Myfab Report 2019

Myfab - The Swedish Research Infrastructure for Micro and Nano Fabrication
www.myfab.se

INTRODUCTION

Myfab, founded in 2004, is a national facility since 2010 and is Sweden's open-access research infrastructure (RI) for micro and nano fabrication with four cleanroom laboratories: Myfab Chalmers, Myfab KTH, Myfab Lund and Myfab Uppsala.

Myfab is the best possible environment for the development and fabrication of materials and device structures for advanced research in physics, materials science, nanoscience, chemistry, life sciences and nanoelectronics in Sweden. From the Myfab environment 2960 peer-reviewed publications and 227 PhD students has emerged 2016-2019, which demonstrate Myfab's capability to provide the best possible environment for the development and fabrication of materials and device structures for advanced research in physics, materials science, nanoscience, chemistry, life sciences and nanoelectronics in Sweden.

Myfab is the place where synthesis – or creation – of new materials, structures, devices and miniaturized systems on the nanoscale are made. Research at Myfab is multi- and cross-disciplinary, and the birthplace of ideas and the playground for their realization. Myfab is the starting point for value chains, where devices are integrated as key enabling components in a system.

Myfab brings together Sweden’s leading nanofabrication labs under a common umbrella, creating a national resource that makes a permanent staff member of 78 people (63 full-time equivalents), a total of 5400 m^2 of clean room area, more than 700 tools and processes openly available to researchers around Sweden and internationally, with the aim of ensuring Sweden's competitiveness in important research areas. In 2019 the lab had 836 unique users.

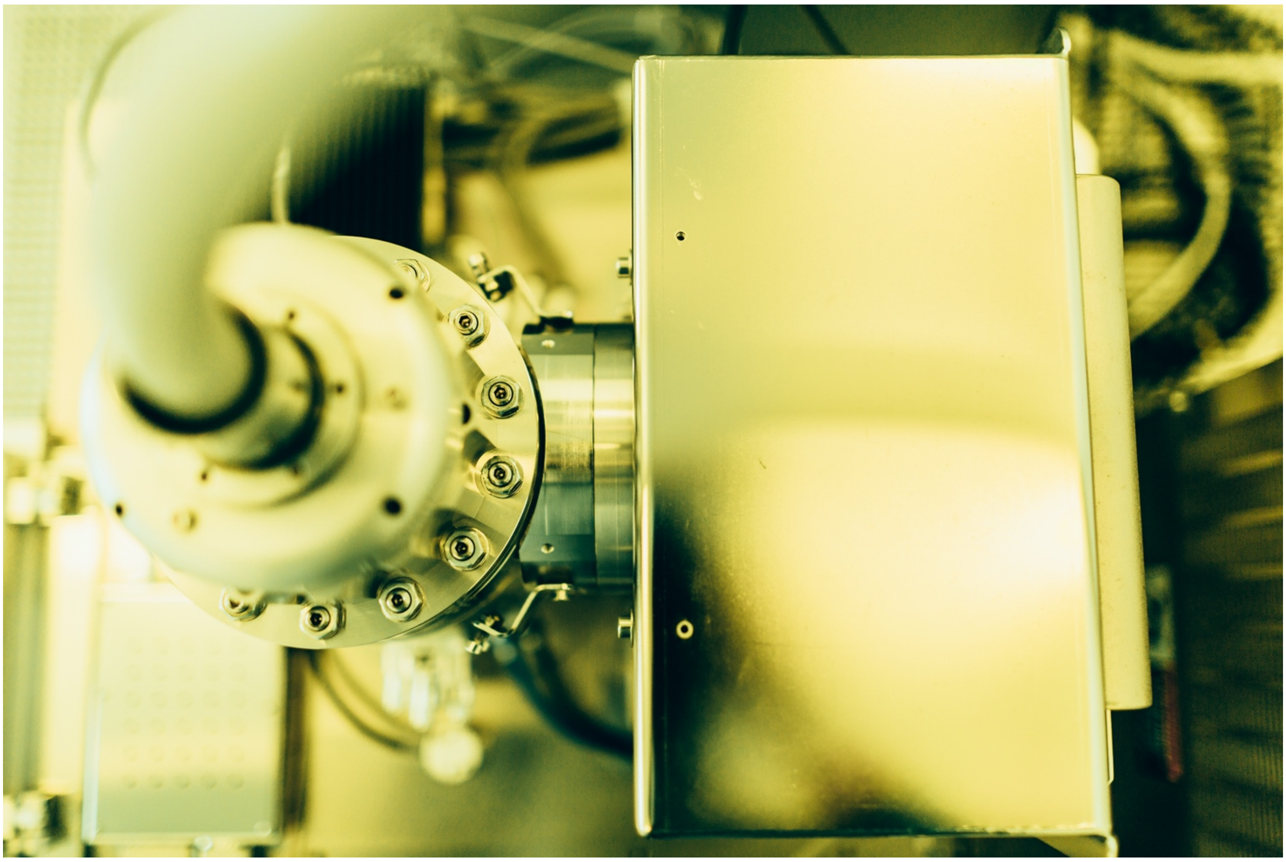
We offer charge based user access with practically no waiting time to experienced and new users, from academic institutions and industry. Myfab’s clean-room staff and expertise serve the users by developing and maintaining processes and tools, and by providing educational courses, process advice and support.

Further, Myfab is part of the Nordic Nanolab Network, where management, experts and users collaborate extensively in improving operations, process development, tool maintenance, user services, problem solving and by arranging common user meetings.

Myfab's distributed research infrastructure (RI) offers both the flexibility needed to advance state-of-the-art science and technology, as well as a quality assured environment for small and medium size manufacturing for spin-off companies and Small and Medium Sized Enterprises (SMEs). Today more than 100 organisations use Myfab, 85 of them are companies. During a 5-year period, typically 20 – 30 start-ups emerge from the environment.

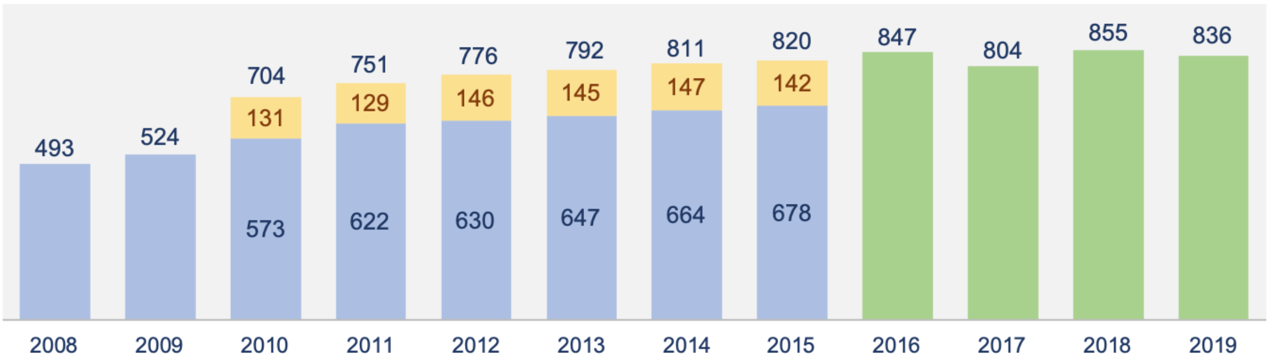
Myfab has set the standard in Europe for efficient user access, follow-up and planning through our operations practices supported by the tailor-made Myfab LIMS system. Myfab LIMS itself, is continuously developed through a community formed by Myfab and five other national RI's in Finland, Norway, Ireland, France and Portugal.

Being Sweden's national research infrastructure for micro and nanofabrication, Myfab attracts a vast majority of Sweden's micro- and nanotechnology researchers and entrepreneurs within a wide range of fields.



Myfab LIMS was introduced at all Myfab laboratories in 2008, and over the twelve years since it has assisted users to access to the whole infrastructure and provided important information to management for both operations and strategic development of the infrastructure.

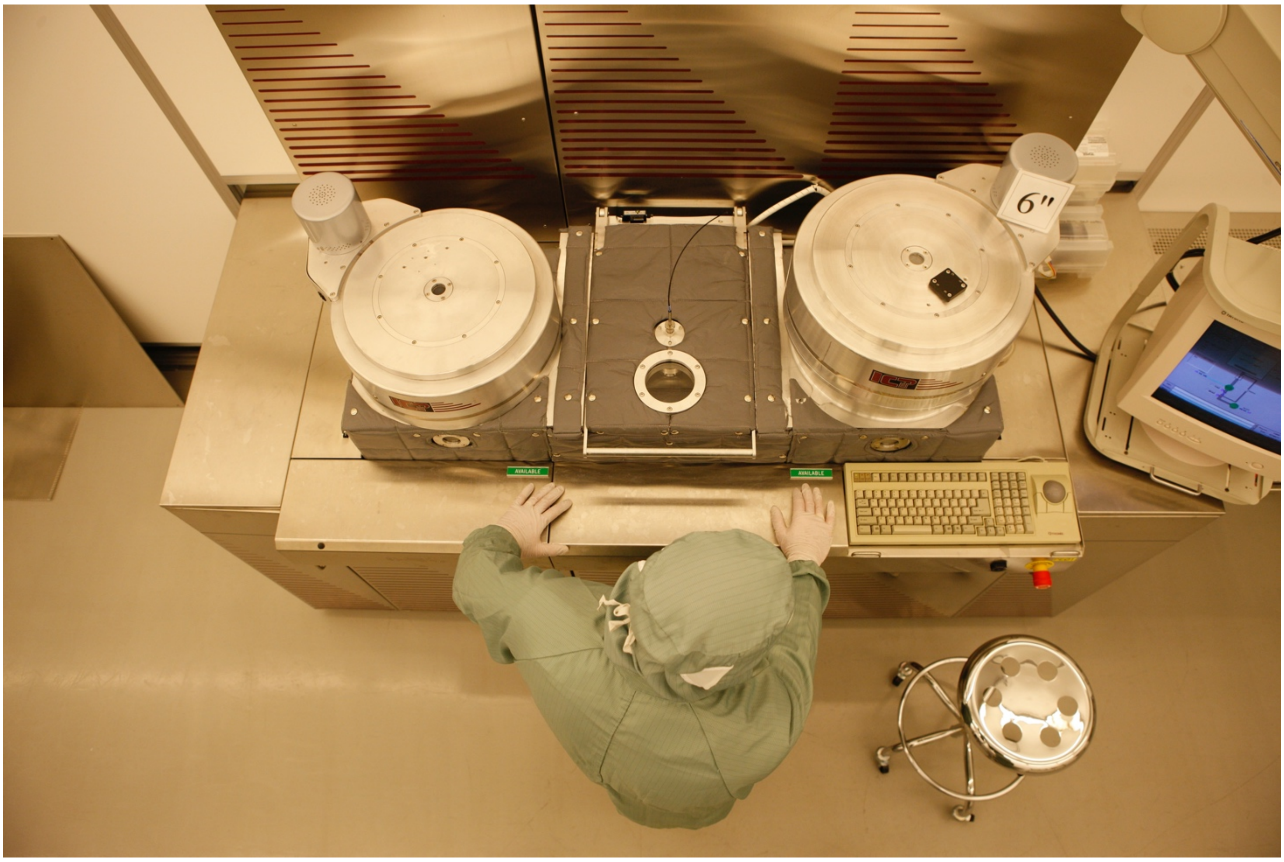
From its statistics, we learn that in 2019, 714 (85 %) users come from academia and 122 (15 %) were commercial users from either industry or research institutes. The total number of booked tool-hours was 187017. New and potentially returning users, with no previous experience from Myfab, are invited to apply for funding for their first project through *Myfab Access*.



***Myfab statistics – from Myfab LIMS**: top: number of active users 2008 – 2019. Myfab Lund started using Myfab LIMS in 2010; their corresponding number of active users is presented in yellow on top of the blue bars for 2010 – 2015. The number of booked hours ranges from 175 000 – 200 000 per year during the last decade.*

DEVELOPMENT

Myfab continuously develop the distributed research infrastructure through collaboration in-between the four national laboratories. The collaboration is a natural part of operation and major meetings are typically arranged as lunch-to-lunch workshops where current operational tasks as well as long-term planning and problem solving is addressed. We have learned that we gain both quality and speed in this process through collaboration with similar infrastructures who have similar goals as Myfab and since more than five years we have extensive collaboration with the corresponding national research infrastructures in the Nordic countries. The Nordic countries have many similarities and we have many synergies by joining forces, therefore essential parts of the development work has been carried out in collaboration our Nordic partners. Not only do we learn best practices from each other, we create a gradually more efficient and attractive regional environment which spans the access and billing models, user support, expert knowledge etc. Planning of Myfabs strategic development is described in the application to the Swedish Research Council for 2020 – 2027, and an extensive amount of work involving operational management, the owner group and the steering group has been carried out during 2019.



Myfab LIMS

We have continued to develop both the software and the user community. During 2019 the UPV fab at the Polytechnic University of Valencia, Spain, joined the user community. The development efforts can be divided into two roughly three equal parts: around 30 minor improvements and new features, continued work on the process manager module that is at a stage where the user community can have a first test, and a fairly cumbersome server move. The server host closed the Gothenburg facility so besides a planned move to an upgraded server we also had to move our server to a facility in Stockholm. For the future we have identified at least eight larger packages to be developed. We will in 2020 arrange a Myfab LIMS user community meeting in order to do a common prioritization of this work.

The Nordic Nanolab Network

Myfab is part of the Nordic Nanolab Network (NNN) which encompass active collaboration by the management, experts and users of the national nanofabrication research infrastructures in the Nordic countries. NNN is most important for the development of all twelve laboratories involved, and is the leading regional network in Europe. During 2019, NNN made plans to further develop NNN towards a Nordic Nanolab Research Infrastructure (NNRI) by planning activities to further increase the collaboration and creating an almost "seamless" environment for users offering "fast track" access and expert support to all laboratories. Toward this goal, we intend to start projects to promote user mobility ("fast track"), organize routines for sample/wafer handling, active/economical support to users for visits in-between laboratories and not the least initiate a coordination process to establish competence and technology hubs with different profile, optimized for our Nordic users. To boost the evolution, we have applied for funding from NordForsk.

The second Nordic Nanolab User Meeting (NNUM'19), hosted by DTU Nanolab was arranged 7 – 8 May in Copenhagen. The meeting which attracted about 260 visitors from all five Nordic countries has a user perspective and the focus is to present the various technologies that the nanofabrication infrastructures in our region offer. Central to the program are the tutorials, where lectures are given by the Nordic Nanolab Expert Network. In addition NNUM'19 comprised four invited presentations from given by international experts, a poster session, guided cleanroom tours, and a conference dinner.

The Nordic Nanolab Expert Network (NNEN) consists of expert groups with members from the Nordic countries and organized in five topical areas: dry etching, thin films, lithography, characterization (in cleanrooms) and facility management. Each NNEN technology group has about 20 active members and meets twice per year with lunch-to-lunch meetings. The NNEN activities is a very efficient way of promoting staff competence development in the most relevant areas for a research infrastructure and its users.

EuroNanoLab

Myfab is part of EuroNanoLab and was one of the co-founders during spring 2016. Today the EuroNanoLab consortium consists of the national research infrastructures of fourteen countries and one international organisation: the Czech Republic, Estonia, Finland, France, Germany, Italy, Latvia, Lithuania, the Netherlands, Norway, Portugal, Romania, Spain, Sweden and the International Iberian Nanotechnology Laboratory, with a total of 44 cleanroom laboratories. The number of participating research infrastructures has almost doubled during the last year, and work with a design study to be submitted to the ESFRI road-map update has been on-going intensively during 2019.

European Nanofabrication Research Infrastructure Symposium 2019 - ENRIS’19

The second ENRIS conference was arranged by NanoLab NL at the University of Twente in Enschede, the Netherlands during Sunday 18 June – Tuesday 20 June 2020 (https://www.enris2019.com) and attracted 160 visitors and exhibitors from 27 countries. The initiative to start ENRIS was taken by the Nordic Nanolab Network in collaboration with EuroNanoLab. ENRIS is the European symposium for staff, experts and researchers working in or using the results from nanofabrication laboratories. The first ENRIS was arranged by NorFab at NTNU in Trondheim (https://www.ntnu.edu/nano/enris2017) in conjunction with NNUM’17 7 – 8 May 2017, and next event will be hosted by RENATECH at the Centre for Nanoscience and Nanotechnology (C2N, CNRS), Paris-Saclay University 14 – 17 June 2021 (https://www.sciencesconf.org/browse/conference/?confid=10251).

NODE ACTIVITIES

Myfab Chalmers

During 2019 we had a record high activity with 208 users booking over 71 000 hours of tool usage. The activity was high for both academic and commercial users, the latter with doubled income, resulting in our best financial result ever with a surplus of 11 MSEK. This will immediately be reinvested in new process tools.

During the second half of 2019, we have together with the user community, developed a first draft of an investment plan. The plan covers five years of tool/system needs (cost around 140 MSEK), and a fifteen-year financial overview with a total investment budget of 285 MSEK. With these long-awaited investments, we will be able to go from an average age of our tools of over 15 years, towards an average age of 10 years.

The alternation of generations in the lab staff will continue during 2020 with three retirements that needs to be replaced. In addition, we will increase the number of technicians with one position to be filled.

Myfab KTH

Myfab KTH consists of two cleanroom facilities. The Electrum Lab is operated in collaboration with the industrial research institute RISE, and the Albanova Nano Lab in collaboration with Stockholm University. Both laboratories are recognized as "KTH Infrastructures", and are hence eligible to apply for funding from KTH for new tools.

Albanova Nano Lab has made a major change in leadership, by introducing Vladislav Korenivski as new Lab Director after David Haviland and Erik Holmgren as new Lab Manager, succeeding Anders Liljeborg.

The Albanova laboratory has installed two new major tools; an Oxford EDX system at the FEI SEM and a KLA surface profilometer, both sported by the KTH infrastructure grants.

Electrum Lab has employed a new staff member, Sven Valerio, with special focus on chemistry and safety. One of his undertakings has been to improve the working procedures in the wet chemistry lab, both regarding safety and cross contamination.

New tools are a Wire Bonder and a Critical Point Drier (the latter supported by the KTH infrastructure grant). For the lab operations, a new system for hydrogen detection has been installed, and the capacity for DI water production has been considerably increased.

Many of the commercial users at Electrum are expanding activities and inquire for increased lab space, both in the cleanroom and in non-cleanroom labs. Simultaneously, some of the academic user groups are planning to leave Electrum for Albano during 2020.

Electrum Lab is covered by the regulations on potentially dangerous operations. Supervision in accordance with the Act on Protection against Accidents has been performed and the lab is now obliged to renew the risk analysis with regard to the handling of poisonous and flammable gases, and to develop the support to the Fire Service in the event of an accident.

The CMP (Chemical Mechanical Planarization) process, established within the SSF research infrastructure fellow project "CMP Lab", is open for external users. The project success was presented at a local workshop on March 29, at the NNUM in Copenhagen, May 7-8, and at the ENRIS in Twente, June 16-18, in order to attract new users.

Myfab Lund

In 2019, Myfab Lund had 142 active users from Engineering, Natural Science and Medical Faculties of Lund University, as well as from other universities and seven commercial companies. There were 34 new users who got the introductory training for getting access to Myfab Lund. The lab users booked over 51 000 hours of tool time, which has been more or less stable in over the last 3 years indicating that the lab has reached capacity for the lab area that is available.

Myfab Lund has been actively planning for a new clean-room facility and in March 2020 it was announced that the Dean of Lunds tekniska högskola (LTH) has commissioned a building contractor to carry out a market survey followed by a procurement of the new Myfab Lund Nano Lab at Science Village, Lund.

There was ongoing and clear improvement of the equipment status in the lab and during 2019, when the following equipment was installed: Zeiss Gemini FEG SEM 500 with EDS and EBSD capability; TEMESCAL e-beam evaporator; 2 APEX SLR ICP RIE (Cl and F based); Rovak Flash Lamp Annealer; Tepla Microwave Plasma System; Sun Simulator and a Bentham PVE300 Photovoltaic QUE. Additional tools have been awarded grants and will be installed in 2020.

In 2019 there were also some changes to the organization: Head of Lund Nano Lab, Maria Huffman, moved on to a new opportunity in May 2019 and was replaced by Luke Hankin in August 2019. There were 2 additional hires for a research engineer with specific chemical expertise (Natalia Volkova) and an opportunity arose to hire a second research engineer with specific expertise in semiconductor hardware (Sung Youn Ju).

Myfab Uppsala

After a record user influx during 2018 (average two new users every week), the flow was somewhat reduced but the number of charged users remained above 400 during 2019. After some staff reductions (mainly retirements) followed by recruitment and replacement efforts, the chemical crew has been successfully restored but there is a remaining deficiency in some key technical competence areas.

A new FIB (focused ion beam) was delivered before the end of the year and other investments include a tool for photo- / electroluminescence and a simple table-top sputter equipment. Some older tools (one ICP-DRIE and two PVD systems) in excellent mechanical condition have been upgraded with new control electronics, software and additional hardware. However, the annual investment procedure, based on proposals and co-financing, was cancelled due to uncertainty about the economic situation.

The cleanroom disposition has been slightly altered, with a smaller (and cleaner) core processing area and a separate coverall entrance.

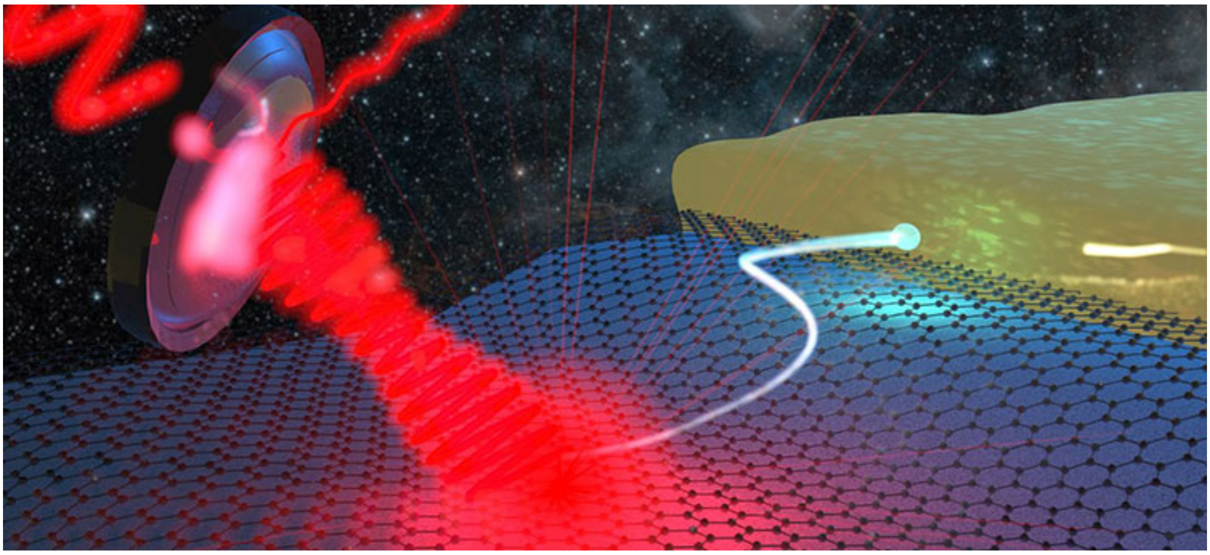
At the end of the year, the Department of Engineering Sciences (host for Myfab Uppsala) was divided into three smaller departments, with the Department of Materials Science being the new host for Myfab Uppsala. After this split, four major departments (Materials Science / Electrical Engineering / Physics / Chemistry) are the main stakeholders in Myfab Uppsala.

SELECTED USER SUCCESS STORIES

Myfab serves users from academy and industry who are active within a wide range of scientific areas and technology areas. In this section we briefly present a selection of our users' extraordinary achievement during 2019.

Graphene detector can revolutionize space telescopes

Beyond superconductors, there are few materials that can fulfil the requirements needed for making ultra-sensitive and fast terahertz (THz) detectors for astronomy. Chalmers researchers have shown that engineered graphene adds a new material paradigm for THz heterodyne detection. According to the theoretical model, this graphene THz detector has a potential to reach quantum-limited operation for the important 1-5 THz spectral range. Moreover, the bandwidth can exceed 20 GHz, larger than 5 GHz that the state-of-the-art technology has to offer. Another crucial aspect for the graphene THz detector is the extremely low power needed for the local oscillator to achieve a trustable detection of faint THz signals, few orders of magnitude lower than superconductors require. This could enable quantum-limited THz coherent detector arrays, hence opening the door to 3D imaging of the universe.



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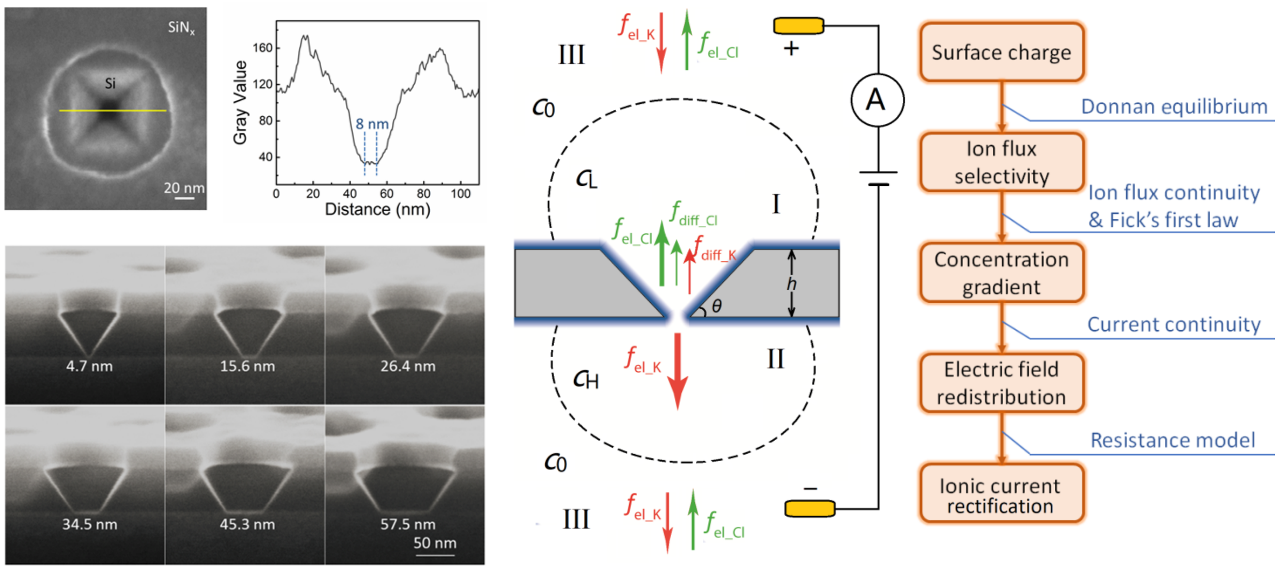
https://www.chalmers.se/en/departments/mc2/news/Pages/Graphene-sets-the-stage-for-the-next-generation-of-THz-astronomy-detectors.aspx

Rectification of ion and molecule transport in solid-state nanopores

Solid-state nanopore technology presents an emerging single-molecule-based analytical tool for the separation and analysis of nanoparticles. Based on a recently developed unique nanofabrication process at Myfab Uppsala, silicon-based truncated pyramidal nanopores with the critical dimension measuring down to sub-5 nanometre were manufactured.



Left: *Top-view SEM image of a small TPP (left) with its side length of the square base measured using the image greyscale analysis (right). Cross-sectional SEM images of TPPs with their side length of the square base measuring from 4.7 nm to 57.5 nm.*

Right: *Schematics of the fundamental processes pertaining to the ionic current rectification in nanopores displaying the causal chain from the surface charge to the ionic current rectification.*

This allowed for a systematic study, experimentally and theoretically, of the transport of ions and molecules through the geometrically asymmetric nanopores. Rectification in the frequency of protein translocation was found and it depended on the size difference between the nanopore and the translocating protein. The maximum rectification factor achieved was around 10. Numerical simulations revealed the formation of an electro-osmotic vortex in such asymmetric nanopores. The vortex-protein interaction was found to play a decisive role in rectifying the translocation in terms of polarity and amplitude. The asymmetric nanopores were also exploited for protein translocation without external bias, a so-called autogenic phenomenon. The translocation was instead driven by an ion concentration gradient. Finally, by clarifying the causal chain starting from the presence of surface charge, an analytical model for rectification of ionic current in asymmetric nanopores was proposed.

References

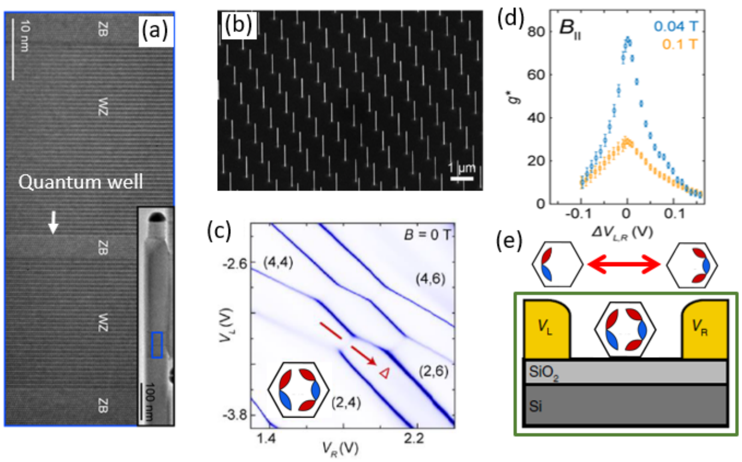
S. Zeng*, C. Wen*, P. Solomon, S.-L. Zhang, Z. Zhang, "Rectification of protein translocation in truncated-pyramidal nanopores", Nature Nanotechnology 14, 1056-1063 (2019). *Equal contribution of these authors.

2C. Wen, S. Li, S. Zeng, Z. Zhang, S.-L. Zhang, "Autogenic analyte translocation in nanopores", Nano Energy 60, 503-509 (2019).

C. Wen, S. Zeng, S. Li, Z. Zhang, S.-L. Zhang, "On rectification of ionic current in asymmetric nanopores", Anal. Chem. 91, 14597-14604 (2019).

Electrical control of spins and giant g-factors in ring-like coupled quantum dots

Development of quantum technologies is expected to significantly impact a large number of application areas such as computation, communication, encryption and sensing. The ability to prepare, detect and control a quantum state is essential to this technology. In recent work we discovered a new approach to manipulate electron spins by coupling two strongly confined quantum dots (QDs) in two separate points.



(a-b) Electron microscopy of MOVPE-grown InAs nanowires having an axial quantum well formed by in-situ control of the InAs crystal phase. (c) The meeting point of two orbitals (2nd and 3rd) between a left and a right QD formed within the quantum well. (d-e) Quantum ring states form exactly at the meeting point. The large orbital contribution to the g-factor from the ring can be quenched by electrostatic detuning of the orbital alignment.

This results in quantum rings which are exceptionally sensitive to both electric and magnetic fields, and where the Landé g-factor can be manipulated from 80 to 0 when quenching the ring with a small electric field. The quantum ring structures are formed during metal-organic vapour phase epitaxy of InAs nanowires grown from gold seeds patterned by electron beam lithography (EBL) and evaporation. Control of the InAs crystal phase during the nanowire growth allows formation of an axial quantum well accessed by two tunnel barriers. A set of electrodes are fabricated to the nanowires using EBL and metal lift-off, which allows the quantum well to be split into two QDs. Due to surface accumulation of electrons, the QDs couple in two points along the nanowire circumference and quantum rings form. We predict that this discovery will provide new opportunities for spin-based qubits, and spin filtering.

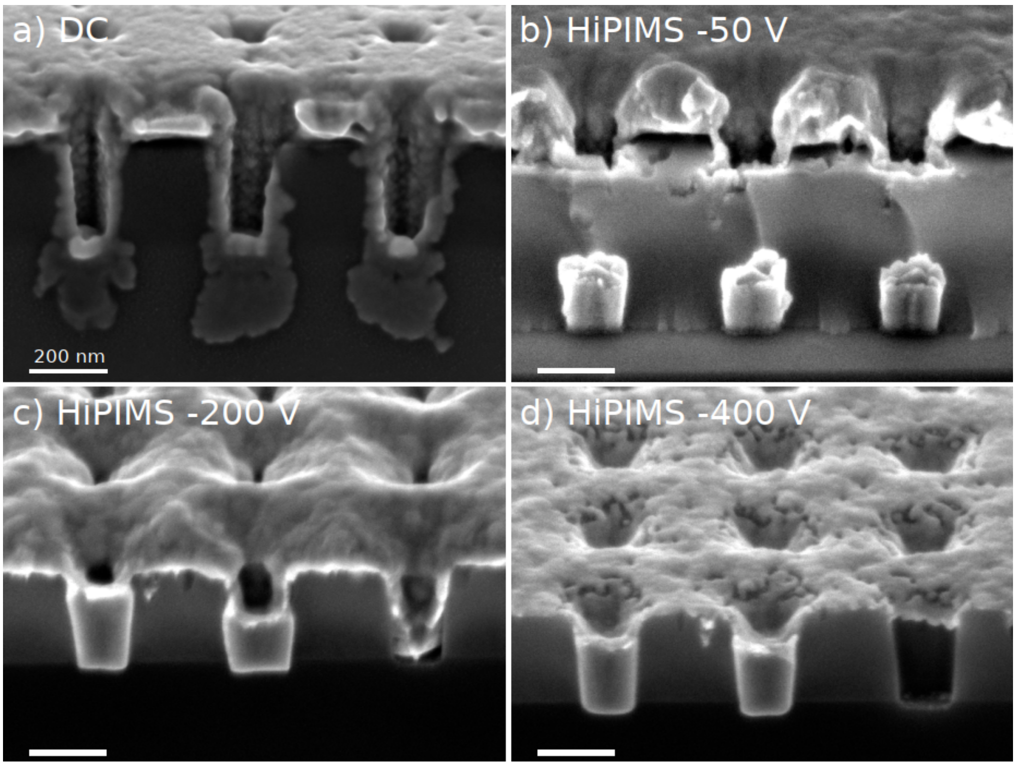
Reference

Electrical control of spins and giant g-factors in ring-like coupled quantum dots. / Potts, H.; Chen, I.–J.; Tsintzis, A.; Nilsson, M.; Lehmann, S.; Dick, K. A.; Leijnse, M.; Thelander, C. In: Nature Communications, Vol. 10, No. 1, 5740, 16.12.2019.

https://doi.org/10.1038/s41467-019-13583-7

Controlling growth of metals in an ionised deposition

Increasing demands on materials for nanoscale semiconductor devices require new approaches. For instance, shrinking dimensions of interconnects call for alternative metals than copper. We have shown that ultrathin Co films become much more conductive when deposited with Co ions instead of Co atoms. Deposition with Co ions leads to much denser films and reduces the surface and interface roughness [1]. Using ions improves also deposition inside nanosized holes [2].



Deposition inside via holes is hugely improved when energetic ions are used (d) in contrast to neutral atoms (a).

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Lukas Jablonka, Pavel Moskovkin, Zhen Zhang, Shi-Li Zhang, Stéphane Lucas, Tomas Kubart, "Metal filling by high power impulse magnetron sputtering", J. Phys. D 52, 365202/1-9 (2019).

World's fastest hydrogen sensor could pave the way for clean energy

Hydrogen is a clean and renewable energy carrier that can power vehicles, with water as the only emission. Unfortunately, hydrogen gas is highly flammable when mixed with air, so very efficient and effective sensors are needed. Now, researchers from Chalmers University of Technology, present the first hydrogen sensors ever to meet the future performance targets for use in hydrogen powered vehicles. The discovery is an optical nanosensor encapsulated in a plastic material. The sensor works based on an optical phenomenon – a plasmon – which occurs when metal nanoparticles are illuminated and capture visible light. The sensor simply changes colour when the amount of hydrogen in the environment changes. The plastic around the tiny sensor is not just for protection, but functions as a key component. It increases the sensor's response time by accelerating the uptake of the hydrogen gas molecules into the metal particles where they can be detected. At the same time, the plastic acts as an effective barrier to the environment, preventing any other molecules from entering and deactivating the sensor. The sensor can therefore work both highly efficiently and undisturbed, enabling it to meet the rigorous demands of the automotive industry – to be capable of detecting 0.1 percent hydrogen in the air in less than a second. Although the aim is primarily to use hydrogen as an energy carrier, the sensor also presents other possibilities. Highly efficient hydrogen sensors are needed in the electricity network industry, the chemical and nuclear power industry, and can also help improve medical diagnostics.

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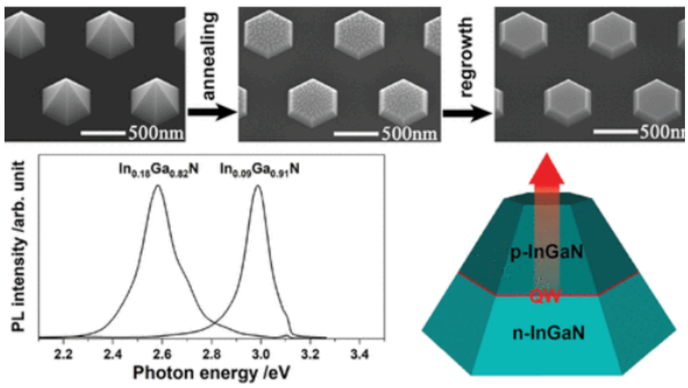
Nugroho, F.A.A., Darmadi, I., Cusinato, L. et al. Metal–polymer hybrid nanomaterials for plasmonic ultrafast hydrogen detection. Nature Materials 18, 489–495 (2019).

https://www.chalmers.se/en/departments/physics/news/Pages/Worlds-fastest-hydrogen-sensor-could-pave-the-way-for-clean-hydrogen-energy.aspx

InGaN Platelets: Synthesis and Applications toward Green and Red Light-Emitting Diodes

A method to synthesize arrays of hexagonal InGaN submicrometer platelets with a top c-plane area having an extension of a few hundred nanometres by selective area metal-organic vapor-phase epitaxy has been developed. The InGaN platelets were made by in situ annealing of InGaN pyramids, whereby InGaN from the pyramid apex was thermally etched away, leaving a c-plane surface, while the inclined $\{10\bar{1}1\}$ planes of the pyramids were intact. The as-formed c-planes, which are rough with islands of a few tens of nanometres, can be flattened with InGaN regrowth, showing single bilayer steps and high-quality optical properties (full width at half-maximum of photoluminescence at room temperature: 107 meV for In0.09Ga0.91N and 151 meV for In0.18Ga0.82N). Such platelets offer surfaces having relaxed lattice constants, thus enabling shifting the quantum well emission from blue (as when grown on GaN) to green and red. For single InGaN quantum wells grown on the c-plane of such InGaN platelets, a sharp interface between the quantum well and the barriers was observed. The emission energy from the quantum well, grown under the same conditions, was shifted from 2.17 eV on In0.09Ga0.91N platelets to 1.95 eV on In0.18Ga0.82N platelets as a result of a thicker quantum well and a reduced indium pulling effect on In0.18Ga0.82N platelets. On the basis of this method, prototype light-emitting diodes were demonstrated with green emission on In0.09Ga0.91N platelets and red emission on In0.18Ga0.82N platelets.

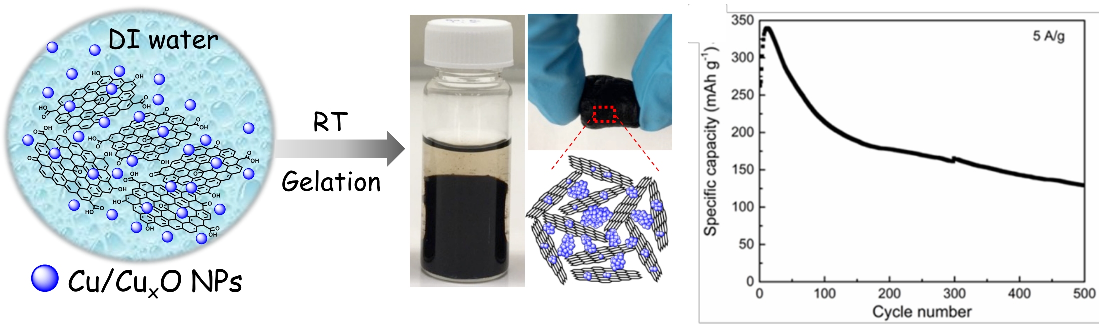


Reference

InGaN Platelets: Synthesis and Applications toward Green and Red Light-Emitting Diodes, Z. Bi, F. Lenrick, J. Colvin, A. Gustafsson, O. Hultin, A. Nowzari, T. Lu, R. Wallenberg, R. Timm, A. Mikkelsen, B. J. Ohlsson, K. Storm, B. Monemar, L. Samuelson. Nano Letters 2019, 19, 5, 2832-2839. DOI: 10.1021/acs.nanolett.8b04781

Graphene-based hydrogels for high-performance energy storage

Monolayer and few-layer graphene sheets constitute the basic building block for three-dimensional (3D) hydrogels in energy storage applications. Recently, we have successfully achieved a 3D reduced-graphene-oxide/copper hybrid hydrogel via a room-temperature, solution-phase and one-pot method. The hydrogel is subsequently transformed into a highly conductive aerogel via freeze-drying. The aerogel, featuring reduced graphene oxide (rGO) networks decorated with Cu and CuxO nanoparticles (Cu/CuxO@rGO), exhibits a specific surface area of 48 m2 g−1 and an apparent electrical conductivity around 33 and 430 S/m prior to and after mechanical compression, respectively. The compressed Cu/CuxO@rGO aerogel delivers a specific capacity of ~ 453 mAh g−1 at a current density of 1 A g−1 and ~184 mAh g−1 at 50 A g−1 in a 3 M KOH aqueous electrolyte evidenced by electrochemical measurements. Galvanostatic cycling tests at 5 A g−1 demonstrates that the Cu/CuxO@rGO aerogel retains 38% (~129 mAh g−1) of the initial capacity (~339 mAh g−1) after 500 cycles. The straightforward manufacturing process and the promising electrochemical performances make the Cu/CuxO@rGO aerogel an attractive electrode candidate in energy storage applications.



Left: *Illustration of the formation of Cu/CuxO@rGO hydrogel by making a mixture of rGO and Cu/CuxO nanoparticles through macro-assembly process at ambient pressure and room temperature (RT).*

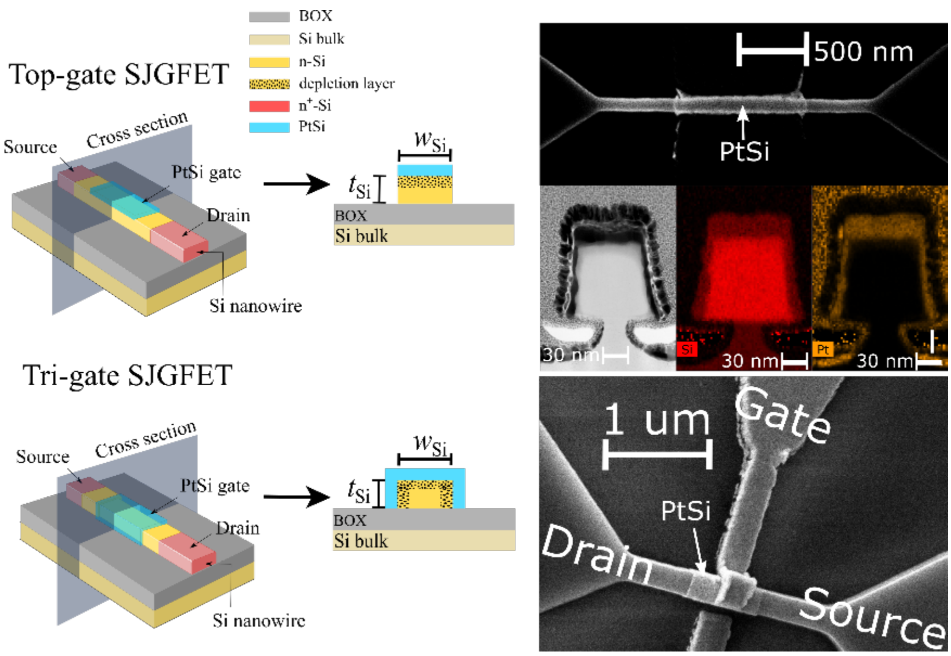
Right: *Specific capacity vs. cycle number at 5A g−1 of the hydrogel as a battery electrode.*

Reference

Jie Zhao, Ruijun Pan, Rui Sun, Chenyu Wen, Shi-Li Zhang, Biao Wu, Leif Nyholm, Zhi-Bin Zhang, "High-conductivity reduced-graphene-oxide/copper aerogel for energy storage", Nano Energy 60, 760-767 (2019).

Low noise Schottky junction gate silicon nanowire field-effect transistor for charge sensing

The random trapping and de-trapping of the carriers in the vicinity of the interface between gate oxide and conduction channel of a metal-oxide-semiconductor field-effect transistor (MOSFET) generate the low frequency noise (LFN) of the device. The LFN performance of MOSFETs is critical for their sensing applications as it determines the signal-to-noise ratio (SNR) and sets the lower detection limit of the sensors. The LFN issue is becoming increasingly prominent for MOSFETs with downscaled channel size, *e.g.*, silicon nanowire (SiNW) FETs, for detection of biomolecules in extremely low concentration ranges. To address this issue, we designed Schottky junction gate SiNWFETs (SJGFETs) using a metal-silicon Schottky junction to replace the noisy gate oxide / silicon interface of the SiNWFETs. Device fabrication and characterisation were performed at Myfab Uppsala. Since there was no gate voltage loss associated to the gate oxide as well as the interface traps, the SJGFETs exhibited a near-ideal gate coupling efficiency as represented by a subthreshold slope of ~60 mV/dec. Most importantly, the LFN for the SJGFETs was significantly reduced in comparison to that for the MOS-type SiNWFETs fabricated in the same batch, and was the lowest among the similar SiNWFETs reported by different university laboratories.



Left: *3D sketch of a Top-gate (upper) and a Tri-gate (lower) SJGFET along with the respective cross-section of the gated SiNW section.*

Right: *SEM images of a Tri-gate SJGFET after the formation of PtSi on the SiNW channel and after the formation of the gate contact arms, together with an XTEM image of the PtSi-gated SiNW channel, including elemental profiles analysed by means of EDX.*

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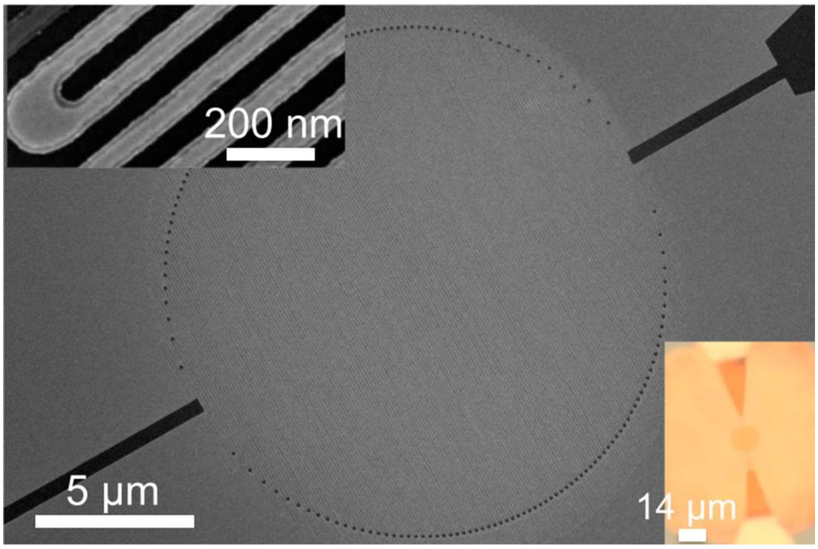
Xi Chen, Si Chen, Shi-Li Zhang, Paul Solomon, Zhen Zhang, “Low noise Schottky junction tri-gate silicon nanowire field-effect transistor for charge sensing”, IEEE Transactions on Electron Devices 66, 3994-4000 (2019).

Two spin-off company examples:

Single Quantum and Intermodulation Products

Single Quantum, a spinoff from the Zwiller group (KTH), commercializes high-performance single-photon detectors based on superconducting nanostructures. The outstanding supercondcuting film deposition and nano-patterning processes available at Myfab KTH enable joint R&D of KTH and Single Quantum on developing a new generation of single-photon detectors with the time resolution, noise level, and detection efficiencies setting new standards in quantum optics [1]. The application space is the booming quantum communications, where SQ is one of the fastest growing start-ups internationally.

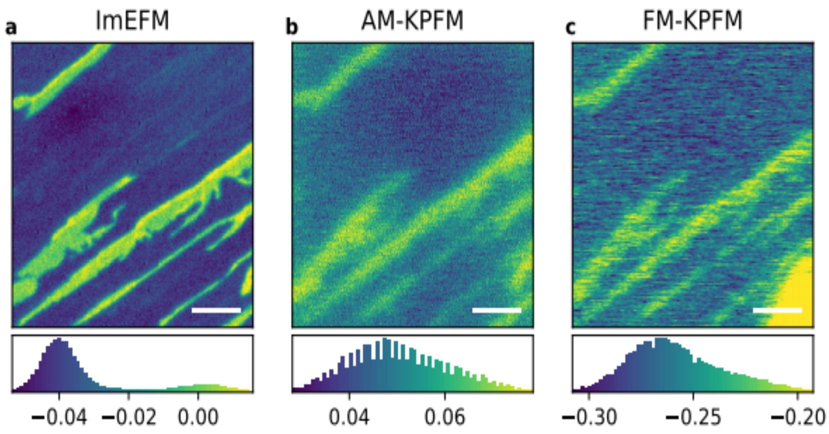


Main panel: top view of superconducting NbTiN meander-patterned single-photon detector; top-left: meander-nanowire close-up; bottom-right: detector integrated with optics.

Reference

Zichi, J. Chang, S. Steinhauer, K. von Fieandt, J. W. N. Los, G. Visser, N. Kalhor, T. Lettner, A. W. Elshaari, I. E. Zadeh, and V. Zwiller, “Optimizing the stoichiometry of ultrathin NbTiN films for high-performance superconducting nanowire single-photon detectors”, Opt. Express 27, 26579-26587 (2019).

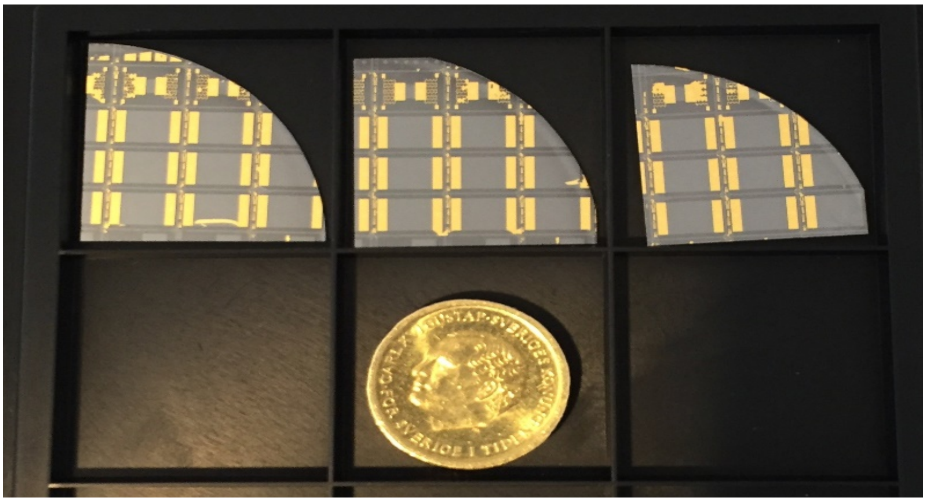
Myfab KTH hosts the biggest and most versatile atomic force microscopy (AFM) lab in Sweden. Thanks to this rich and flexible environment, Intermodulation Products AB was founded as a spinoff of the Haviland group (KTH). Intermodulation Products AB commercializes add-on equipment to labs and users who want to extend the measurement capabilities of their AFM with mechanical, electrical and magnetic characterization, for applications ranging from energy materials to life sciences. All the special modes developed by Intermodulation Products are available to users of the Myfab KTH AFMs. The start-up is actively expanding its products space, e.g. to high-speed multi-frequency lock-in systems.



Comparison of Inter-modulation EFM and KPFM by first-time users of AFM at Myfab KTH. Maps and histograms of work function in volts measured on a graphene monolayer (blue) with flakes of bilayer graphene (yellow). The graphene is thermally grown on a silicon carbide (SiC) substrate. The white scale bars are 3 µm. From R. Borgani, PhD Thesis, KTH 2018.

Cost-effective onsite crime-scene analysis tools

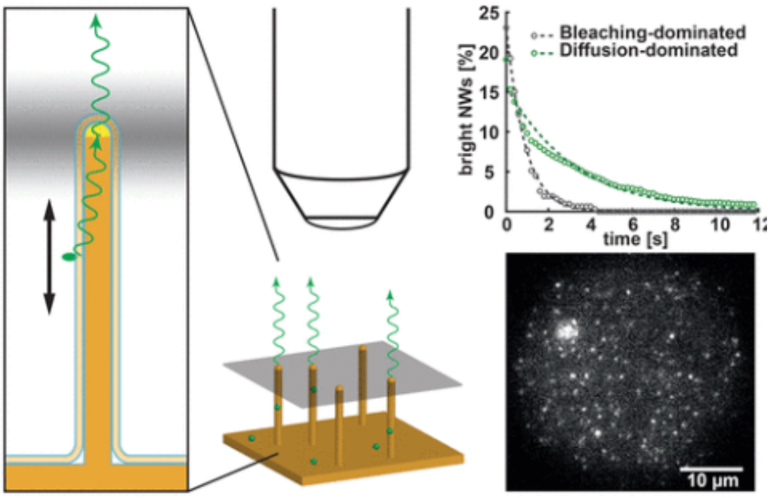
In recent years RISE has established collaborations with the Swedish National Forensic Centre (NFC) aiming to develop cost-effective onsite crime-scene analysis tools for detection of narcotics/explosives and age determination of biological traces (ex. blood), in projects funded by VINNOVA and SSF respectively. The idea is to bridge science fiction and reality for crime scene investigation by integrating research, development and innovation and using the joint and complementary competences and facilities of the partners. The work has been focused on exploration of nano-photonic/electronic sensors based on wafer-scale graphene on SiC, large area CVD graphene, and quantum dots to address the forensic applications. See examples in papers listed in the publication section. It is worth to note that the sensor technology developed for this purpose can also be used for a wide range of applications such as medicine, drinking water inspection, food quality assessment, industrial processing and environmental monitoring.



Sensors based on epitaxial graphene on SiC substrate

Single-Molecule Detection with Lightguiding Nanowires: Determination of Protein Concentration and Diffusivity in Supported Lipid Bilayers

This work demonstrates the ability to optically detect single molecules with a relatively simple optical setup by using nanowires to enhance, collect and concentrate the light emission from fluorescent molecules. To demonstrate this, supported lipid bilayers were formed on a surface containing GaP nanowires epitaxially grown at Myfab Lund, and both the coverage and diffusivity of bilayer-bound proteins (GM1 gangliosides) at extremely low coverage were measured. The unique light harvesting and light guiding properties of the nanowires allows fluorescent emission from diffusing bilayer-bound molecules to be efficiently collected and projected to a camera for subsequent analysis. This approach has the advantages that (i) the high signal-to-noise ratio allows us to use a standard epifluorescence microscope for single-molecule detection; (ii) by observing "blinking" from hundreds of individually resolved nanowires at the same time, we can collect sufficient data for analysis in just a few seconds of acquisition time; (iii) we show that we can successfully correct our analysis for photobleaching, making the method suitable for a range of dyes. These features open up for



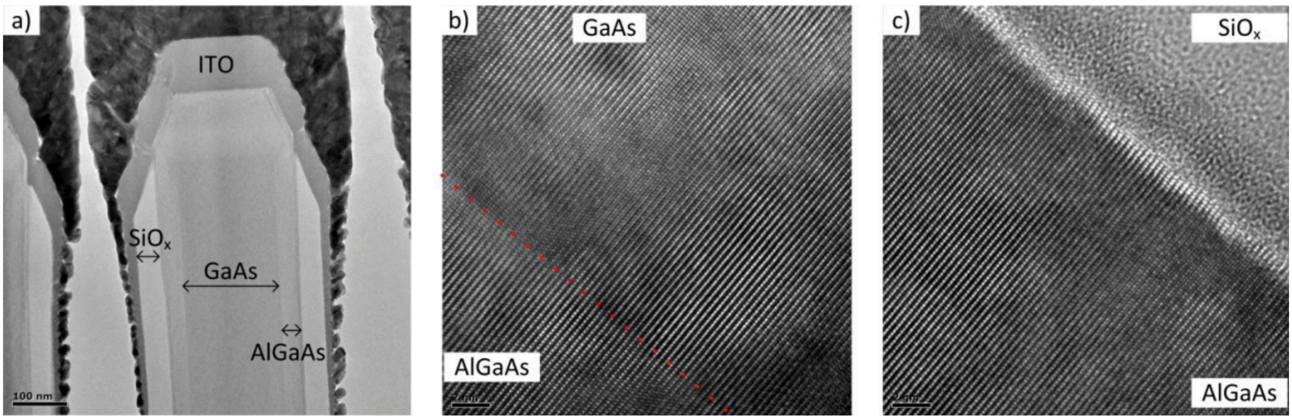
many uses of nanowires surfaces for high-sensitivity, optical biosensing, and form the of the spin-out company AligND Systems AB founded in 2019.

Reference

Single-Molecule Detection with Lightguiding Nanowires: Determination of Protein Concentration and Diffusivity in Supported Lipid Bilayers. / Verardo, Damiano; Agnarsson, Björn; Zhdanov, Vladimir P.; Höök, Fredrik; Linke, Heiner. In: Nano Letters, Vol. 19, No. 9, 2019, p. 6182-6191. https://pubs.acs.org/doi/10.1021/acs.nanolett.9b02226

Radiation Tolerant Nanowire Array Solar Cells

Space power systems require photovoltaics that are lightweight, efficient, reliable, and capable of operating for years or decades in space environment. Current solar panels use planar multijunction, III-V based solar cells with very high efficiency, but their specific power (power to weight ratio) is limited by the added mass of radiation shielding (e.g., coverglass) required to protect the cells from the high-energy particle radiation that occurs in space. We showed that III-V nanowire-array solar cells have dramatically superior radiation performance relative to planar solar cell designs.



TEM images of a NW solar cell irradiated with 100 keV p+ at a fluence of 1012 p + /cm2

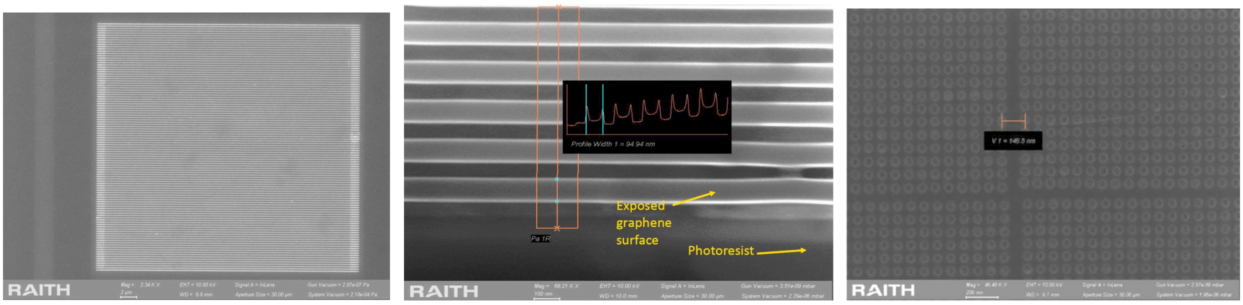
Nanowire cells exhibit damage thresholds ranging from ~10-40 times higher than planar control solar cells when subjected to irradiation by 100-350 keV protons and 1 MeV electrons. Using Monte Carlo simulations, we showed that this improvement is due in part to a reduction in the displacement density within the nanowires arising from their small dimensions. Radiation tolerance, combined with the efficient optical absorption and the improving performance of nanowire photovoltaics, indicates that nanowire arrays could provide a pathway to realize high-specific-power, substrate-free, III-V space solar cells with substantially reduced shielding requirements. The exceptional reduction in radiation damage suggests that nanowire architectures may be useful in improving the radiation tolerance of other electronic and optoelectronic devices as well.

Reference

Radiation Tolerant Nanowire Array Solar Cells. / Espinet-Gonzalez, Pilar; Barrigón, Enrique; Otnes, Gaute; Vescovi, Giuliano; Mann, Colin; France, Ryan M.; Welch, Alex J.; Hunt, Matthew S.; Walker, Don; Kelzenberg, Michael D.; Åberg, Ingvar; Borgström, Magnus T.; Samuelson, Lars; Atwater, Harry A. In: ACS Nano, Vol. 13, No. 11, 26.11.2019, p. 12860−12869. https://pubs.acs.org/doi/abs/10.1021/acsnano.9b05213

Graphene-based plasmonic structures for sensing applications

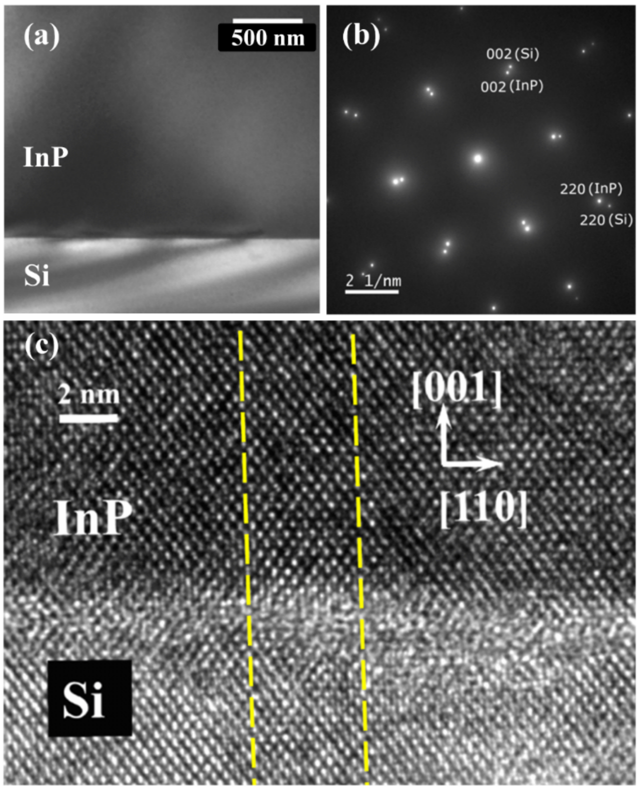
RISE, with its industrial partners, has worked on graphene-based plasmonic structures to sense CO2 and/or alcohol in IR regimes. It is well known that it is challenging to define nano structures in large areas, but the work has proceeded at a good pace and also benefits from collaborations with the Institute of Solid-State Physics (ISSP), Latvia, within the frame of the EU CAMART2 project, https://www.camart2.com/. The outcome of the work will help to provide joint offer(s) within the Riga-Stockholm (RIX-STO) collaboration and technology transfer platform to industrial and academic partners. The RIX-STO platform aims to increase the scientific collaboration between research partners from Latvia and Sweden but also develop collaboration with other countries; promote the mobility of students and researchers between partner organizations; encourage the sharing of research infrastructure and maximize the impact on the industrial growth in the region.



SEM images of nanoribbon and nanohole arrays on large area CVD graphene on SiO2/Si substrate

Technology for Si based multi-junction solar cells

The monolithic integration of device quality III-V compound semiconductor materials on Silicon substrate has attracted attention in fundamental semiconductor materials research for decades. One of the major motivations for this effort is the integration of high efficiency III-V photovoltaic (PV) on low cost Si substrate (compared to high-cost conventional GaAs or Ge). It is worth noting that in addition to the economic benefit, the physical properties of Si itself will provide important performance advantages in the III-V/Si integration approach. Innovative corrugated epitaxial lateral overgrowth (CELOG) technology has been developed in hydride vapor phase epitaxy (HVPE) reactor by exploiting the inherent selective growth characteristics of HVPE. As shown in the figures, high crystal quality coherent InP/Si heterojunction can be fabricated by CELOG, which is promising for Si based multi-junction solar cell application.



High crystal quality coherent InP/Si heterojunction revealed by high-resolution transmission electron microscopy (HRTEM).

(a) Bright field TEM image showing the smooth interface between InP and Si in the CELOG region. No threading dislocations contrast is observed in the InP film.

(b) Selected area electron diffraction pattern acquired at the film-substrate interfacial region.

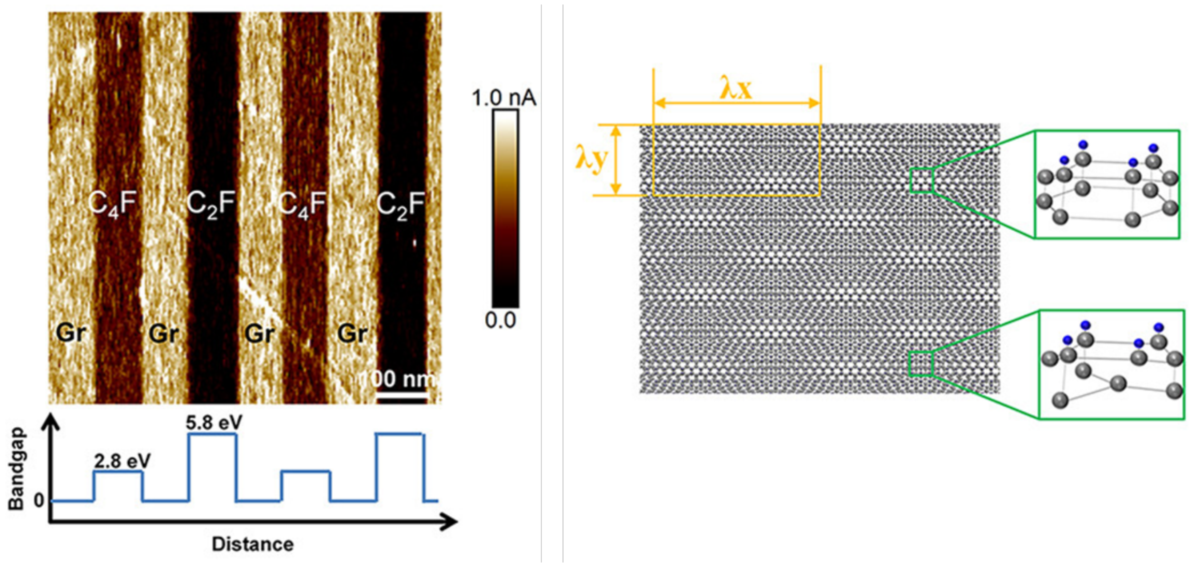
(c) HRTEM cross section of CELOG InP/Si interface. The yellow lines marked in the HRTEM are parallel to (110) atomic planes. By counting the number of (110) planes between the lines in both layers, one missing plane in the InP layer can be inferred.

Reference

Giriprasanth Omanakuttan et al., Opt. Mater. Express 9, 1488-1500 (2019)

Nanoscale fluorination opens the door to tunable bandgap graphene and new type of rectangular moiré superlattices

The Electron Microscopy and Nanoengineering (ELMIN) group developed an electron-beam-activated fluorination process, which allows for directly writing of tunable bandgap (up to 5.8 eV) structures onto monolayer graphene, and demonstrated a previously unseen rectangular moiré structure, generating from C_2F (boat)/graphene bilayer superlattice. This original work is published in *Applied Physics Reviews*, and also been selected as the Annual Highlight Paper by the American Institute of Physics (AIP), and is thus collected in the AIP special science-highlight journal-*Scilight* (DOI: 10.1063/10.0000677). The success of this story is enabled by the superior thin film modification and characterization facilitates in Myfab Uppsala.



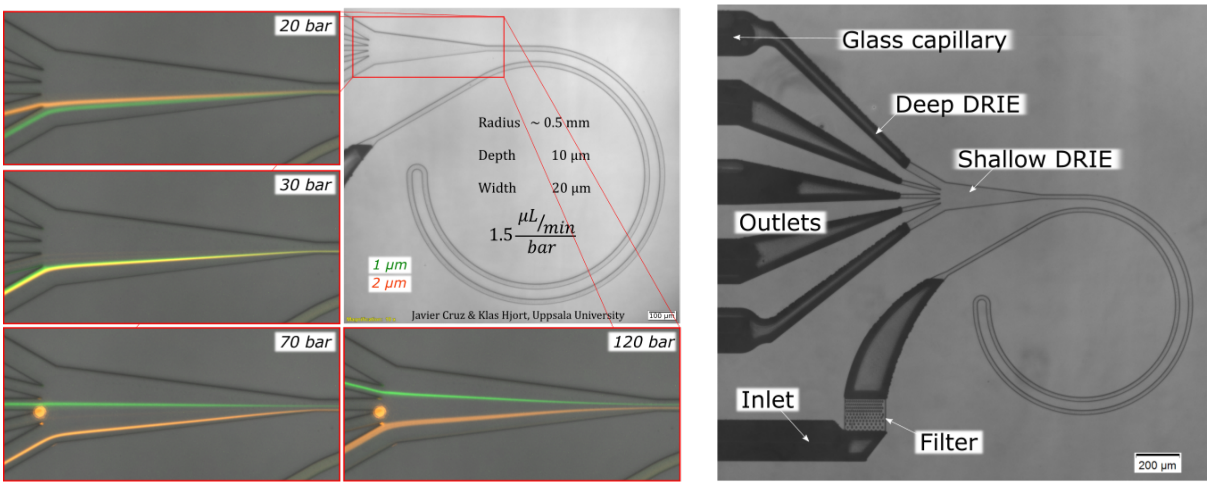
Conductive AFM image of the fluorinated nano-stripes of graphene with various bandgaps and the schematic of the bilayer rectangular moiré superlattices formed by C2F (boat)/graphene. The nano-stripes are directly written on monolayer graphene surface through the developed E-beam-activated fluorination technique, and the rectangular moiré patterns are originated from the mismatch of the top layer C2F (boat) and the bottom layer graphene.

Reference

Hu Li, Tianbo Duan, Soumyajyoti Haldar, Biplab Sanyal, Olle Eriksson, Hassan Jafri, Samar Hajjar-Garreau, Laurent Simon, and Klaus Leifer, “Direct writing of lateral fluorographene nanopatterns with tunable bandgaps and its application in new generation of moiré superlattice.” Applied Physical Reviews, 7, 011403 (2020)

Inertial focusing with sub-micron resolution for separation of bacteria

In this study we demonstrated the use of microfluidics for concentration and separation of particles with diameters between 0.5 and 2.0 µm; a range of biological relevance since it comprises a multitude of bacteria and organelles of eukaryotic cells. The devices are based on Inertial Focusing, a passive technique for high-resolution particle manipulation where the velocity profile of the fluid induces migration of particles to size-dependent equilibrium positions. Sub-micron resolution was achieved in the separation, with recoveries superior to 95% and high throughputs (hundreds of µL/min). The systems were validated with three bacteria species (Escherichia coli, Salmonella typhimurium and Klebsiella pneumoniae) showing good focus while maintaining the viability in all cases.

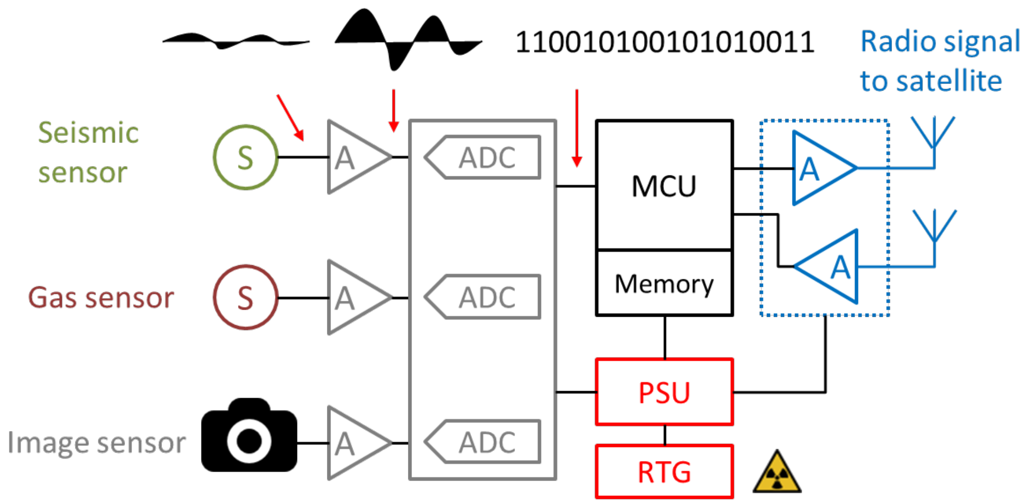


Overview of a microfluidic chip for Inertial Focusing and equilibrium positions of 1 and 2 µm particles as the pressure/flow rate increases. To achieve such high-quality performance, high pressure (tens of bars) is needed and the tolerance in the dimensions of the microchannels is critical. The chips were therefore made on silicon-glass, allowing for high precision microfabrication and safely standing pressures up to 200 bar.

Reference

J. Cruz, T. Graells, M. Walldén and K. Hjort, Lab Chip, 2019, 19, 1257–1266.

Aiming for space with high temperature integrated electronics



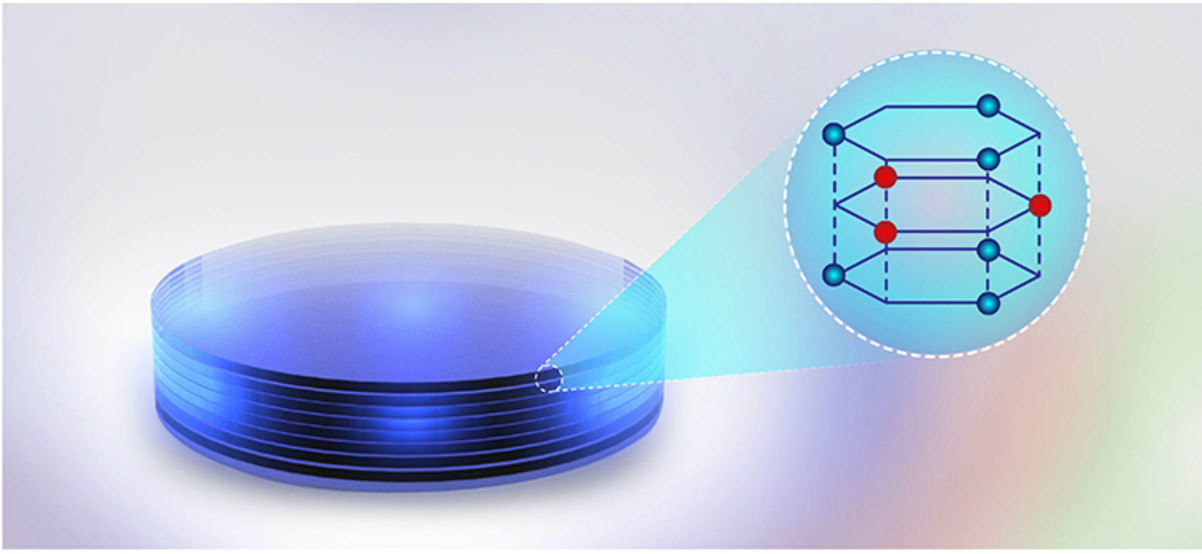
The Knut and Alice Wallenberg funded project "Working on Venus" has finished after 5 years and 8 PhD students. The result of the project was to demonstrate all parts of a Venus Lander necessary to survive a surface temperature of 460 °C. This included sensors, pixel-detectors, amplifiers, analogue-to-digital converters (DACs), microcontroller with memory, radio transceiver and power supply. All the integrated circuits and devices were fabricated in Myfab KTH. Although the launch cost to Venus is high, the advances open to terrestrial applications including high temperature operations in gas turbines and other combustion monitoring, down-hole oil and gas drilling, and nuclear energy. Single- project leaders include Mikael Östling, Christer Fuglesang, Per-Erik Hellström, Gunnar Malm, Hans-Peter Nee, Frank Niklaus, Ana Rusu, and Carl-Mikael Zetterling. Anita Lloyd Spetz from Linköping University was also a part of the project contributing gas sensors. The scientific output includes the following four PhD theses with included articles.

Reference

http://www.workingonvenus.se/

Light box that opens new doors into the nanoworld

Researchers at Chalmers have discovered a completely new way of capturing, amplifying and linking light to matter at the nanolevel. Using a tiny box, built from stacked atomically thin material, they have succeeded in creating a type of feedback loop in which light and matter become one. The researchers used a well-known transition metal dichalcogenide, TMDC, material – tungsten disulphide – but in a new way. By creating a tiny resonance box – much like the sound box on a guitar – they were able to make the light and matter interact inside it. The resonance box ensures that the light is captured and bounces round in a certain 'tone' inside the material, thus ensuring that the light energy can be efficiently transferred to the electrons of the TMDC material and back again. It could be said that the light energy oscillates between the two states – light waves and matter – while it is captured and amplified inside the box. The researchers have succeeded in combining light and matter extremely efficiently in a single particle with a diameter of a mere 100 nanometres. This all-in-one solution is an unexpected advance in fundamental research, but can hopefully also contribute to more compact and cost-effective solutions in applied photonics.



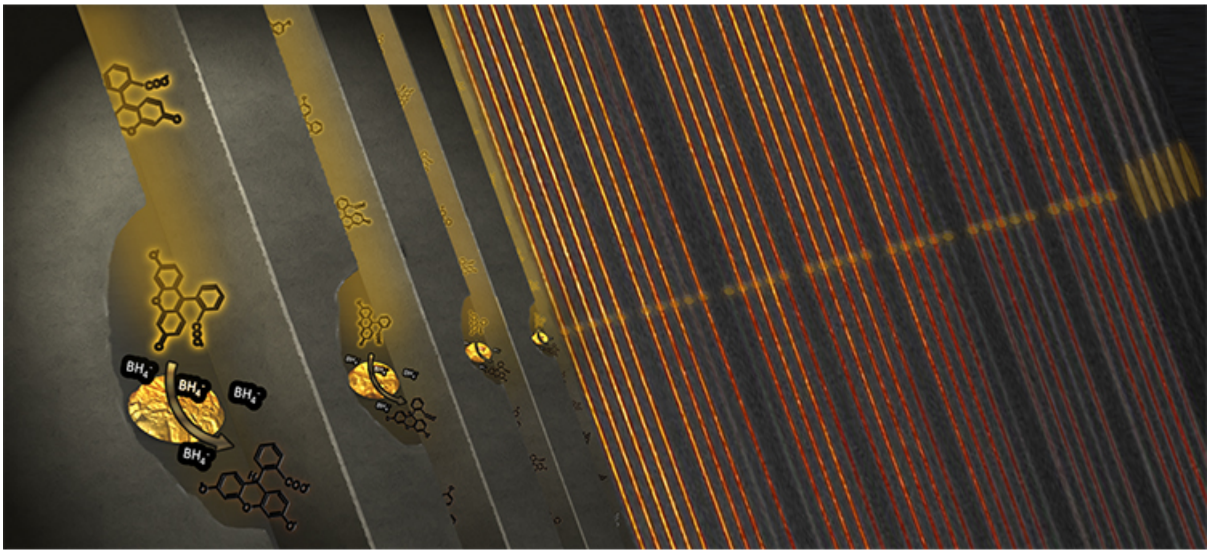
Reference

Verre, R., Baranov, D.G., Munkhbat, B. et al. Transition metal dichalcogenide nanodisks as high-index dielectric Mie nanoresonators. Nature Nanotechnology. 14, 679–683 (2019).

https://www.chalmers.se/en/departments/physics/news/Pages/Light-box-that-opens-new-doors-into-the-nanoworld.aspx

Light at the end of the nanotunnel for catalysts of the future

Using a new type of nanoreactor the researchers have succeeded in mapping catalytic reactions on individual metallic nanoparticles. Their work could help improve chemical processes, and lead to better catalysts and more environmentally friendly chemical technology. To better understand the catalytic process, it is necessary to investigate it at the level of individual nanoparticles. The new nanoreactor has allowed the Chalmers researchers to do exactly this. The reactor consists of around 50 glass nanotunnels filled with liquid, arranged in parallel. In each tunnel the researchers placed a single gold nanoparticle. Though they are of similar size, each nanoparticle has varied catalytic qualities – some are highly effective, others decidedly less optimal. To be able to discern how size and nanostructure influence catalysis, the researchers measured catalysis on the particles individually. Effective catalysis is essential for both the synthesis and decomposition of chemicals. For example, catalysts are necessary for manufacturing plastics, medicines, and fuels in the best way, and effectively breaking down environmental toxins.



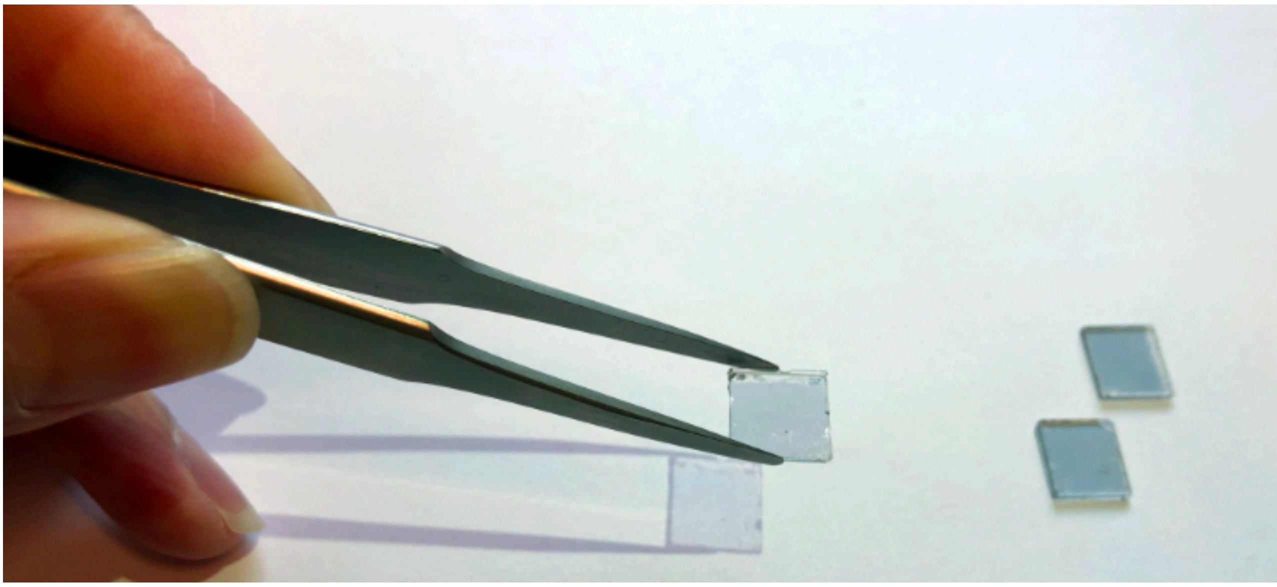
Reference

Levin, S., Fritzsche, J., Nilsson, S. et al. A nanofluidic device for parallel single nanoparticle catalysis in solution. Nature Communications 10, 4426 (2019).

https://www.chalmers.se/en/departments/physics/news/Pages/Light-at-the-end-of-the-nano-tunnel-for-future-catalysts.aspx

ORGANISATION

Myfab's organisation is tailor-made for efficient operation of a distributed research infrastructure with a national mission, several owners and financiers. The consortium agreement and the contracts with the Swedish Research Council presents the full formal picture of the organisation. The owner group, formed by representative from the four laboratory owners (*i.e.* Chalmers, KTH, LU and UU) is in charge of strategical questions and undertakings relating to the laboratories and their staff. The steering group is in charge of the economy and strategic decisions during the period of operation. The director is in charge of operations and to implement the decisions by the steering group. The operational management consists of the director and the four laboratory managers and is in charge of day-to-day operation and collaboration with the steering group and the owner group. The over-all structure of Myfab's management gives a balance between the bodies involved.



Myfab's owner group

Myfab is a joint undertaking of four universities: Chalmers University of Technology, KTH Royal Institute of Technology, Lund University and Uppsala University. Each university owns the local cleanroom laboratory. The owner group has been formed in order to address matters where Myfab's undertakings and the University's strategy overlap. The participating universities collaborate according to the Consortium Agreement, and according to the Main Contract between the host university (Chalmers) and the Swedish Research Council (SRC). The members of the owner group in 2019 were Professor Mikael Fogelström, Chalmers, Professor Carl-Mikael Zetterling, KTH, Doctor Anneli Löfgren, Lund University, and Professor Åsa Kassman, Uppsala University.

Myfab’s fourth period of operation was 2016 – 2019, and concerning the next period (2020 – 2024), a new body Stämman, with representatives from the vice chancellor groups, will replace the owner group. This in accordance with plans for made for all national research infrastructures by the URFI group.

Myfab’s steering group

Myfab’s steering group consisted of the following members during 2019: Anne Borg, (Prof. Physics NTNU, Norway),), Susanne Holmgren (Prof. Emerita, University of Gothenburg), Mikael Jonsson (Prof. Uppsala University), Anneli Löfgren, (Admin. Research Director Lund Nano Lab), Henrik Thunman (Prof. Chalmers) Jonas Wallberg (Director ICT, the Association of Swedish Engineering Industries, Teknikföretagen), and Mikael Östling, (chairman, Prof. and Deputy President KTH).

Operational management

Myfab’s operation is managed by the Director Thomas Swahn in collaboration with the laboratory managers Maria Huffman (Lund University, Q1 and Q2), Luke Hankin (Lund University Q3 and Q4) Peter Modh (Chalmers), Stefan Nygren (Uppsala University) and Nils Nordell (KTH). Cristina Andersson, Chalmers, support the operational management as support systems officer and project manager.

ECONOMY

Myfab's financial report for 1 January – 31 December 2019, submitted separately and undersigned by Chalmers financial controller, has been delivered to the Swedish Research Council. The report presents how the Myfab operations grant has been distributed, in accordance with the decisions taken by Myfab's steering group. The table below present the total economy of the Myfab laboratories and sets the Myfab operation grant in perspective to each laboratory's total economy. The Myfab grant in this table represents the full-year 2019.

Income [kSEK]	**Myfab Chalmers**	**Myfab KTH**	**Myfab Lund**	**Myfab Uppsala**	**Myfab all four labs**
Faculty grants	31 934	13 732	21 596	11 669	**78 931**
Fees, academic	17 079	13 368	12 622	15 043	**58 112**
Fees companies incl. RISE	16 195	22 629	1 428	2 451	**42 703**
Myfab SRC grant	3 292	3 292	3 292	3 292	**13 168**
Financed depr.	4 572	939	5 317	5 821	**16 649**
Projects SSF, EU		4 876	3 609		**8 485**
Services	6	2 592	278		**2 876**
Income Total	**73 078**	**61 428**	**48 143**	**38 276**	**220 925**
Costs [kSEK]					
Personnel	15 322	14 722	11 115	7 843	**49 002**
Rent premises	18 200	9 338	9 550	14 000	**51088**
Operation	13 734	24 937	8 810	8 211	**55 692**
Overhead	5 059	6 726	6 143	2 026	**19 954**
Financed depr.	4 572	939	5 317	5 821	**16 649**
Depreciations	4 701	3414	8 736	2 143	**18 994**
Costs Total	**61 588**	**60 076**	**49 672**	**40 044**	**211 380**
Result	**11 490**	**1 352**	**-1 528**	**-1 768**	**9 545**

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MYFAB STANDARD REPORT 2019 – KEY NUMBERS FROM MYFAB LIMS

	Chalmers	KTH	Lund	Uppsala	2019 Myfab	2018 Myfab	2017 Myfab	2016 Myfab	2015 Myfab
Users with access	403	506	303	436	**1648**	**1658**	1611	1592	1476
Active users	208	216	142	270	**836**	**855**	804	847	820
Female active users	43	56	36	75	**210**	**224**	198	211	193
Gender balance, active users	21%	26%	25%	28%	**25%**	**26%**	25%	25%	24%
University active users	183	166	126	239	**714**	**723**	669	716	695
Institutes active users	0	10	2	2	**14**	**11**	11	12	11
Commercial active users	25	40	14	29	**108**	**121**	124	119	113
Companies with own personnel	9	18	7	17	**51**	**56**	56	59	50
Number of booked hours	71072	33840	51254	30843	**187017**	**191280**	195615	199303	192802
-from universities	64078	23355	49627	28919	**165979**	**168885**	170101	170980	166520
-from institutes	0	1851	300	82	**2233**	**2323**	3220	3630	3169
-from commercial users	6995	8634	1328	1848	**18804**	**20072**	22293	24694	23099
Number of tools	186	264	98	190	**738**	**706**	709	697	683
Booked tools	135	105	75	90	**405**	**408**	404	399	407

ANNEXES

A. Key numbers as specified from Appendix 1 (Bilaga 1) to Myfab's contract (Dnr: 2015-06030).

B. Peer-reviewed publication lists and doctoral theses from Myfab Chalmers, Myfab KTH, Myfab Lund and Myfab Uppsala.

ANNEX A

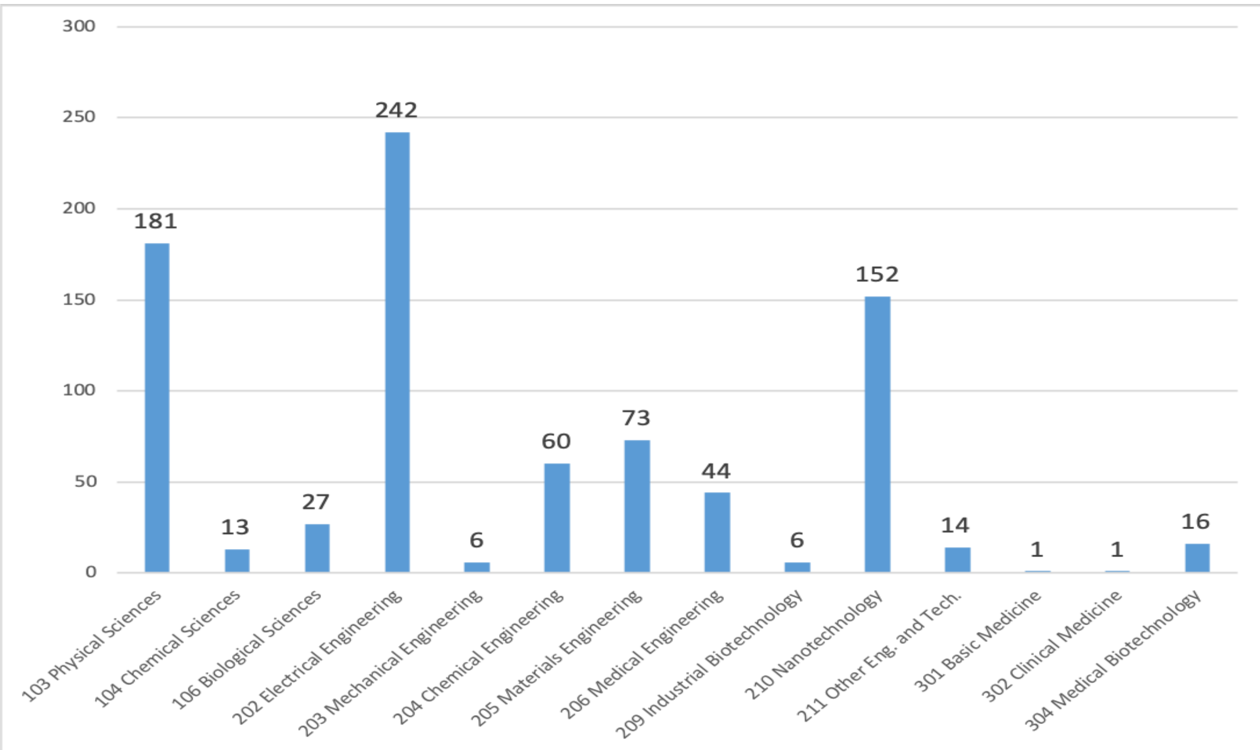
Key numbers as specified from Appendix 1 (Bilaga 1) to Myfab's contract (Dnr: 2015-06030)

1). Number of users per Myfab site, including other organisations, companies etc.

See the standard report in Annex A.

2). Number of users per scientific area (SCB-codes, on the 3-digit level)

The distribution of active users in various research areas (SCB standard) is presented below. As this diagram clearly indicates, our users are active in many different disciplines but physical sciences, electrical engineering and nanotechnology dominate.



During 2019 the Myfab infrastructure hosted 836 active user individuals (making at least one tool booking). Considering all activities connected to this lab work, such as theoretical modelling, computer simulations, device evaluations, etc., the total number of scientists and developers benefitting from the infrastructure can be counted in thousands. Among the active users, 85 % (714) were academics, accounting for 89 % of the utilization. The gender balance is still not equal, with only 25 % female active users. The industrial users comes from 85 companies, most of which are spin-out companies or small SMEs needing cleanroom, tools and process lines to advance their innovations.

3). Number of female and male users

Total number of active users 2019:	836	
Total number of female active users 2019:	210	(25 %)
Total number of male active users 2019:	626	(75 %)

4). Average number of individuals that are connected to a group leader ("PI")

Not available from Myfab data. Users are normally affiliated with a department or a division.

5). Number of active users per laboratory (i.e. active users 2019)

Myfab total	836
Myfab Chalmers	208
Myfab KTH	216
Myfab Lund	142
Myfab Uppsala	270

An active user made at least one tool booking during the past year. It should be pointed out that a large portion of the users only utilize simple tools without booking requirements, or their own proprietary tools installed in one of the cleanrooms. Taking these individuals into account the total number of users with access to the Myfab laboratories exceeds the number of active users by about 100 %.

6). Number of users that has applied for access to the infrastructure but were not given access

Myfab provides open user access based on user fees. Users or projects may be denied access for feasibility or compatibility reasons, but statistics for this has not been recorded. There is no need to limit access due to capacity constraints or scientific quality concerns; user fees require project funding that has been granted based on a scientific evaluation. The access model, according to "European Charter for Access to Research Infrastructures", European Commission (ISBN 978-92-79-456) is denoted Market-driven access. Myfab gives regularly relevant clean-room and tool educations to its users.

7). Number of driver's licenses (individuals) that has passed the compulsory education during 2019 and are allowed to use the laboratory, reported per laboratory

The total number of users that has passed the compulsory education is about twice the number of active users, but this not a relevant number. In Myfab LIMS we keep track of users whose education is still valid, other previously active users are removed. Above (point 5) we report the number of active users. Here we report the number of new active users during 2019, as well as their fraction of the total number of active users.

New active users during 2019		(fraction of users active 2019)
Myfab total	229	(27 %)
Myfab Chalmers:	41	(20 %)
Myfab KTH:	73	(34 %)
Myfab Lund:	34	(24 %)
Myfab Uppsala:	81	(30 %)

8). Number of scientific publications and patents, published 2018 and to which the infrastructure has contributed

Number of scientific publications, (journal and conference papers) and PhD exams.

	Publications	PhD exams
Myfab total:	737	58
Myfab Chalmers:	163	9
Myfab KTH:	175	16
Myfab Lund:	153	6
Myfab Uppsala:	246	27

Number of patents:

Myfab does not have information on user's patents, nor does Myfab require its users to report this kind of information.

ANNEX B - MYFAB PUBLICATIONS 2019

Peer-reviewed publication lists and Myfab Lund Doctoral Theses from Myfab Chalmers, Myfab KTH, Myfab Lund and Myfab Uppsala.

Myfab Chalmers Peer Reviewed Journal and Conference Papers

1. Sepehri, Sobhan, Agnarsson, Björn, Zardán Gómez de la Torre, Teresa, Schneiderman, Justin F., Blomgren, Jakob, Jesorka, Aldo, Johansson, Christer, Nilsson, Mats, Albert, Jan, Strömme, Maria, Winkler, Dag, Kalaboukhov, Alexei, Torre, Teresa, Strømme, Maria, de la Torre, Teresa Zardán Gómez & Stromme, M., 'Characterization of binding of magnetic nanoparticles to rolling circle amplification products by turn-on magnetic assay', Bärbar influensa diagnostic "FLU-ID"., 2019

2. Verardo, Damiano, Agnarsson, Björn, Zhdanov, Vladimir P., Höök, Fredrik & Linke, Heiner, 'Single-Molecule Detection with Lightguiding Nanowires: Determination of Protein Concentration and Diffusivity in Supported Lipid Bilayers', Nano Letters., 19:9, s. 6182-6191, 2019

3. Wahlsten, Olov, Ulander, Frida, Midtvedt, Daniel, Henningson, Måns, Zhdanov, Vladimir, Agnarsson, Björn & Höök, Fredrik, 'Quantitative Detection of Biological Nanoparticles in Solution via Their Mediation of Colocalization of Fluorescent Liposomes', Physical Review Applied., 12:6, 2019

4. Andrén, Daniel, Länk, Nils Odebo, Sípová-Jungová, Hana, Jones, Steven, Johansson, Peter, Käll, Mikael, Odebo Länk, Nils & Jungová, Hana, 'Surface Interactions of Gold Nanoparticles Optically Trapped against an Interface', Journal of Physical Chemistry C., 123:26, s. 16406-16414, 2019

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10. Verre, Ruggero, Baranov, Denis, Munkhbat, Battulga, Cuadra, Jorge, Käll, Mikael & Shegai, Timur, 'Transition metal dichalcogenide nanodisks as high-index dielectric Mie nanoresonators', Nature Nanotechnology., 2019

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