Nanotools MicroFabrication Facility

Annual Report

June 2012 – May 2013

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Nanotools MicroFabrication Facility

Content

Executive Summary

In the fiscal year 2012-2013 income from user fees was $310 909. Compared to 2011/12, this is an effective 18% increase. **For a third year in a row, the McGill Nanotools Microfab is recovering all operating expenses from user fees.** The University and NanoQuebec support the cost of manpower at 100%. Average user fees amounted to $38.99/h. After 4 years of strong growth nearly all outputs quantifiable with reasonable effort show a stabilization of usage in 2012/13:

Usage is at 7976h, an increase of 14% compared to 2011/12. This is a threefold increase compared to five years ago. There were 55 PIs using the Microfab (50 in 2011/12), with 14 users using it for more than 100h (14 in 2011/12). In 2012/13 36% of all PIs were external, using the fab for a total of 1237h (16% of total usage), 14 non-McGill academic (717h, 9%) and 6 users from 5 companies (520h, 7%). 115 students worked in the Microfab (107 in 11/2), resulting in at least 68 publications (52 in 11/12), 13 patents (8 in 11/12). 25 HQP graduated with a project that had a major Microfab component (44 in 11/12), while 5 external companies used the Microfab (5 in 11/12). Given the competitive funding climate a remarkable high amount of new operating grants worth $4,169,250 ($ 3,925,476 in 2011/12) were acquired directly by the fab PIs, in addition to $11,300,000 for the successful CFI LEF Nanotools 2 upgrade. Two CRC 2 chairs with major fab usage were also renewed successfully. Note: all $ values indicated are the total values, even for multi-year grants. The 7th installment of the Hands-on Nanobiotechnology lecture and lab course was offered from March 4-8, 2013, attracting 38 participants (10 from other academic institutions, 6 from industry).

These numbers demonstrates that the user base of the Microfab is broad and stable; the Microfab clearly meets the needs of many users. A clear trend is observable in all the data: stabilization at a high level with reduced growth when compared to previous years.

The McGill Nanotools Microfab has reached steady state operation. The data shows that the McGill Nanotools Microfab continuous to be core to the research of many, mainly recently hired, faculty in Engineering, Science and Medicine at McGill. The outside user base and usage is increasing slightly. The implementation of the successful 11.3M$ CFI VII 'Nanotools II' will substantially increase our capabilities, in particular for rapid prototyping, materials deposition and biomedical applications and is expected to lead to growth of life science users once implemented. We have established ANANDA (Advanced Nano Design Applications), a partnerships with the MNI, as a bridgehead to better serve the life science and biomedical community. We continue to observe that companies are interested in the whole 'package': PI, HQP and access to excellent facilities. Indeed most companies access the McGill Nanotools Microfab via collaborative mechanisms such as NSERC Strategic projects, CRD or in other partnership agreements with McGill researchers. Together with the successful CFI the McGill Nanotools Microfab is well positioned for renewal of the NanoQuebec infrastructure support in 2013.
Finally, it is noteworthy to point out the excellent team work of our fab staff: every day on average more than 4 different processes are performed by the users! This is a constant challenge to our staff in terms of equipment maintenance, operations stability, safety and training.

Organization

Academic Oversight

In November 2009, the position of Academic Microfab director was created. The academic Microfab director is responsible for:

- updating or creating policies
- supporting training and teaching opportunities
- enabling scientific and technological development
    1. Taking advantage of available expertise and capabilities (active/passive 'matchmaking')
    2. Identification of needs and what to do about it
    3. Coordination of capital equipment grants (CFI)
- developing in- and outreach initiatives
- ensuring financial stability of the Microfab
- evaluation of Microfab personal
- receiving and following up on suggestions and complaints about Microfab operations
- generate an annual report (accountability, transparency and information)

To achieve these goals, the academic director is supported by an Advisory Committee (AC). The AC provides feedback to the Microfab director, but has no executive decision power, which rests with the Microfab director.

Academic Microfab Director:	Prof. Peter Grutter, Assoc. Dean of Res. & Grad. Educ. (Fac. of Science).
Advisory Committee:	Prof. David Juncker (Medicine)
	Prof. Walter Reisner (Science)
	Prof. Thomas Szkopek (ECE)
	Prof. Srikar Vengallatore (Mech. Eng)
	Dr. Matthieu Nannini (Fab manager)

Prof. Walter Reisner was added due to his hands-on expertise in microfabrication.

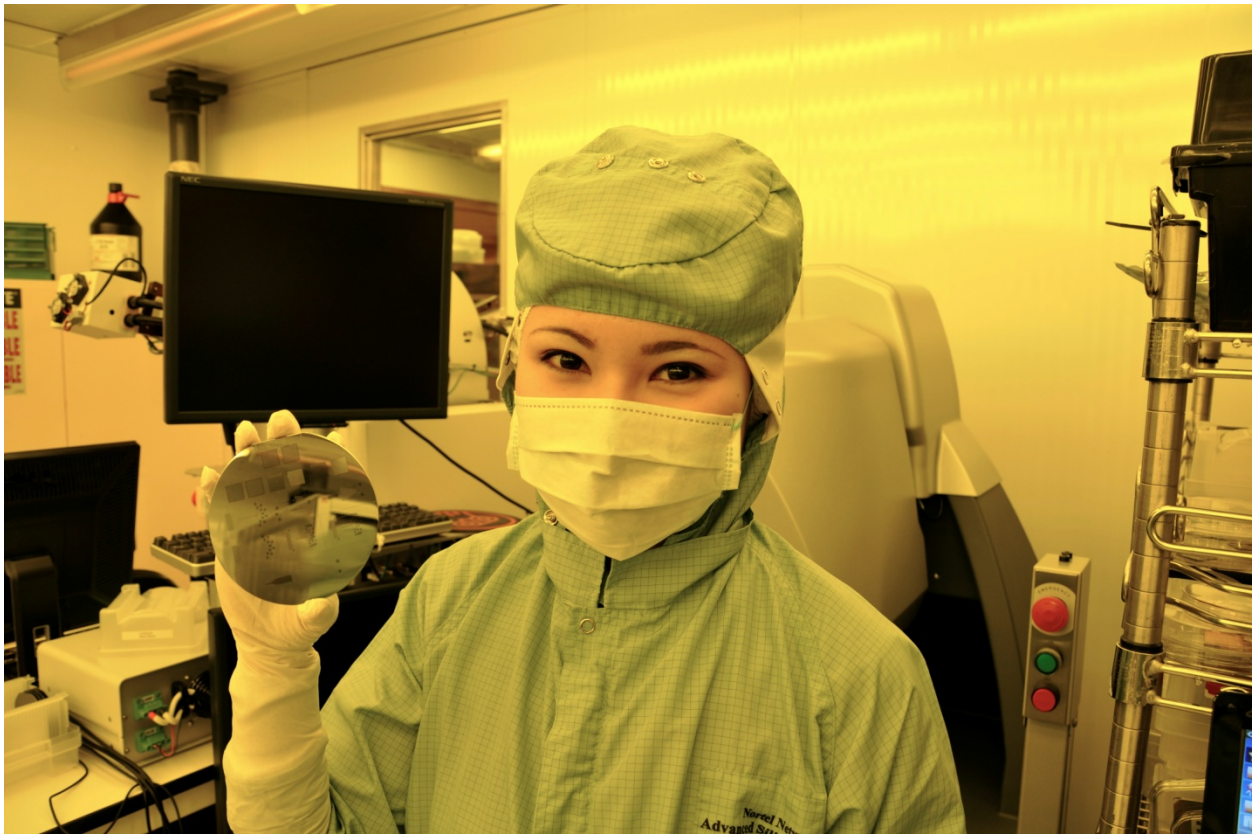
Starting Nov. 2012 Dr. Matthieu Nannini was replaced ad-interim by Dr. Lino Eugene and Jun Li (acting fab managers during Nannini's paternity leave).

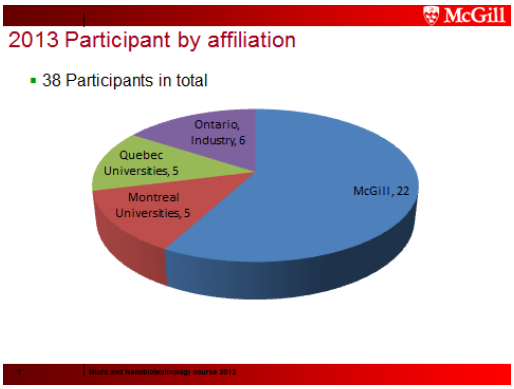
Achievements and key improvements

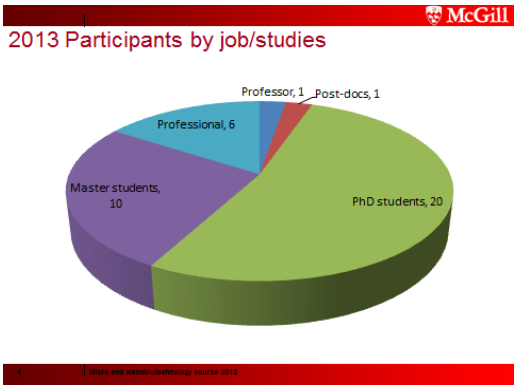
A major success for the Microfab was obtaining **$11.3 M$ from the call VII CFI LOF competition.** This will allow a major upgrade of the Microfab, addition of a rapid prototyping facility, MBE growth capabilities and extended characterization capabilities. Necessary additional space was made available by the Physics department, renovations should start late 2013 and equipment is expected to be on-line by April 2014.

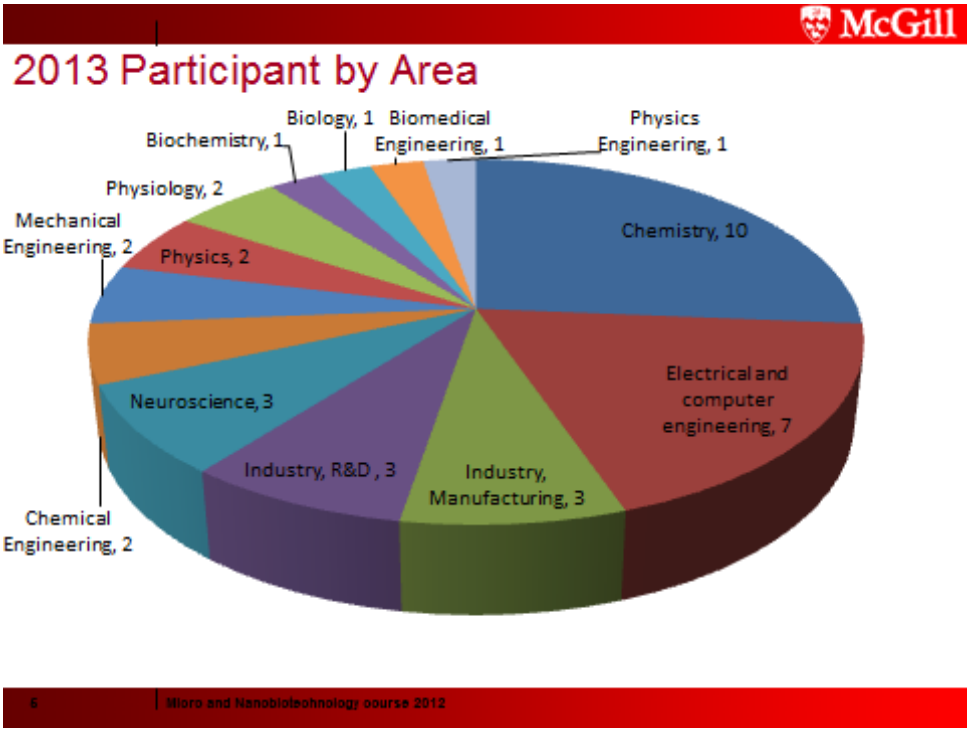
The annual **Microfab user meeting** was held 18 April 2013 with more than 30 participants as art of the annual MIAM meeting. In the spring of 2012 no meeting was organized due to many individual interactions necessary with many fab users to develop the CFI call VII Nanotools II proposal.

The 7th instalment of the **Hands-on Workshop in Micro and Nanobiotechnology** lecture and lab course was offered from March 4-8, 2013. This year's course drew 38 participants, with 22 coming from McGill, 6 from industry, and the other 10 from Concordia, U de Montreal, Sherbrooke, and U of Ottawa. Participants received basic instruction on microfabrication and each made their own wafers in the clean room. Microfluidic techniques and microcontact printing were demonstrated in the lab, as well as brainstorming sessions to help them design devices specific for their research. The keynote speaker was Dr. Ali Khademhosseini of Harvard University, who showcased exciting research in the in the field of micro- and nanoscale technologies for stem cell bioengineering and tissue regeneration. More details can be found at mcgillmicronano.com.









Finally, an annual **evaluation of all Microfab staff** was performed. The process consists of a self-evaluation followed by an evaluation by the supervisor, as specified in the job description. The Microfab manager is evaluated by the academic Microfab director; all staff members of this facility are evaluated by the Microfab manager. Reappointment of all staff was recommended. The manager and staff form a highly motivated, dynamic and hard working group.

Major new policies

No new major policies needed to be implemented in 2012/13.
All McGill Nanotools Microfab policies (including user fees) can be found at:
http://mnm.physics.mcgill.ca/content/policies

User Agreement:

McGill Nanotools Microfab staff is committed to providing an environment conductive to high-quality research and learning. To ensure that everyone knows their responsibilities, all members of the MNM community (students, staff, faculty, and industrial visitors) are asked to annually read and sign a McGill Nanotools User Policy Agreement outlining responsibilities and consequences for breaking rules.

The wording of the User Agreement can be found at:
http://mnm.physics.mcgill.ca/system/files/McGill%20Nanotools%20User%20Policies%20Agreement%202011-11-10.pdf

Weekend access policies:

The fab can be accessed during week-ends and National statutory holidays except for the Christmas break with the following conditions:

1. A plan of ALL experiments that "urgently" needs to be submitted 48h in advance (Thursday before 08:00). Fab staff can refuse weekend access if they feel that EHS might be compromised. Their decision is final and cannot be appealed.

2. All users (including buddy) need to pass an oral exam by the fab manager to ensure that they know about the EMO in case of danger for the tool or for their health. This will ensure an adequate training level of the user. This exam has to be renewed every 2 months. Set up an appointment with the fab manager.

3. Strictly enforced buddy system: always 2 knowledgeable users in the fab at all times.

4. The following processes are off-limits:

- AMP5000 (RIE, PECVD)
- Tylan (furnaces)
- HF and TMAH usage

5. Same user fees.

6. Doubling of penalties in case fab rules are not strictly adhered to (spot check via video)

7. Users are responsible of getting their access to the building during off-hours. Contact Louise Decelles chairsec.physics@mcgill.ca

Update on Manpower and Equipment

McGill Nanotools Microfab Operation Staff

Microfab Manager:	Dr. Matthieu Nannini
Technologist:	Don Berry
Equipment technologist :	John Li
Research Assistant:	Lino Eugene
Academic Associate	Seddik Benhammadi

Note: this list is only the clean room staff directly reporting to the fab manager. Several other FTE relevant for the operation of the Microfab (billing, repairs, IT) are paid for from departmental resources or funded by the Centre for the Physics of Materials through a FQRNT funded Regroupement Strategique in Advanced Materials (RQMP).

ANANDA (Advanced Nano Design Applications)

Many life science researchers would like to use microfluidics and silicon-based devices, but lack the knowledge to design, develop and build such devices. To meet this need, ANANDA (Advanced Nano Design Applications) was created as a joint venture between the McGill Nanotools Microfab and the Montreal Neurological Institute (www.mcgill.ca/ananda). ANANDA was founded in the fall of 2012 in an effort to expand the use and the development of cost-effective solutions for the design and manufacture of new microdevices to improve biomedical research and diagnostics. It will thus drive business to the McGill Nanotools Microfab, stimulate new designs, processes and create IP.

ANANDA operates in proximity to a research environment where biological problems can be understood and applied solutions can be tested. ANANDA has an enthusiastic, multidisciplinary R&D team that work in collaboration with the McGill Microfabrication facility for precision machining and molding in micro and nano scales.

ANANDA will enable any researcher to use microfluidic devices for cell culture based assays and protein micro-patterning to reduce the cost of consumables or to control and quantify cellular responses. Miniaturized versions of bioassays offer many advantages, including: design versatility, low cost, minimal reagent and sample requirements, plus integration with other miniaturized devices. It will also increase usage of the McGill Nanotools Microfab.

Dr. Margaret Magdesian was hired as the manger of ANANDA in the fall of 2012.

Changes in Tools

The following pieces of new equipment were purchased and commissioned in 2012-2013:

A new e-beam evaporator was installed as a backup during summer 2012:
NexDep from Angstrom Engineering
http://www.angstromengineering.com/nexdep.html

The NanoSpec reflectometer was upgraded with the F40-NSR from Filmetrics.
http://www.filmetrics.com/thicknessmeasurement/f40-nsr

No piece of equipment was deemed obsolete by the community. However, the JEOL JSPM-5200 AFM was not often used in the past 2 years. After consultation with all the fab users this tool was removed from the clean room and placed in Prof. P. Grutter's lab, where it will remain accessible to any user. The advantage of this arrangement is that it provides for technical expertise and support via the Grutter group.

Outcomes: Publications, HQP and Grants

Summary

After 5 years of strong growth nearly all outputs quantifiable with reasonable effort shows a steady output or sustainable growth in the last three years. 136 students worked in the Microfab (107 in 11/12), at least 68 publications (52 in 11/12), 13 invention disclosures and patents (8 in 2011/12), 140 talks and presentations (42 in 2011/12), 25 HQP graduated with a project that had a major Microfab component (48 in 11/12) and 5 external companies used the Microfab (5 in 2011/12). New grants worth $4,169,250 ($ 3,925,476 in 2011/12) were acquired directly by the fab PIs, in addition to $11,300,000 as a result of successful CFI LEF Nanotools 2 proposal.

Publications (including Patents and Disclosures)

In 2012/13, at least 68 peer reviewed publications and 13 issued or filed patents resulted from work with an intensive Microfab component (as in previous years some of the minor Microfab users did not provide an annual report, so these numbers are expected to have a substantial potential error). This is a leveling off of the trend observed in the past few years: 52/8 publications/patents in 2011/12, 57/6 publications/patents in 2010/11, 41/2 in 2009/10 and 21/7 in 2008/09.) Appendix A gives the detailed titles, authors and references (note that publications, for annual consistency reasons, were only counted in a given calendar year, whereas all other data is from June 2012- May 2013.

Trained and graduated HQP

The total number of HQP **trained** in the Microfab has increased slightly to **115** (compared to 107 in 2011/12, 91 in 2010/11, 64 in 2009/10 and 57 in 2008/09)). The distribution has remained roughly constant, with 55 (48%) HQP from Engineering, 32 (28%) from Science, 14 (12%) from Medicine and 14 (12%) non-McGill academics.

A substantial number of HQP **graduated** with a major component of their work being performed in the Microfab: **25** compared to 44 in 2011/12 and 52 in 2010/1 (see appendix for details). This is mainly due to a reduction of the number of undergraduates as well as the large number of graduated PDF last year. The average hours spent in the fab (and thus the fab intensity of the HQP training) has increased, as the number of hours of fab usage has increased. We do not have the corresponding numbers for previous years, but are starting to track this.

Table: Number of students graduating from the fab as provided by the PIs.

HQP category	2012/13	2011/12	2010/11	2009/10
Undergraduates	5	13	12	5
Masters & Ph.D.	16	19	33	16
PDF	4	12	7	2

Research Grants acquired due to access to fab

The total of ***new*** individual grants and contracts directly linked to the fab acquired by PIs (excluding Discovery Grants) had a value of **$ 15,561,750.** This includes $ 11,300,000 as a result of the successful CFI LEF Nanotools 2 proposal led by Grutter (Physics) with co-applicants El-Gamal (ECE), Gervais (Physics), Guo (Physics), Juncker (Bio. Med. Eng.), Kambhampati (Chemistry), Mi (ECE), Reisner (Physics), Szkopek (ECE) and Vengallatore (Mech. Eng.).The newly acquired operating funds of $ 4,169,250 are a slight increase of 6% compared to the $ 3,925,476 in 2011/12 (Note that CFI IOF are not included in any of these sums).

The distribution of newly acquired *operating* funds across faculties is similar to last year: 56% (52%) from engineering, 16% (22%) from science, 18% (23%) medicine and 11% (3%) from outside of McGill. What is interesting to note is that all of the NSERC SPG and most of the FRQNT Team grants have co-applicants from Engineering and Science. Note that in 2009/10 the PIs of these grants were almost exclusively from the faculty of engineering.

Details can be found in the appendix.

Budgetary report

Fiscal year 2013 (May, 1st 2012 to April 30th, 2013)

Summary

	Total expenses	Total invoiced	Difference
FY13 Q1	73 782.81 $	83 554.94 $	+ 9 772.13 $
FY13 Q2	67 022.26 $	98 747.47 $	+ 31 725.21$
FY13 Q3	83 194.72 $	66 333.12 $	- 16 861.60 $
FY13 Q4	52 215.39 $	62 273.74 $	+ 10 058.35 $
Total FY13	**276 215.39 $**	**310 909.27 $**	**+ 34 694.09 $**

History

Year	Total expenses	Total invoiced	Difference
FY08	137 038,35 $	83 184,13 $	- 53 854,22 $
FY09	115 529,12 $	77 432,85 $	- 38 096,19 $
FY10	147 748,18 $	140 843,08 $	- 6 905,10 $
FY11 (11 months)	181 131.58 $	207 265.31 $	+26 133.72$
FY12	241 595.04 $	265 119.99 $	+23 525.69$

Expenses Details for FY12

		FY13	FY12	FY11	FY10	FY09	FY08
PM-Repair: includes equipment and facilities repair expenses	97 571.14 $	35.3%	34%	42.%	42%	51.8%	60.9%
Consumables: includes chemicals (acids, solvents, litho…), materials, substrates, …	108 598.48 $	39.3%	39%	41%	38%	40.5%	25.6%
Purchase: small tools, fab improvements	32 196.85 $	11.7%	16%	7.6%	5%	1.8%	8.8%
Office: includes NCS charges, computer and office supplies, IT improvement	7 325.69 $	2.7%	5%	7.0%	10%	5.3%	2.5%
Travel	3 625.54 $	1.3%	0.5 %	1.0%	5%	-	-
External: work done in other core facilities	11 140.19 $	4.0%	2%	0.4%	1%	0.3%	1.6%
Courrier	9 429.49 $	3.4%	1%				
Broker	6 327.80 $	2.3%	2%				

Note that all manpower related cost is covered by McGill and NanoQuebec funding, the budget above is only for operations.

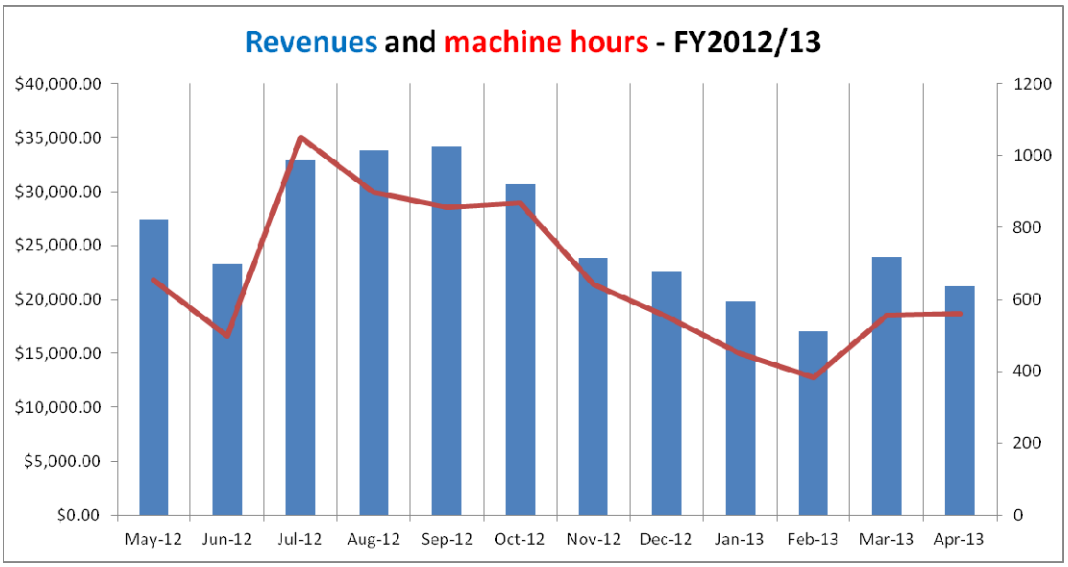
Revenues

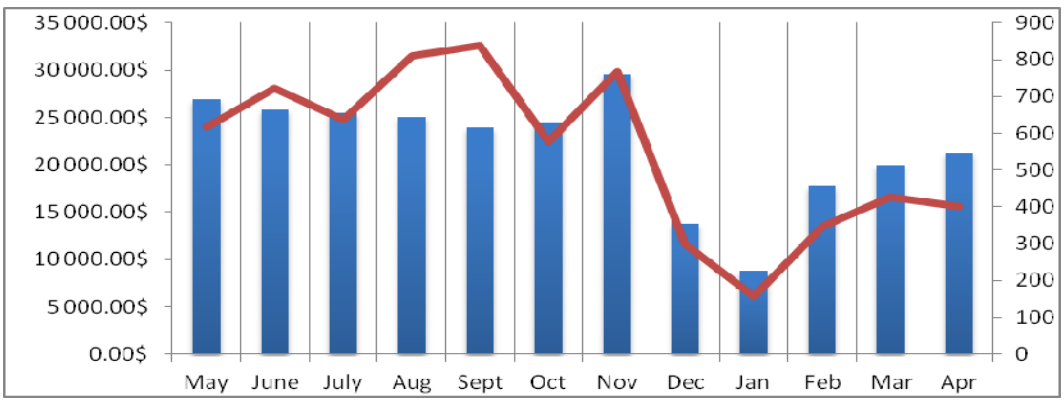
Total revenues from May-12 to April-13: $310,909.27. Compared to 2011/12 this is an effective 18% increase. Whereas the regular base user fee is $50, the average hourly user fee (total income divided by total billed hours) is only $38.99 and remained stable compared to $37.51 in 2011/12. This is mainly due to the soft cap set at $1000/month after which only 25% of the costs are charged, benefitting major users with many HQP using the fab.[1] The philosophy for this soft cap is that major users contribute to the fab in terms of process development and that their students often also coach other students. With this user fee structure the McGill Nanotools Microfab is covering 100% of the cost of operation for a third straight year.

The following chart summarizes revenues and billed hours per month for the FY 2012/13. We took a severe drop in revenues for Dec. 2012 – May 2013 mainly due to 2 factors:

- Christmas break (2 weeks, starting up early January)
- EBL system down mid January to the end of June due to the flood in the Wong building.

Revenues for the FY 2012/13 (total number of 56 PI) and 11/12 (total number of 50 PI):





[1] Details of user fee structure can be found at http://miam2.physics.mcgill.ca/?q=content/rates

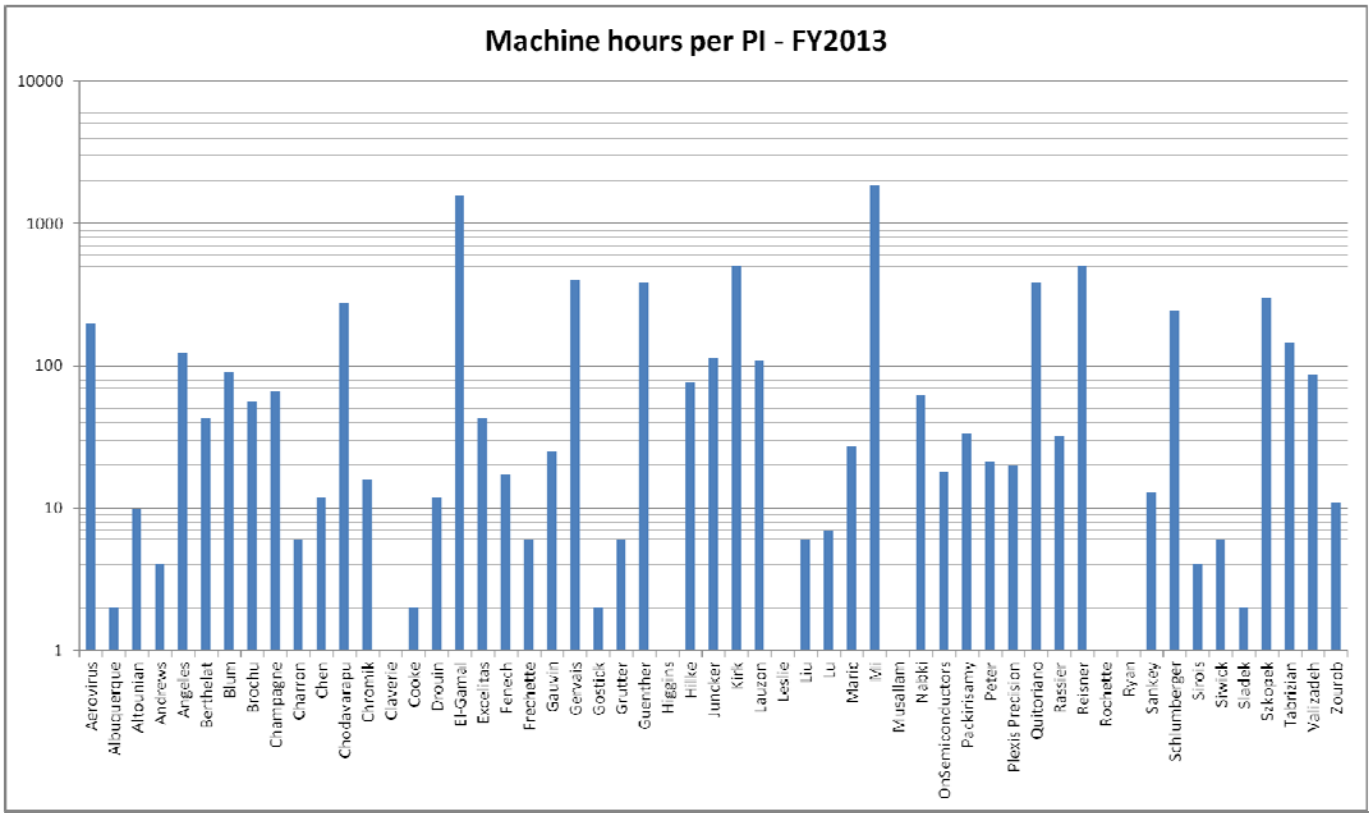
Usage

In 2012/13 the Microfab generated **7976 billable hours**, a 14% increase over last year with 7004 h. This is close to a threefold increase compared to 2007/08 (with a little more than 2700 billable hours).

The **55 PIs** sent a **total of 115 HQP** to work in the Microfab, compared to 50 PIs who sent a total of 107 HQP in FY 2011/12 – a 10% increase in the number of PIs and 7% increase in the number of HQP. On average, each HQP spent close to 70h (65 h in 2011/12) in the Microfab.

We have sustained the **number of major** users at 14 (14 in 2011/12, 11 in 2010/11), including two with more than 1500h. A major PI is defined as a PI who use the Microfab more than 100 h per year. Note that two major users are not McGill based (Guenther (U. Toronto), one company). Not all 2012/13 major users were in this category in 2011/12.

These numbers demonstrates that the user base of the Microfab is broad and stable; the Microfab clearly meets the needs of many users. This will ensure sustainability of its operation.



Total hours per PI for FY 2012/13. Note the broad, sustainable basis of major users with more than 100h.

Usage breakdown according to faculties:

The faculty of Engineering is the major user in terms of hours (~2/3 of total usage). Science and External users are similar, each about 10-20% of the usage by Engineering. Growth was observed for Engineering (22% or 948h), Science (32% or 274h), and External Academics (67% or 269h). Industrial usage remained ~ constant, a major user from Education did not use the fab this year due to successful termination of the project. The total number of PIs increased slightly by 12%.

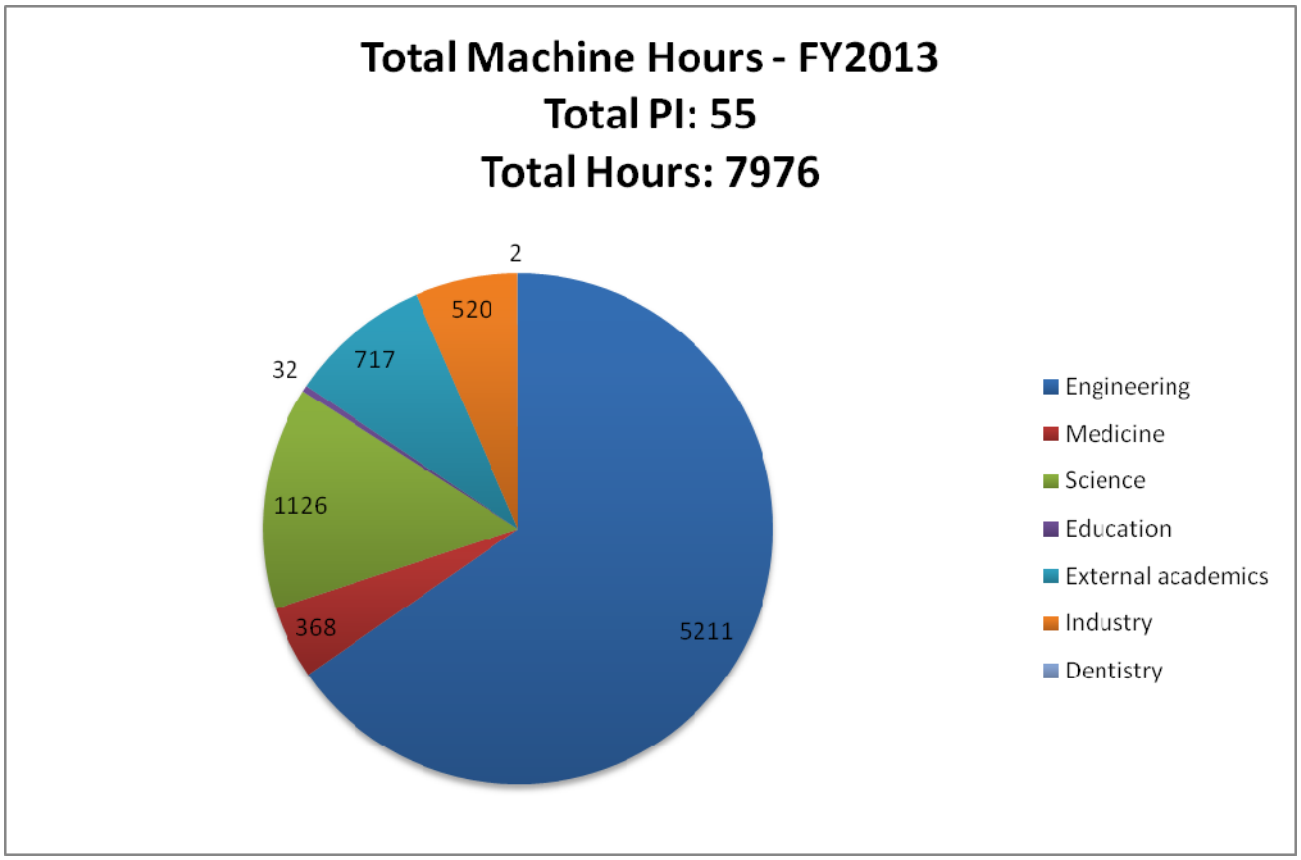
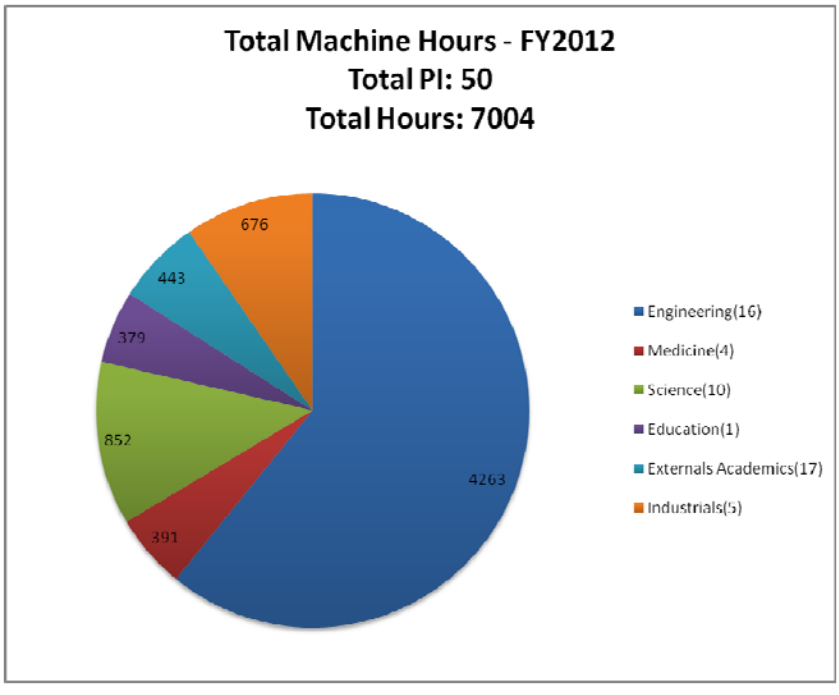


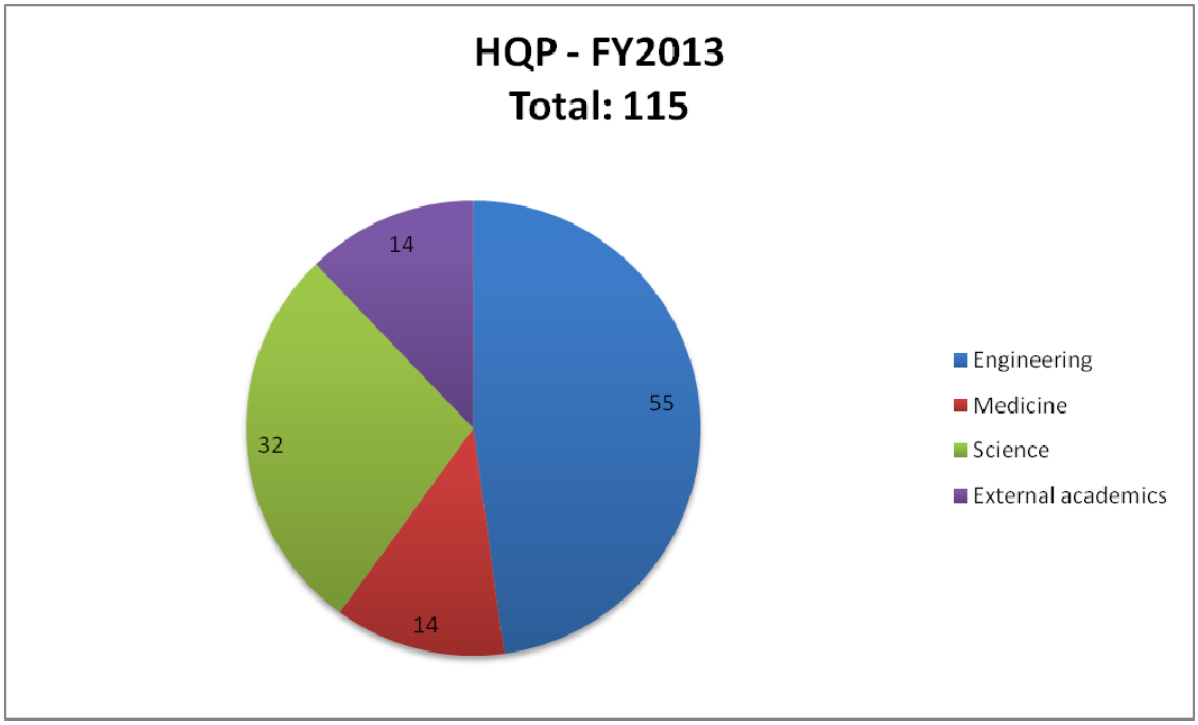
Figure 1: Breakdown of hours of Microfab facility usage for fiscal years 2012/2013 and 2011/2012. The number of principal investigators (PIs) for each category is also given in brackets. PIs affiliated with the Faculties of Engineering are major users, with Medicine, Science and external industrial usage also noteworthy.



The total number of HQP trained in the Microfab increased by 7% from 107 to 115 in 2012-13, thus stabilizing after a 42% increase two years ago. Roughly half these HQP are engineering students. In addition to these 105 HQP, staff from 3 industrial users directly accessed the fab.

It is noteworthy that for a 240 workday year (48 weeks of operation), assuming an 8 hour day and given the total of 7976h billed hours, **on average there were 4.2 HQP in the Microfab at all the times** (this is an increase from the 3.7 in 2011/12). This translates to more than 4 different processes being executed on a given day in the Microfab, a major challenge in terms of training, support and scheduling of equipment.

The overall number of HQP trained in the fab increased by 7% compared to the last period:



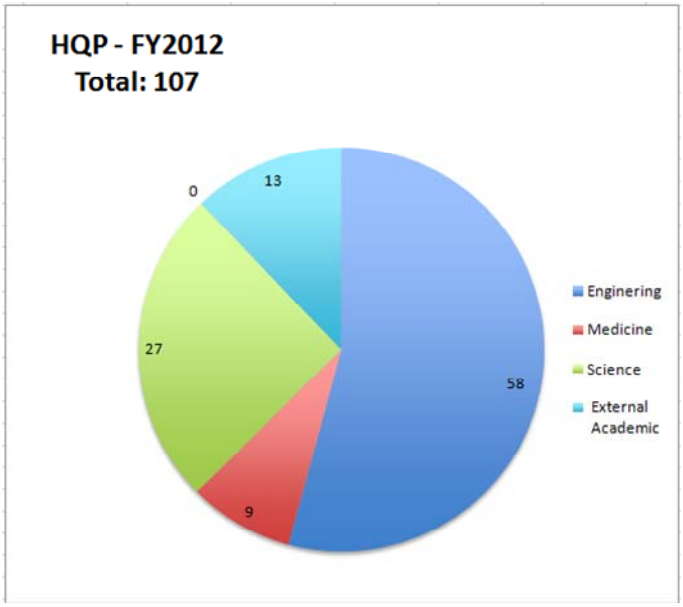


Figure 2: Number of academic HQP using the Fab for fiscal years 2012/13 compared to 2011/12, broken down by Faculty affiliation. The overall number of HQP trained in the fab increased by 7% compared to the last period.

External (non-McGill) Usage

In 2012/13 36% of all PIs were external, using the fab for a total of 1237h (16% of total usage): 14 academic (717h, 9%) and 6 users from 5 companies (520h, 7%).

External Academic users

Alexandre Champagne	Physics	Concordia University
M. Packirisamy	ECE	Concordia University
Pouya Valizadeh	ECE	Concordia University
Yves-Alain Peter	Eng. Physics	Ecole Polytechnique de Montreal
Frédéric Sirois	EC	Ecole Polytechnique de Montreal
Mohammed Zourob	EMT	INRS
Dominique Drouin	ECE	U. de Sherbrooke
Luc Frechette	Mech. Eng.	U. de Sherbrooke
Jérome Claverie	Chemistry	UQAM
Frederic Nabki	CS	UQAM
Frédéric Charron	Biochem.	Institut de recherches cliniques de Montréal
Marianne Fenech	Mech. Eng.	U. of Ottawa
Axel Guenther	Biomed. Eng.	U. of Toronto
Zhao Lu		CMC Microsystems

Industrial Usage

Companies which used the fab directly in 2012-13:

Aerovirus Technologies (Ste Hyacinthe QC) has a research contract with the fab to develop a prototype sensor.

PlexisPrecision (St-Laurent QC) has a service contract with the fab to characterize laser micromachined parts.

OnSemiconductors (Burlington ON) has a research contract with the fab for dry etching of a TiW/Al/TiW layer.

Excelitas (Vaudreuil-Dorion QC) has a service contract with the fab for plasma etching, metal and oxide depositions.

Schlumberger (Edmonton AB) has a service contract with the fab to fabricate microfluidic devices.

We observed that companies are not very interested in directly accessing the Microfab. A strong increase in academia-industry collaborations and partnerships leads to the conclusion that companies prefer to access the McGill Nanotools Microfab via collaborative mechanisms such as NSERC Strategic projects or in other partnership agreements with McGill researchers instead of directly using it. This is corroborated by informal and non-representative discussions with several companies: they are interested in the whole 'package': PI, HQP and access to excellent facilities.

The following companies have used the Microfab in 2012/13: (collaborating PI indicated in brackets)

MEMS-Vision Inc. is a spin-off company from McGill (Mourad El-Gamal).

Lockheed Martin Corporation (SPG with Zetian Mi)

Boston Microsystems (Research collaboration, Srikar Vengallatore)

Bombardier and Thales (industrial sponsors of a CRIAQ project entitled "Data Networks and Smart Sensors for Safety-Critical Avionics Applications". Mourad El-Gamal)

DALSA Semiconductor (Bromont) has committed $20,000 per year of funding as part of a NanoQuebec project entitled 'Integrated polymer electro-optic switches', (PI Andrew Kirk, with Mark Andrews), leveraging $66,667 per year of funding from NanoQuebec (2010-2012)

ICP Solar Technologies and Silonex Inc.
'Full-Solar-Spectrum InGaN Tandem Solar Cells on Si' (Z. Mi)

Outside, non-academic users

Similar to industrial users, several organizations sponsor applied research with a strong fab component:

Defense Research and Development Canada
'*Design and fabrication of InN nanowire photodiode detectors'* (Z. Mi, $100,000)

Sandia National Laboratories (USA):
'Nanoelectronics Experiments Using Coulomb Drag to Study Coupled One-Dimensional'
(G. Gervais, US$ 22,068)

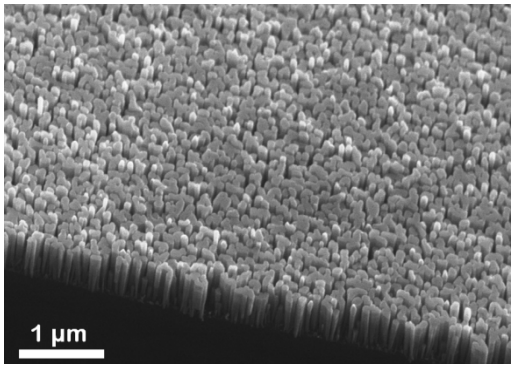
Major Success Stories

Some highlights and major achievements with key input from the McGill Nanotools Microfab.

Research

The research group of Zetian Mi is one of the major users of the Microfab. The group has had several notable achievements in 2012:

1. High efficiency phosphor-free nanowire white LEDs without efficiency droop:



Mi et al. have demonstrated that electron overflow in nanowire LEDs can be effectively prevented with the incorporation of a p-doped AlGaN electron blocking layer, leading to the achievement of phosphor-free white light emitting diodes that can exhibit, for the first time, virtually zero efficiency droop for injection currents up to ~ 2,200 A/cm^2. This work has identified and addressed one of the major obstacles of nanowire LEDs for applications in future high power phosphor-free, all-semiconductor based solid state lighting. Ref: Nano Lett., 12, 1317, 2012.

Figure 1: SEM image of high efficiency InGaN/GaN nanowire heterostructures on Si.

2. Demonstration of 1.55 µm InAs quantum dot tube lasers

Mi et al. report the achievement of a semiconductor tube laser that can operate in the optical communication wavelength range for applications in the emerging Si-photonics. Such nanoscale devices are fabricated from self-organized InAs/InGaAsP quantum dot nanomembranes through a strain-driven self-rolling mechanism using standard photolithography process. Under continuous wave optical pumping, the devices exhibit an ultralow lasing threshold of 1.26 μW, with multiple emission wavelengths in the S band of optical communications.

Ref: *Appl. Phys. Lett.,* **101**, 033104, 2012.

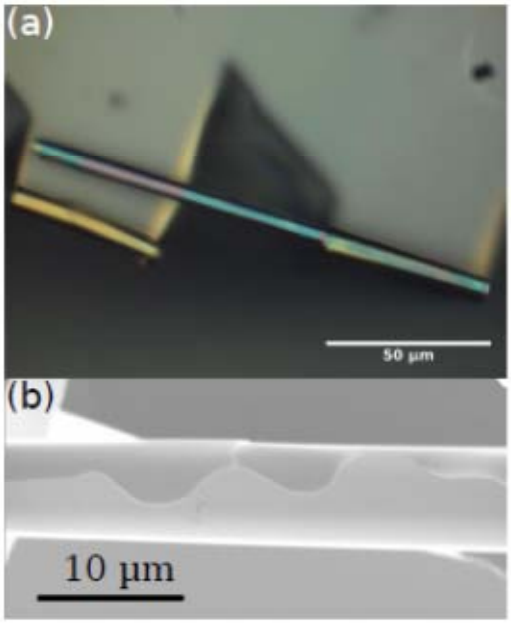


Figure 2: (a) Optical microscopy image of a rolled-up tube. (b) Scanning electron microscopy image showing a detailed view of the surface modifications on a different tube structure.

3. One-step overall water splitting under visible light using multi-band InGaN/GaN nanowire heterostructures

The conversion of solar energy into hydrogen via water splitting process is one of the key sustainable technologies for future clean, storable and renewable source of energy. Therefore, development of visible light responsive and efficient photocatalyst material has been of immense interest, but with limited success. Here, we show that overall water splitting under visible light irradiation can be achieved using a single photocatalyst material. The Rh/Cr_2O_3 core/shell nanoparticle decorated multi-band InGaN/GaN nanowire heterostructures can lead to stable hydrogen production from pure (pH~7.0) water splitting under ultraviolet, blue and green light irradiation (up to ~ 560 nm), the longest wavelength ever reported. At ~440-450 nm, the quantum efficiency is estimated to be ~ 13%, the highest value reported in the visible wavelength range. The turnover number under visible light well exceeded 73 in 12 hours. Detailed analysis further confirms the stable photocatalytic activity of the nanowire heterostructures. This work establishes the use of metal-nitrides as viable photocatalyst for solar-powered artificial photosynthesis for the production of hydrogen and other solar fuels.

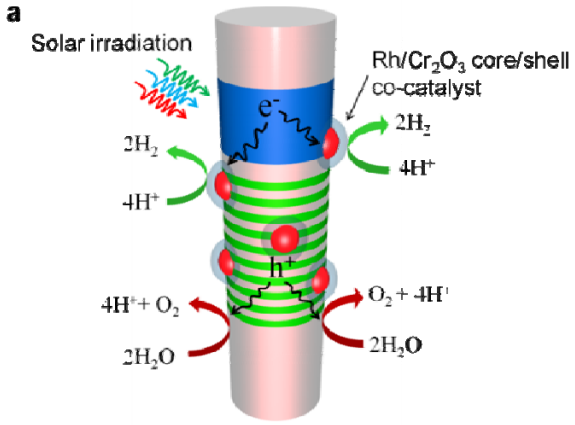


Figure 3: Schematic of the photocatalytic overall water splitting reaction mechanism on multi-band InGaN/GaN nanowire heterostructures.

Reference: Report of Invention, "High efficiency broadband semiconductor nanowire devices"

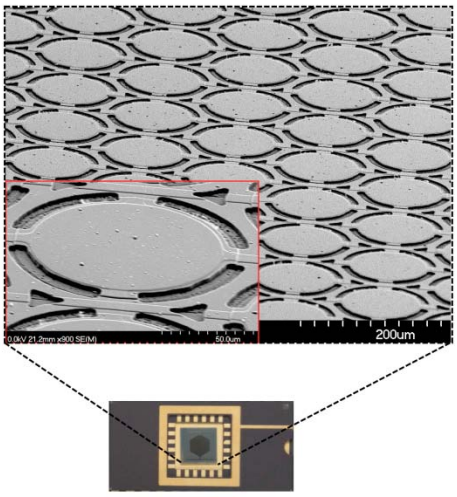
4. CMOS compatible capacitive micromachined ultrasonic transducers (Mourad El Gamal)

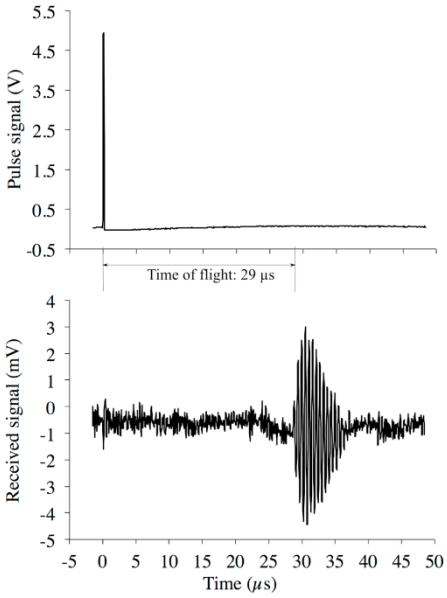
One of our major success stories in 2012 was the successful demonstration of fully functional and quite robust capacitive micromachined ultrasonic transducers (CMUT). What is unique about these CMUT's is that they use SiC as their main structural, and the fabrication process is fully CMOS compatible.

An SEM micrograph of a CMUT array is shown , along with the photograph of a test die wirebonded to a package.

The same CMUT can be used as a transmitter or receiver. The transmitter acts as a speaker, and the receiver as a microphone (but at 1.5 MHz of frequency).

The following plots show the result of exciting one CMUT by a narrow pulse, and the ultrasonic signal received by a second CMUT



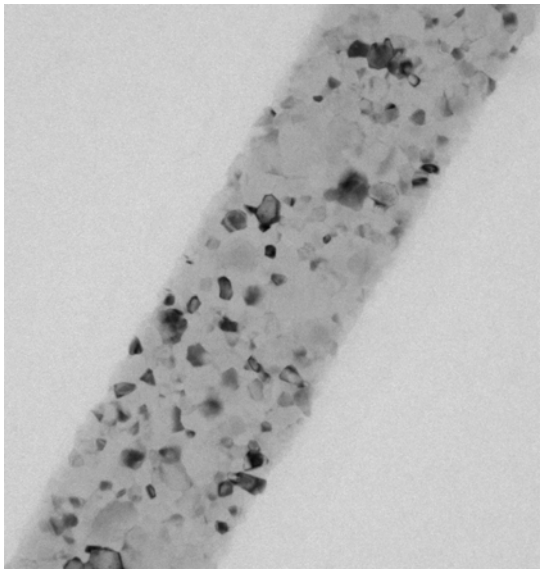


Ultrasonic transmission/reception has a wide range of applications in sensing and imaging. A highly miniaturized platform can be used in high quality localized medical imaging inside a human body. Another very interesting application is measuring gas flow in small tubes and pipes, as well as the detection of very fine cracks in surfaces.

A US provisional patent was filed, before a JMEMS paper was submitted and accepted in 2013.

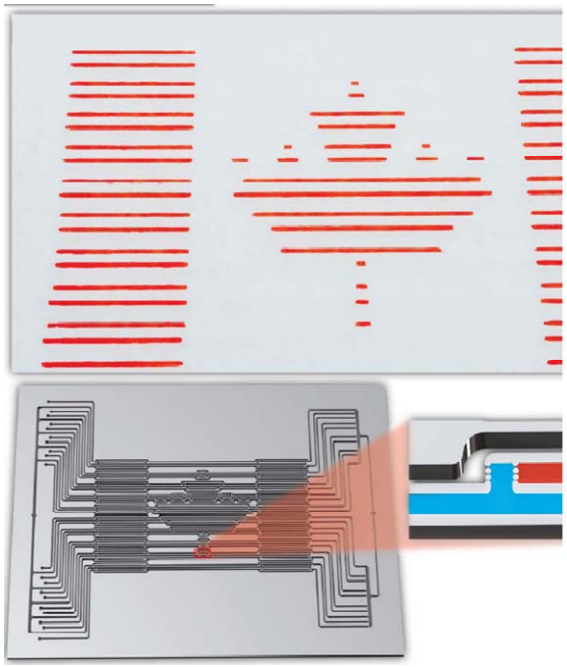
5. Measurement of Intrinsic Material Dissipation (Srikar Vengellatore)

Development of a microcantilever platform that led to the first measurements of dissipation and internal friction in nanocrystalline thin films and nanowires (disseminated via two papers in *Nanotechnology* and several invited talks). The NanoTools Microfab facilities enabled the creation of test platforms and devices. A new processing capability was established for integrating nanowires (and other nanomechanical structures) with MEMS by combining spray coating of electron-beam resist with a lift-off process implemented using electron-beam lithography and evaporation. The image shows a transmission electron micrograph of an aluminum nanowire (400 nm in width and 50 nm in thickness) integrated on a silicon nitride nanomembrane.



6. Fully automated flow chemistry system (Axel Guenther, U. of Toronto):

We have developed a fully automated flow chemistry system based on silicon fabricated devices. The technology was published in several papers. Later this year we will have some papers coming out that describe results for using this approach to screen for different types of solution-processed nano materials.



Oskooei A; Abolhasani M; Guenther A "'Bubble gate for in-plane flow control", Lab Chip, **13** (13), 2519-2527, 2013

Training

Noteworthy is that two of our recent graduates obtained positions in industries in Quebec taking advantage of their fab experience: K. Das, Ph.D. Mech. Eng. is now an Engineer at the MiQro Innovation Collaborative Center (C2MI), Bromont, QC and D. Neill, M.Eng. Mech. Eng. is employed as an Engineer at Rolls Royce Canada, Montreal, Qc. More details can be found in Appendix.

Roozbeh Safavieh won the Medtech Innovation award valued at $36K for his startup Sensoreal Inc. using microfluidic technologies developed in the microfab

Outlook

In the 2012 Outlook, the following objectives for 2012-13 were defined:

1. **Funding**: with the announced reduction of direct financial support by McGill we need to develop a long term financial plan. An essential part will be the expansion of services to the life science community, which will enable larger and more stable user income. Success in the current CFI VII competition will be a key element in addition to current discussions with the Montreal Neurological Institute on expanding services.
   The creation of ANANDA as a partnership with the Montreal Neurological Institute will expand our services to the life science community.
   The successful 11.3 M$ CFI funded Nanotools upgrade will enhance our services, including the necessary manpower associated with this expansion.
2. **Infrastructure**: Implement the CFI requested upgrade of the Nanotools infrastructure.
   Qualification of new tools to be done by summer 2014. Some new tools will be available before fall 2013 (e.g. UHF vibrometer, new RTA)
3. **Usage**: increase the usage by researchers from the life sciences by hiring dedicated manpower funded from current NanoQuebec support.
   Done: In the fall of 2012 Dr. Margaret Magdesian, a trained neuroscientist with hands-on experience in physics labs, joined the team. She is manager of ANANDA.
4. **Operations**: improve microfab operations at the administration, tool maintenance and training level in terms of efficiency and effectiveness.
   Ongoing by being responsive to user needs and requests. An example is the recent acquisition with bridge funding of an urgently needed replacement of the RTA.

In 2012-13 the McGill Nanotools Microfab objectives are:

1. **Implementation of CFI Nanotools upgrade.** One of the major objectives in 2013/14 will be to successfully upgrade the fab, allowing all users to be more productive and embark on new projects. The challenge will be to remain on budget, in particular for the renovations, and minimize the associated fab operation disruptions. In parallel, the gas handling system of the fab will be brought up to code. Fab staff will have to deal with planning, acquisition and commissioning of new equipment in addition to their normal services of training users, maintaining the fab operational and interacting with outside clients. It is planned to add 1-2 new staff, to be funded from the CFI IOF.
2. **Usage**: Validate the investment in ANANDA in terms of revenue, output and training.
3. **Operations**: The last 5 years have seen an important increase by a factor 3 in terms of usage hours (7976h in 2012/13 compared to 2708h in 2007/08). The corresponding usage intensity also went up by a factor 3: in 2012/13 there were on average 4.2 processes running at any given time compared to 1.4 five years ago. It is a reasonable to assume that 4.2 processes correspond to 4.2 HQP in the fab at any given time. The number of clean room staff only increased from 3 to

5 during the past 5 years. The current ratio of staff/processes = staff/HQP is 4.2/5 = 1.2 in 2012/13. Five years ago this ratio was 2.1. Since tool usage as well as the number of tools has increased staff needs to perform more equipment maintenance, and thus has relative less time to train and supervise the increased number of users running the processes. The decrease from 2.1 to 1.2 staff/processes is thus probably even larger. This ratio needs to be monitored, as it affects training capacity, process support, and safety. The observed higher intensity of usage by more users makes it necessary to hire at least one more staff to ensure sustained equipment uptime, consistent training, and safe facility operations.

4. The **limited space** of the Microfab is starting to become an impediment to further increase in usage and safe operation.

Appendices

A) Publications in 2012 that used some aspect of the McGill Nanotools Microfab

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[67] Luminescent Iridium(III)-Containing Block Copolymers: Self-Assembly into Biotin-Labeled Micelles for Biodetection Assays, K. Metera, K. Hanni, G. Zhou, M. Nayak, H. Bazzi, D. Juncker, and H. Sleiman ACS Macro Letters, 1, 954 - 959 (2012)

[68] Antibody Colocalization microarray: A scalable technology for multiplex protein analysis in complex samples, M. Pla-Roca, R. F. Leulmi, S. Tourekhanova, E. Moreau, V. Laforte, S. Goselin, N. Bertos, M. Hallett, M. Park, & D. Juncker, Molecular & Cellular Proteomics, 11, M111.011460 (2012)

- Highlighted in over 10 news outlets in Canada including: Montreal Gazette, Ottawa Citizen, Toronto Star, Global TV Toronto (at the 22 min mark), Vancouver Sun.
- Also featured in online news and scientific websites including: Voice of America Africa (April 7th, 2012 at the 16:30 mark, in French), McGill Alumni Magazine, McGill Newsroom,Science Daily,Futurity,Nanowerk, The Engineer Online, GenomeWeb, Technorati, Fierce Biomarkers, The Times of India, and Forest Science News (in Japanese)

B) Patents and Invention Disclosures

[1] *Microfluidic devices and methods for the extrusion of tubular structures*
McAllister A., Guenther A,
US Prov. Patent Application 61817720, April 30 2013

[2] *Skin Printer: Microfluidic Approach for Skin Regeneration and Wound Dressing*
Leng L., Ba Q., Amini-Nik S., Jeschke M., Guenther A.,
US Prov. Patent Application 61817860, April 30 2013

[3] *Benchtop Nanocrystal Processor*
Abolhasani M., Hassan Y., Kumacheva E., Scholes G. D., Guenther A.
US Prov. Patent App 61817443, April 30, 2013.

[4] *Microreactor Pen for Mass Transfer and Colloidal Materials Preparation*
Abolhasani M., Hassan Y., Kumacheva E., Scholes G. D., Guenther A.
US Prov. Patent App. 61817454, April 30, 2013.

[5] *Devices and methods for producing planar polymeric materials using microfluidics,*
Leng L., Zhang B., McAllister A., Wollard A., Radisic M., Guenther A.
PCT Application, 2012

[6] *Isotropic Accelerometer Strapdowns and Algorithms for Rigid-body Pose and Twist Estimation,*
Angeles, J. and Zou, T.,
Provisional Patent Application at USPTO under EFS ID: 13268626, Application # 61672366,

[7] *Methods and Systems for Magnetic Solid State Cooling*
G. Gervais, T. Szkopek and J. Guillemette
US #61/652,931(McGill ROI #12070 & #13007 combined).

[8] *Methods and Systems for Ultra-high Quality Gated Hybrid Devices and Sensors,*
G. Gervais, K. Bennaceur
US #61/737,391

[9] *Method of manufacturing tunable epitaxial InN nanowires and devices thereof*
Z. Mi, S. Zhao, K. Bevan, H. Guo, and D. Liu,
Provisional US patent application, filed on May 8, 2012.

[10] *GaN nanowires on silicon oxide*
Z. Mi and S. Zhao,
Provisional US patent application 61/728,310, filed on Nov. 20, 2012.

[11] *Universal microchip for detection separation, isolation and controlled attachment and spreading of cells*
T. Fatanat Didar, K. Bowey, M. Tabrizian

McGill ROI 12082, April 2012

[12] *Microelectromechanical bulk acoustic wave devices and methods,*
M. Elsayed, P. Cicek, F. Nabki, M. El-Gamal,
US Provisional Patent Application filed, October 2012.

[13] P*rocess for above-IC microfabrication of highly sensitive silicon carbide diaphragms with hermetically-sealed capacitive gaps,*
Q. Zhang, P. Cicek, F. Nabki, M. El-Gamal,
US Provisional Patent Application filed, April 2013.

C) Names and current position of graduated HQP

Undergraduate students (5):

David Morris (now M. Eng U. of Toronto)
Jana Chaaban (now M.Sc. at ETH Zurich)
Wayne Yang (now M.Sc. McGill)
Patrick Dupressoir (now undergrad engineering student, McGill)
Hamza Riaz (now RF Hardware Developer at Ericsson, Montreal)

Master and PhD students (16):

Daisy Daivasagaya – M. Eng. in Electrical and Computer Engineering,
Sales Engineer COMSOL Inc. Boston, Massachusetts USA
An Hu – PhD in Electrical and Computer Engineering,
Electronics Design Engineer at *Integrated Device Technology* (IDT) Corporation, Phoenix, Arizona, USA
Marie-Pier Côté, M.Eng. in Mechanical Engineering,
Engineer, Héroux-Devtek (Mirabelle, Qc).
Chenxu Shao, M.Sc.
Now doing a professional degree at Stanford.
M. Massicotte, M. Sci. in Physics,
now PhD student in Barcelona
E. Whiteway, M. Sci. in Physics,
now PhD student at McGill
Andra St Quentin, M.Eng. in ECE,
Engineer at L3 Wescam Inc, Ontario
Shouvik Mukherjee, M.Eng. in ECE,
Engineer at BIT Systems.
Hieu Nguyen, M.Eng. in ECE,
Postdoctoral research fellow, McGill University
Yuning Zhang, M.Sc. in Physics
PhD student at McGill
Rob Welch (M.Sc.in Physics)
Medical School (McGill)
Shahriar Al Imam, Ph.D. in Mech. Eng.,
PDF at SUNY Albany, NY.
K. Das, Ph.D. Mech. Eng;
Engineer at the MiQro Innovation Collaborative Center (C2MI), Bromont, QC.
S. Joshi, M.Eng. Mech. Eng.
Research Assistant at McGill University
D. Neill, M.Eng. Mech. Eng
Engineer at Rolls Royce Canada, Montreal, Qc
T. Saha, M.Eng., Mech. Eng.
Engineer with AMD semiconductors, Toronto, Canada

PDF and RA (4):

Dr. Pantcho Stoyanov (PDF): Fraunhofer Institute, Karlsruhe, Germany
Dr. Philip Roche (PDF): Research Associate, Jewish General Hospital, Montreal
Dr. Shamsul Arafin (PDF): Postdoctoral Research Fellow at Univ. California, Los Angeles
Dr. Saeed Fathololoumi (PDF): Engineer in Kotura Inc. Monterey Park, California

D) Grants and contracts

The total of ***new*** grants and contracts directly linked to the fab had a value of **$ 14,788,300.** This sum *excludes* NSERC Discovery Grants. This includes a total of $11,300,000 for the successful CFI LEF Nanotools 2 upgrade and 2 renewals of CRC 2 chairs with major fab components. A total of $2,395,800 new operating funds were obtained. Note: all $ values indicated below are the total values, even for multi-year grants.

Grants directly for the Microfab:

Tools for Nanoscience and Technology upgrade ('Nanotools II')
CFI Leading Edge Fund (LEF) Round VII
Grutter (PI) and 9 other fab users.
$11,300,000 (2012-2014)

NSERC:
3-Dimensionally integrated nanophotonic circuits on Si for terahertz-speed chip-level optical communications,
NSERC Strategic Project Grant, Z. Mi (PI), D. V. Plant, and A. G. Kirk,
$408,000

Chemical transformation and storage of carbon dioxide via solar-powered artificial photosynthesis on semiconducting nanowire arrays,
NSERC Strategic Project Grant, Z. Mi (PI), H. Guo, and K. Bevan,
$424,500

High power nanowire green lasers monolithically grown on silicon: Bridging the green gap,
NSERC Strategic Project Grant, I. Shih (PI), Z. Mi, and H. Guo,
$403,500

Three-dimensional laser engraver for micro-structuring of materials, surface patterning, micro-machining and rapid prototyping.
NSERC Research Tools and Instruments
F. Barthelat (PI), A. M. Kietzig, R. Mongrain, M. Rochette, and S. Vengallatore.
$92,417

Multidimensional separation isolation and characterization of circulating tumour cells
NSERC/CIHR Collaborative Health Research Projects
David Juncker
$ 552,250 (2013-2016)

FRQNT:
Materials for Bioactive and Biocompatible Neural Implants
FRQNT - Projet de Recherche en Equipe,
Lenore Beitel (PI), Vamsy Chodavarapu, Janet Henderson, Sam Musallam, Mesoporous,
$148,000 (2012- 2015)

Graphene Nanofluidics
FRQNT Team grant (PI: Michael Hilke)
$120,000 (2012-2014)

Études thermoélectriques dans des nanostructures de carbone dopées
FRQNT Équipe (PI: R. Martel, co-I: D. Menard and T. Szkopek),
$123,000 (2012-2015)

Single Crystal Diamond: A New Material for Optomechanical Devices
FRQNT New Researcher
Jack Sankey
$40,000 (2012-14)

Automated Robotic Microinjection of the Worm C. Elegans,
FQRNT New-Researcher Program,
X.Y. Liu,
$40,000 (2012-14)

Varia:
Experimental Optomechanics
Jack Sankey, CRC Tier 2 (new)
$500,000 (2012-1017)

Nanoscale Electronics
Thomas Szkopek, CRC Tier 2 (renewal)
$500,000 (2012-2017)

Quantum Materials and Devices in the MicroKelvin Regime
CFI New Initiative Fund (NIF), J. Folk (PI) UBC
$1.67 Million (2012-2014)
Team equipment grant with Josh Folk (UBC) and four other co-applicants.
G. Gervais' share, ~ 5% = $83,500

Design and fabrication of InN nanowire photodiode detectors,
Defense Research and Development Canada,
Z. Mi,
$100,000

Long-wavelength infrared photovoltaic devices using novel InGaN/GaN dot-in-a-wire nanoscale heterostructures on Si substrates,
Lockheed Martin Corporation,
Z. Mi,
$150,000

Blood-based protein test for early detection of breast cancer using antibody colocalization microarrays
Canadian Cancer Society. Program: CCS Innovation Grant

David Juncker
$190,000 (2013-15)

Low cost Microchip for Point of Care high Sensitive Assays
Mitacs Accelerate program
David Juncker
$8,500 (2013)

A Low-Cost, Paper-Based Diagnostic Device for Point-of-Care Immunoassays in Resource-Limited Settings
Stars in Global Health Program, Grant Challenge Canada,
X.Y. Liu (PI) and M. Thuo
$100,000

Cavity Coupling Gradient and Torsional Optomechanics
INTRIQ Funding.
Jack Sankey
$26,000

An Automated Microfluidic System for High-Throughput, Worm-Based Drug Screening,
McGill Collaborative Development Fund
X.Y. Liu (PI) and S. Hekimi
$15,000

Artificial Muscles and Molecular Machines: Building Blocks of Biomimetic Micro/Nanosystems.
McGill Collaborative Research and Development Fund.
S. Vengallatore (PI) and D. Rassier.
$15,000

Quantitative experiments and stochastic modelling of growth cone navigation in controlled nanodot environments
David Juncker
McGill University – Imperial College of London Funding
$22,700

Artery-on-a-Chip for drug development
Lilly Research Award Project
Axel Guenther (U. of Toronto), co-PI: Steffen-Sebastian Bolz, Dept. of Physiology, U of T,
$150,000 (2012-2014)

Skin Printer
Connaught Innovation Award
Axel Guenther (U. of Toronto) PI, Dr. Marc Jeschke, Sunnybrook Health Sciences Centre,
$100,000 (2013)