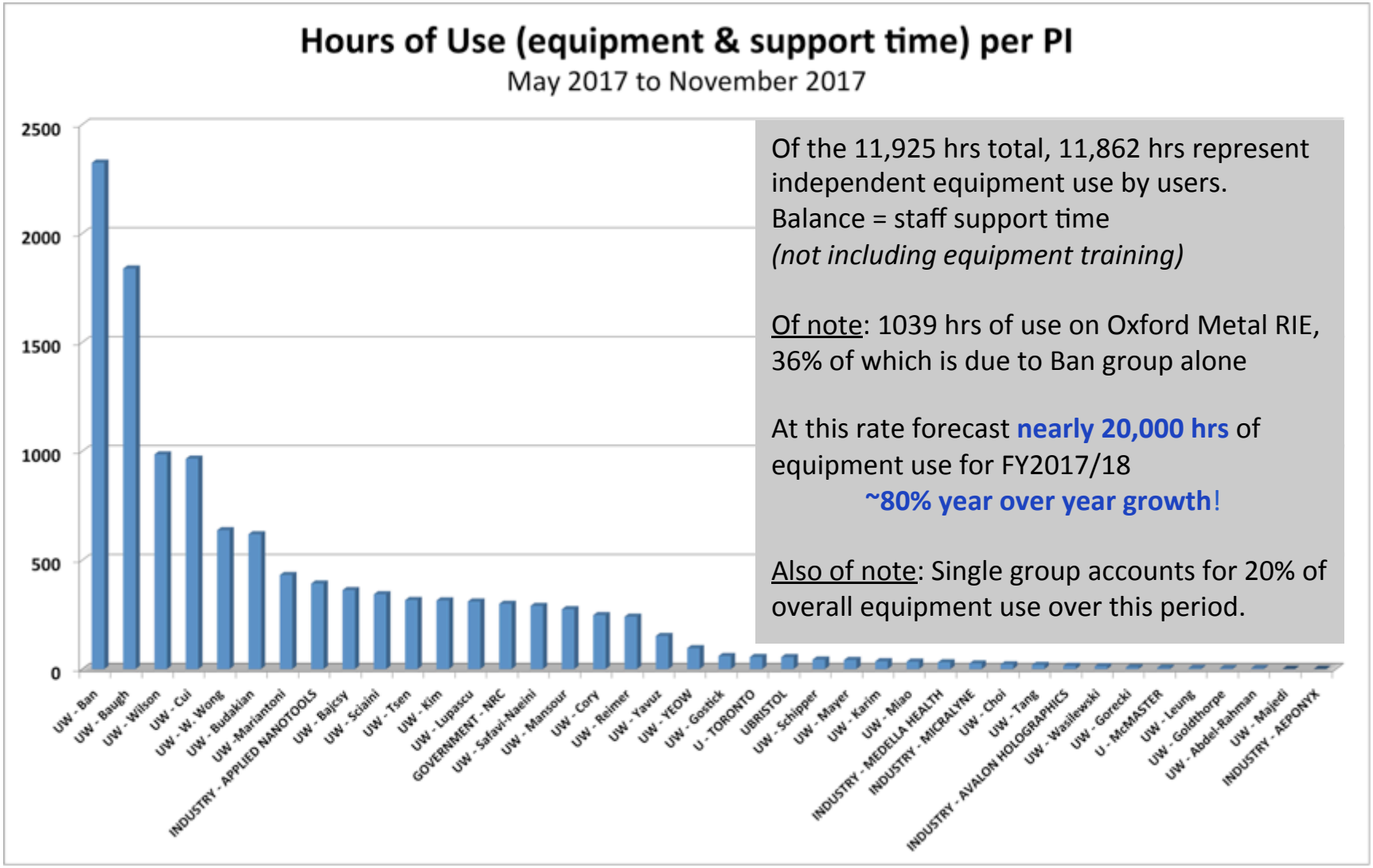
- **16 new PI's since May 1, 2017**
- **Now over 60 PI's registered since 2014**

Pricipal Investigator	Institution	Institute	Faculty	Department
Abdel-Rahman	UW	WIN	Engineering	SYDE
Aziz	UW	WIN	Engineering	ECE
Bajcsy	UW	IQC	Engineering	ECE
Ban	UW	WIN	Engineering	ECE
Cui	UW	WIN	Engineering	ECE
Dolgaleva	U of Ottawa	N/A	Engineering	ECE
Gebotys	UW	N/A	Engineering	ECE
Goldthorpe	UW	WIN	Engineering	ECE
Gostick	UW	N/A	Engineering	Chem Eng
Karim	UW	WIN	Engineering	ECE
Kim	UW	IQC	Engineering	ECE
LaPierre	McMaster	N/A	Engineering	Physics Eng
Majedi	UW	WIN	Engineering	ECE
Mansour	UW	WIN	Engineering	ECE
Mayer	UW	N/A	Engineering	Mechanical
Miao	UW	IQC	Engineering	ECE
Mitra	UW	WIN	Engineering	Mechanical
Musselman	UW	WIN	Engineering	Mechanical
Nieva	UW	WIN	Engineering	Mechanical
RANOVUS	INDUSTRY	N/A	Engineering	ECE
Safavi-Naeini	UW	N/A	Engineering	ECE
Saini	UW	WIN	Engineering	ECE
Sivoththaman	UW	WIN	Engineering	ECE
Tsui	UW	WIN	Engineering	Chem Eng
Wasilewski	UW	IQC & WIN	Engineering	ECE
Wilson	UW	IQC	Engineering	ECE
Wong	UW	N/A	Engineering	SYDE
Wong	UW	WIN	Engineering	ECE
Yavuz	UW	WIN	Engineering	Mechanical
Yeow	UW	WIN	Engineering	SYDE
Yim	UW	N/A	Engineering	Chem Eng

Pricipal Investigator	Institution	Institute	Faculty	Department
Aeponyx Inc.	INDUSTRY	N/A	N/A	N/A
Aitchison	U Toronto	N/A	N/A	N/A
Applied Nanotools	INDUSTRY	N/A	N/A	N/A
Avalon Holographics	INDUSTRY	N/A	N/A	N/A
Carson	U Western Ontario	N/A	N/A	N/A
Chip Delayering	INDUSTRY	N/A	N/A	N/A
High Q	INDUSTRY	N/A	N/A	N/A
Inrs-Emt	INDUSTRY	N/A	N/A	N/A
Lindsay	U Bristol	N/A	N/A	N/A
Micralyne	INDUSTRY	N/A	N/A	N/A
National Resesarch Council	INDUSTRY	N/A	N/A	N/A
Redlen Technologies	INDUSTRY	N/A	N/A	N/A
Transonic Scisense Inc.	INDUSTRY	N/A	N/A	N/A
Baugh	UW	IQC	Science	Chem
Budakian	UW	IQC	Science	Physics
Choi	UW	IQC	Science	Physics
Cory	UW	IQC	Science	Chem
Leung	UW	N/A	Science	Chem
Lupascu	UW	IQC	Science	Physics
Mariantoni	UW	IQC	Science	Physics
Nazar	UW	WIN	Science	Chem
Pawliszyn	UW	WIN	Science	Chem
Sciaini	UW	N/A	Science	Chem
Smith	UW	WIN	Science	Chem
Tang	UW	WIN	Science	Chem
Tsen	UW	IQC	Science	Physics
Wang	UW	WIN	Science	Chem
Medella Health	INDUSTRY	Velocity	Student Success Office	N/A

Facility use per PI: May '17 to Nov '17 (11,925 hrs!)

Substantial growth in facility use & user base: growing burden on fab staff



Of the 11,925 hrs total, 11,862 hrs represent independent equipment use by users.
Balance = staff support time
(not including equipment training)

Of note: 1039 hrs of use on Oxford Metal RIE, 36% of which is due to Ban group alone

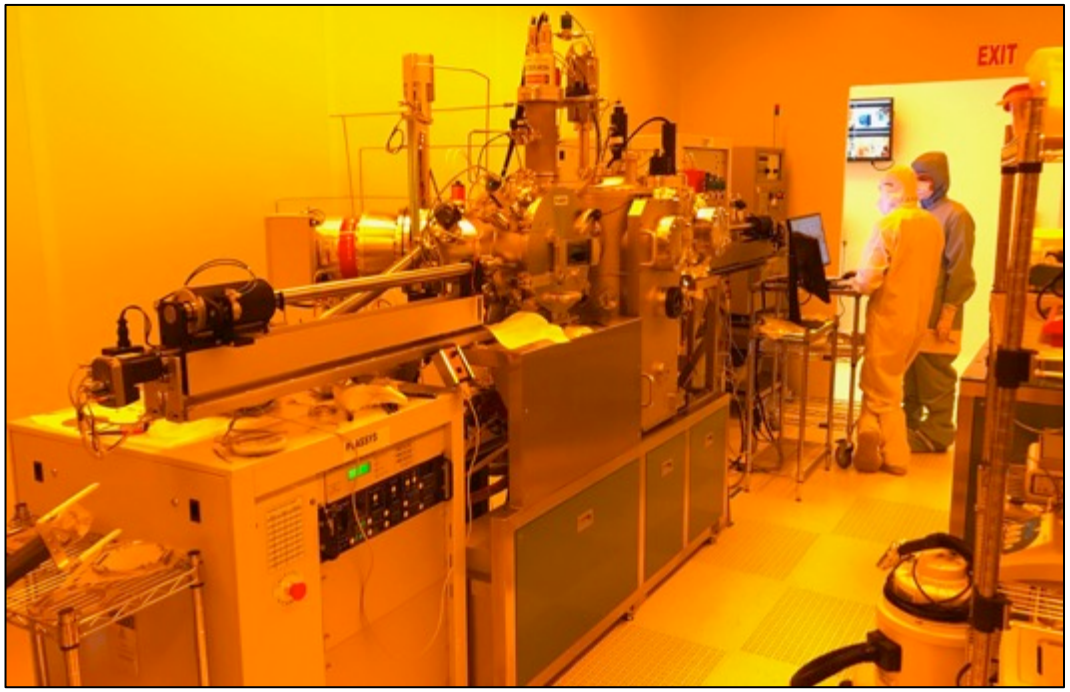
At this rate forecast **nearly 20,000 hrs** of equipment use for FY2017/18
~80% year over year growth!

Also of note: Single group accounts for 20% of overall equipment use over this period.

Benefitting from IQC funding

New $900k Plassys MEB 550 SL3 UHV e-beam evaporator & oxidation system

- Angle aluminum e-beam evaporator dedicated to Josephson Junction formation
- Installed late August 2017; SOP & training plan nearly complete
- Process commissioning ongoing (lead by Mariantoni & Wilson groups)



Of Note: IQC also funded acquisition of $3M JEOL JBX-6300FS 100kV EBL system in 2015

Benefitting from:

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE – TQT Transformative Quantum Technologies

Quantum NanoFab Team staff hires (CFREF-TQT funded)

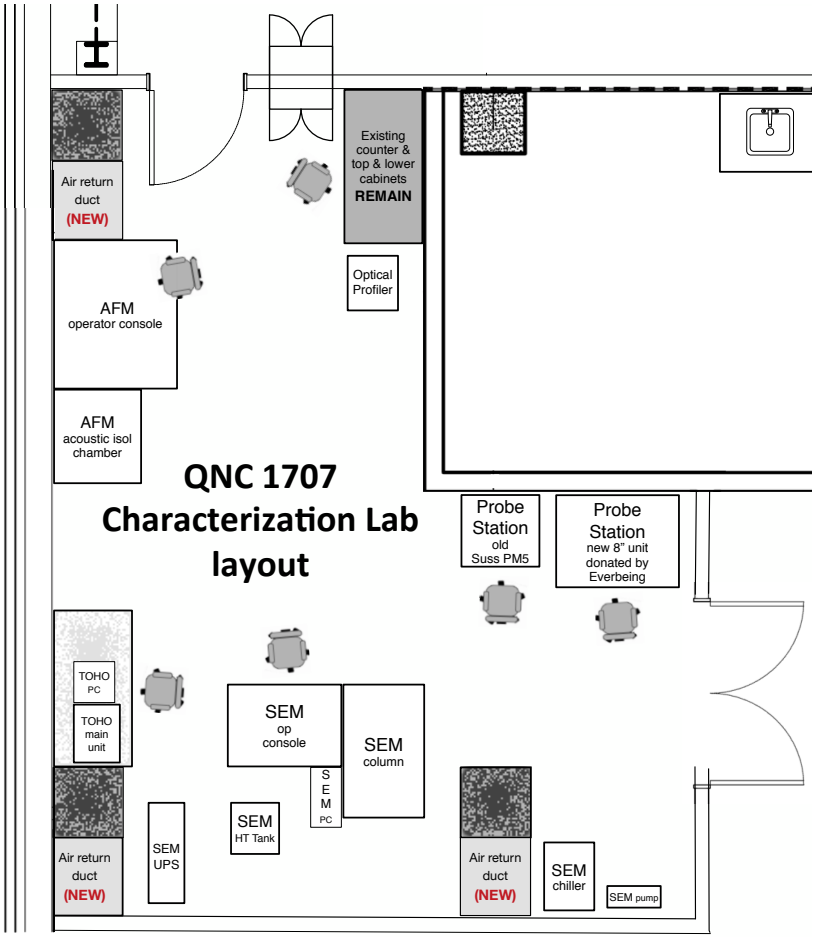
- Dr. Greg Holloway hired into *E-Beam Lithography Scientist* position
- New *Nanofabrication and Characterization Scientist* position
- New *RAC1 Lab Technologist* position

Equipment & S/W maintenance contracts (CFREF-TQT funded)

- JEOL JBX-6300FS 100kV E-beam litho system
- BEAMER EBL S/W package
- JEOL JSM-7200FS Scanning Electron Microscope

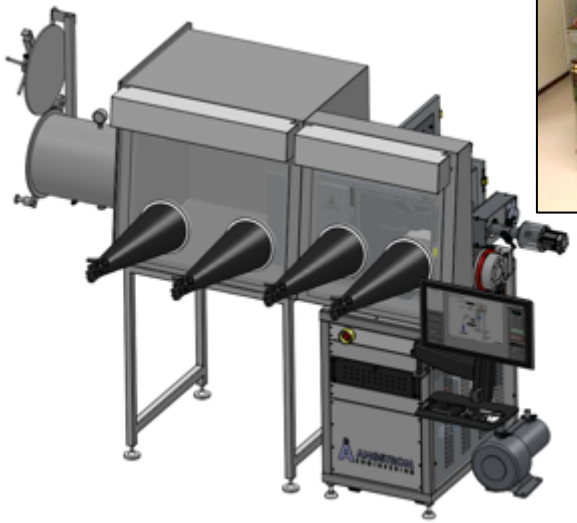
Lab renovations (CFREF - TQT funded)

- QNC 1707 converted into ISO 7 cleanroom: new *Characterization Lab*
- RAC1 cleanroom renovation: clean assembly space + chemical & mechanical processing



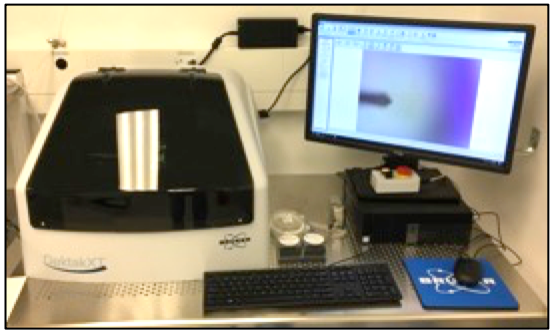
New equipment (CFREF - TQT funded)

- Maskless aligner & exposure system (*Heidelberg MLA150* - installed & released)
- Scanning Electron Microscope (*JEOL JSM 7200F* - currently being installed)
- AuBe evaporator for p-type ohmic contacts (*Angstrom Engineering* - ordered Nov 2017)



New equipment (CFREF - TQT funded)

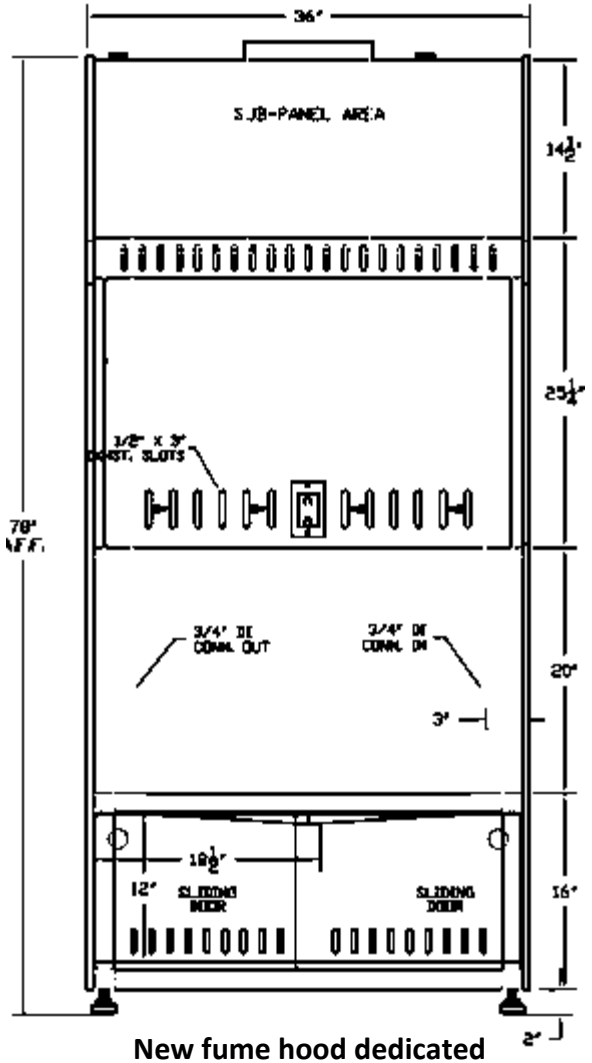
- Critical point dryer (*Tousimis Autosamdri 815B* - installed & released)
- Atomic Force Microscope (*Bruker Dimension FastScan* - installed)
- Stylus profilometer (*Bruker DektakXT* - installed)
- JEOL EBL cassettes & pre-alignment microscope (expected Jan 2018)



RAC1 Satellite Lab

Coming soon:

- Sample polisher, cutter, etc.
- Fume hoods: acids, caustics, organics (currently installed)
- UV ozone & O_2/Ar plasma cleaners (received)
- Microscopes
- Etc.



New fume hood dedicated to HF acid processing

RAC2 Satellite Labs

Coming soon (phase 1):

- Microscopes
- Veeco AFM
- Wirebonder

Expenses, Revenues & Operating fund sources

Expenses for last two fiscal years (ending April 30):

		2016	2017
SALARY & BENEFITS EXPENSES			
	Sub-Total:	**$460,623**	**$613,184**
SUPPLIES, MAINTENANCE & EQUIPMENT EXPENSES			
Equipment service contracts (6 machines total)		$217,902	$333,371
Supplies, maintenance & general repairs		$217,299	$310,018
	Sub-Total:	**$435,201**	**$643,389**
BULK NITROGEN			
	Sub-Total:	**$153,830**	**$158,815**
	GRAND-TOTAL EXPENSES:	**$1,049,653**	**$1,415,388**

Revenues & Funding sources since 2012:

	2012	2013	2014	2015	2016	2017	TOTAL
User fees invoiced:	$86,583	$157,915	$111,333	$80,860	$348,371	$539,638	**$1,324,700**
User fees collected:	$66,638	$120,084	$106,072	$59,806	$278,535	$450,607	**$1,081,742**
IQC:	$131,658	$290,397	$191,519	$204,799	$383,548	$218,342	**$1,420,263**
CFI-IOF:	$192,380	$105,987	$205,842	$319,428	$267,063	$675,638	**$1,766,339**
Office of VP Academic & Provost:	$0	$0	$0	$103,000	$153,830	$158,815	**$256,830**
	$390,676	$516,468	$503,434	$687,033	$1,082,976	$1,503,402	**$4,525,174**

Lab User Survey: June 2017

Platform used: UW-IST supported enterprise-class online survey system, *Qualtrics*

Distribution methodology: All registered lab users and Principal Investigators invited to participate via fab mailing list, *qncfabmembers@lists.uwaterloo.ca*

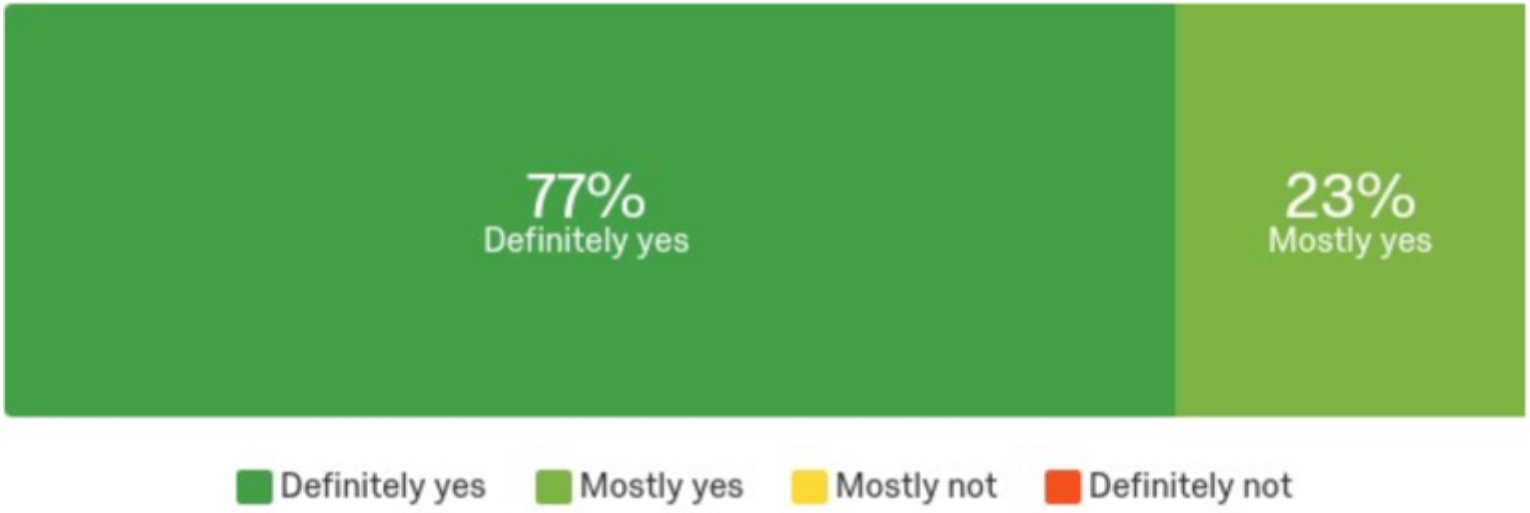
Number of submissions received: 52 (some partial responses)

Breakdown of participants:

Please describe your current position:	%	Count
Faculty member or Principal Investigator	26%	13
Postdoctoral Researcher	18%	9
Research Assistant	4%	2
Graduate student (PhD)	44%	22
Graduate student (Masters)	8%	4
Undergraduate student	0%	0
Total	**100%**	**50**

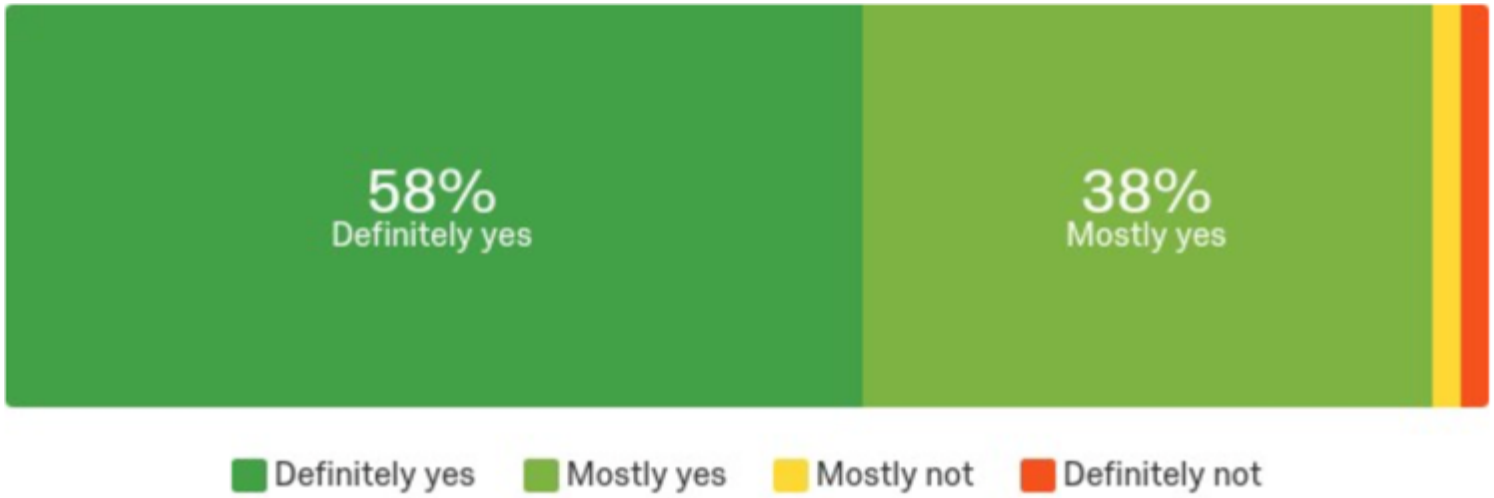
How long have you been a user of the QNF?	%	Count
Less than 6 months	11%	6
Between 6 and 12 months	25%	13
Between 1 and 2 years	27%	14
More than 2 years	37%	19
Total	**100%**	**52**

Q1 - Is there a clear path to becoming a user of the facility?



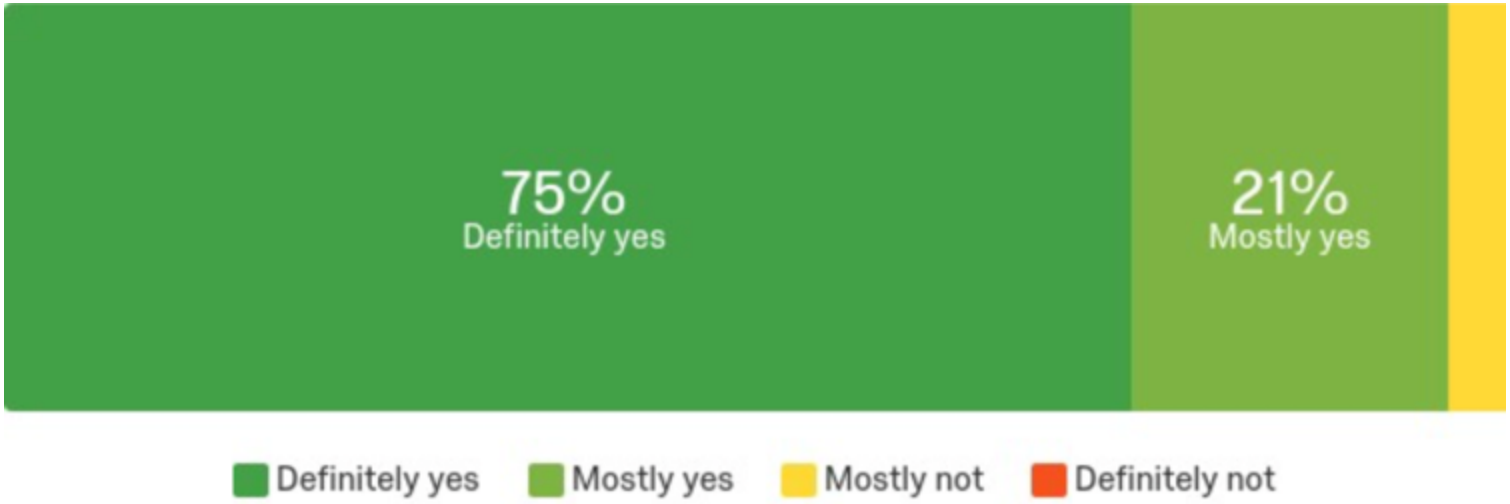
#	Answer	%	Count
1	Definitely yes	77%	40
2	Mostly yes	23%	12
3	Mostly not	0%	0
4	Definitely not	0%	0
	Total	100%	52

Q2 - Is the training provided appropriate and thorough?



#	Answer	%	Count
1	Definitely yes	58%	30
2	Mostly yes	38%	20
3	Mostly not	2%	1
4	Definitely not	2%	1
	Total	100%	52

Q3 - Is the staff knowledgeable and helpful?



#	Answer	%	Count
1	Definitely yes	75%	39
2	Mostly yes	21%	11
3	Mostly not	4%	2
4	Definitely not	0%	0
	Total	100%	52

Q4 - Are the tools well maintained?

#	Answer	%	Count
1	Definitely yes	50%	26
2	Mostly yes	50%	26
3	Mostly not	0%	0
4	Definitely not	0%	0
	Total	100%	52

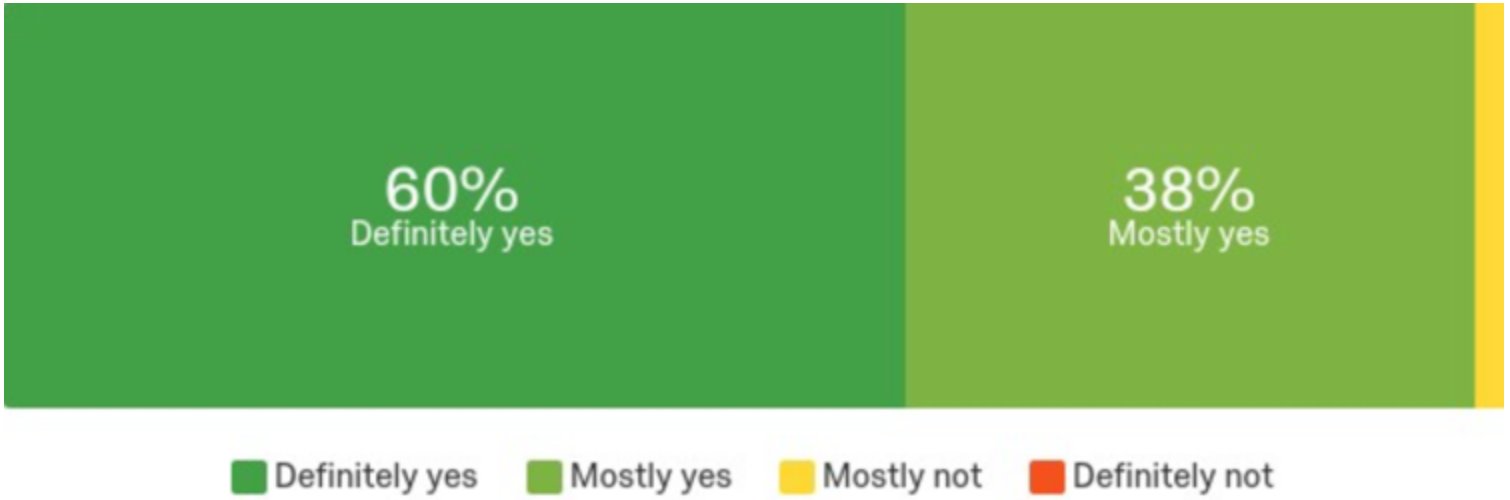
Q5 - Are you able to book time on equipment with relative ease?

#	Answer	%	Count
1	Definitely yes	27%	14
2	Mostly yes	57%	29
3	Mostly not	16%	8
4	Definitely not	0%	0
	Total	100%	51

Q6 - Are there well prepared Standard Operating Procedures (SOPs) for the equipment you need?

#	Answer	%	Count
1	Definitely yes	73%	38
2	Mostly yes	25%	13
3	Mostly not	2%	1
4	Definitely not	0%	0
	Total	100%	52

Q7 - Is there a clear path for bringing new processes into the facility?

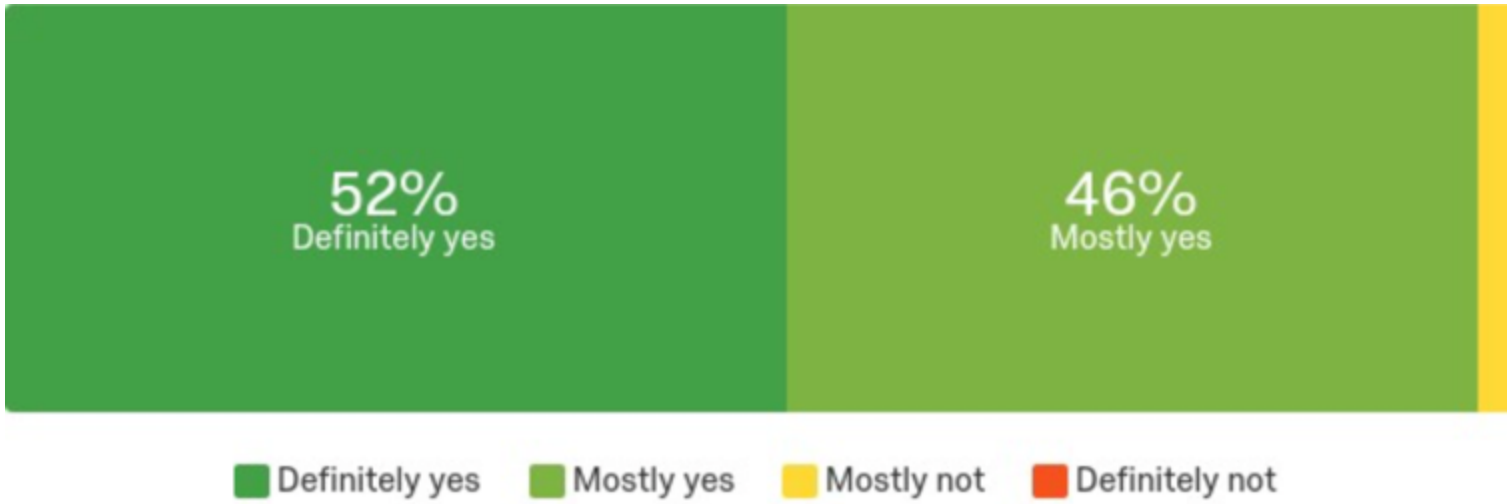


#	Answer	%	Count
1	Definitely yes	60%	30
2	Mostly yes	38%	19
3	Mostly not	2%	1
4	Definitely not	0%	0
	Total	100%	50

Q8 - Have you been able to effectively use the facility for your projects?

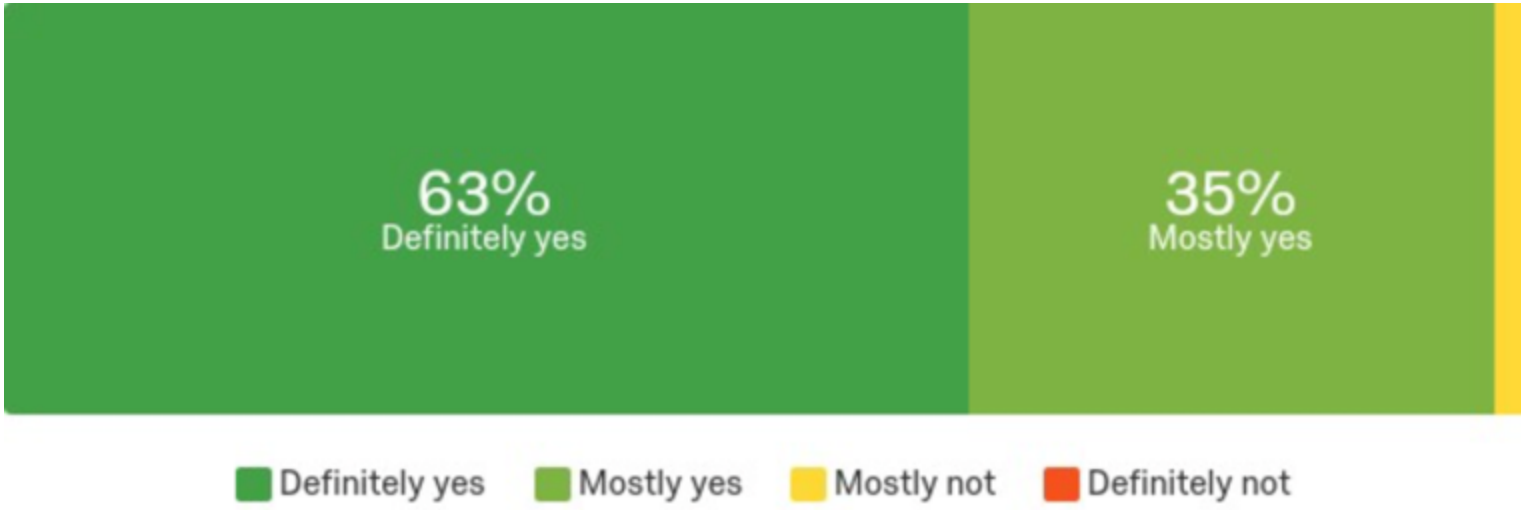
#	Answer	%	Count
1	Definitely yes	71%	36
2	Mostly yes	27%	14
3	Mostly not	2%	1
4	Definitely not	0%	0
	Total	100%	51

Q9 - Does the facility continue to grow and add capabilities that are of interest to the user community?



#	Answer	%	Count
1	Definitely yes	52%	26
2	Mostly yes	46%	23
3	Mostly not	2%	1
4	Definitely not	0%	0
	Total	100%	50

Q10 - Are you getting good value?



#	Answer	%	Count
1	Definitely yes	63%	33
2	Mostly yes	35%	18
3	Mostly not	2%	1
4	Definitely not	0%	0
	Total	100%	52

Q11 - What do you appreciate most about the facility?

- **Staff** responsiveness to issues is quick & helpful
- Good technical **staffing**
- SOPs for each equipment are very helpful & easy to follow
- Very well managed & well maintained by **staff**
- High quality equipment with well trained & very helpful **staff**
- All the tools needed in one place
- Ability to discuss new ideas & improve things with **staff**
- **Staff** are knowledgeable & helpful
- Organization of equipment into modules by function
- **Very professional** & clean
- Up-time of most tools
- Addition of off-hour access is beneficial for effective use of facility
- Willingness of **staff** to work with us to help us with process challenges
- Equipment is fully functional & well maintained by **staff**
- Policies & procedures are complete & thorough
- The **team is exceptional**!
- **Staff**, booking system, enforcement of rules & strict access regulation
- Excellent, helpful and friendly **staff** members

	# of times mentioned
Quality of staff & help provided	23
Quality of equipment & maintenance of these	17
Well organized & professional operations	11
Rules, procedures & their consistent application	6
Safety is a top priority	2
Extended hours of operation	2
Low cost	1

Q12 - Are there any areas for improvement?

✓
- More support for e-beam lithography
- Broader stock of EBL resists would be helpful

- Reduce time it takes to obtain equipment training
- Long waiting time for initial training

- Downtime of certain pieces of equipment
- People who cause equipment downtime should see stronger consequences
- Hold users who do not follow SOPs more accountable
- Users who overbook and underuse equipment
- Users could be more considerate and clean
- Too many cancelled equipment bookings

✓
- Change time for fab general cleaning activities from mid-day to early morning

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- Cost of using equipment is very high; affects ability to develop process from ground up

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✓
- More measurement & characterization tools
- More open table space

- All users should be able to operate on nights and weekends

Q13 - What piece of equipment would you recommend be added to most benefit the fab's broad community of users?

Equipment description	# People who recommended
SEM	18
E-beam depositon chamber (one more)	6
TEM	3
Spin coating station (one more)	3
AFM	2
XRD	2
Chlorine-based RIE (one more)	2
Laser writer	2
Digital holographic microscope	1
FTIR	1
Scanning confocal microscope	1
UV-vis Spectrophotometer	1
Angle evaporator for making Al junctions	1
Evaporator for p-type contacts for III-V semiconductors	1
Indium deposition	1
Wafer lapping system	1
Wafer stepper	1
Wire bonder (one more)	1

Key objectives 2018

People

- *Taso Alkiviades*, new hire for *RAC1 Lab Technologist* position, starting with us on Jan. 2
- Hire *Characterization & Nanofabrication Scientist* for new Characterization Lab
- Ongoing Co-op student positions (dependent on continued IQC funding)

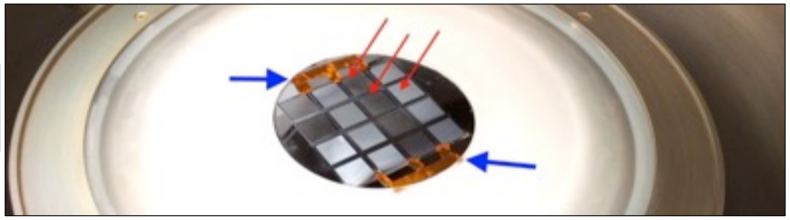
Lab Equipment & Processes

- SOP's, technical reports & training plans for multiple new tools in QNC, RAC1 (& RAC2 as needed)
- Final batch of equipment installation & commissioning activities (including AuBe evaporator)
- Extensive training activities: much interest in new maskless aligner & SEM systems in particular
- Documenting new basic MEMS process module

General

- Improving cleanliness & safety of chemical work stations (Piranha hood as a recent example)
- Fab Team taking lead on 2-day cleanroom training modules for IQC USEQIP & WIN UBristol
- Mid-January 2018: Publish 2016/17 annual report
- January 2018: external review of Quantum NanoFab (& other UW labs) initiated by VP University Research

Dble-sided Kapton tape used to hold dies down in Si DRIE chamber: Lab users find new ways of challenging us . . .



Discussion

- Questions
- Concerns
- Suggestions
- Additional items?