Myfab Report 2023

Myfab - The Swedish Research Infrastructure for Micro and Nano Fabrication

INTRODUCTION

Myfab is the national research infrastructure for nano- and microfabrication. This distributed cleanroom infrastructure is the best possible environment for the development and fabrication of materials, structures, and devices for advanced research in a wide field, including physics, materials science, nanoscience, chemistry, life science and nanoelectronics.

Myfab's mission is to provide Swedish researchers, entrepreneurs, and industry with leading-edge micro- and nanofabrication equipment in a nationally distributed infrastructure of operationally excellent cleanroom facilities, supported by expert and collaborative staff.

Myfab was founded in 2004 and became a national research infrastructure in 2010, with cleanroom laboratories at Chalmers University of Technology, KTH Royal Institute of Technology, and Uppsala University. Since 2016, Lund University has been a full member of the infrastructure, and further expansion is under consideration. The four large cleanroom laboratories form a powerful organisation, nurtured by synergies and collaboration, where users have access to and support from the whole infrastructure.

Together during almost two decades, we have developed an internationally recognized operational model, offering user-fee based open access with practically no waiting time, available to academy and industry year-round. The distributed character and interconnecting Myfab LIMS system make this an efficient infrastructure, combining local presence [1] and national coverage. Each node offers an entry point to the whole infrastructure, where dedicated staff provides education, training, process advice and support to the users. The expert staff interacts within Myfab, with the user community and in international networks to improve the operation and develop the infrastructure.

Within a total cleanroom area of 5400 m^2, Myfab provides more than 750 processing and characterization tools maintained by a staff of 80 engineers and researchers (57 full-time equivalents, of which more than 40% holds a PhD degree). During 2023 this environment

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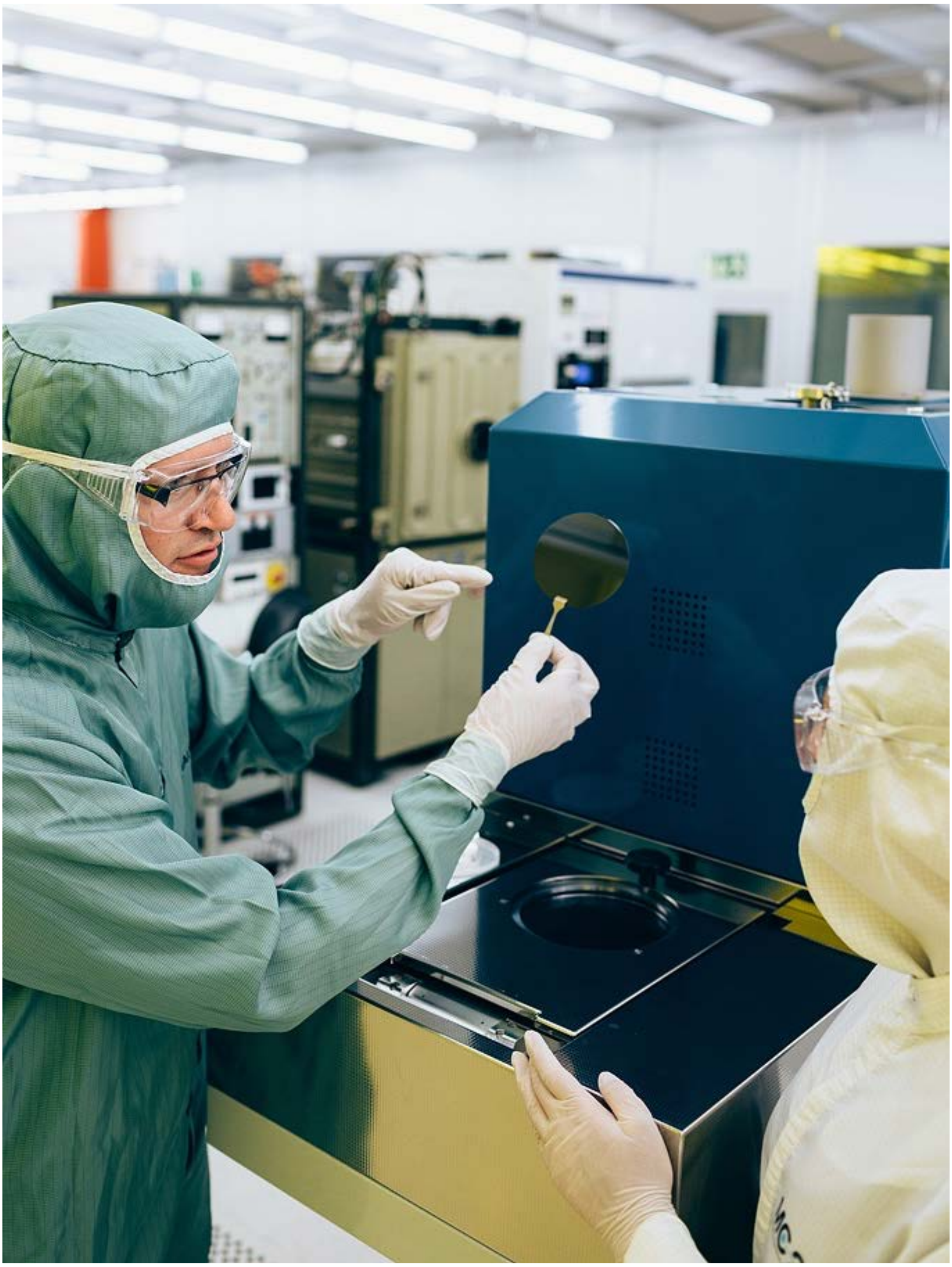
[1] Within 60 minutes travel are an estimated 4.4 million people in the Gothenburg, Malmö, Stockholm, and Uppsala regions.

hosted 820 active users (78,3% academic users, 82,4% academic booked hours). This is a very dynamic user base, as evidenced by the fact that about 1/3 is replaced every year, creating a significant output of well-trained researchers and engineers. Many young and successful PIs are attracted to the environment to establish new research groups. In Mars 2023, at Myfab Chalmers alone, 24 PIs started their activities and researchers received 28 prestigious grants from Knut and Alice Wallenberg's foundation (KAW), the Swedish Research Council (SRC) and the European Research Council (ERC). Our users produce truly impressive results in terms of scientific discoveries, innovative ideas, and original products.

Myfab Infrastructure Overview			
5400 m^2 Cleanroom area	750 Bookable Tools	80 Expert Staff	820 Active Users
Myfab Research			
24 ERC Grants	30 KAW Grants	709 Publications 2023	51 Ph.Ds. 2023

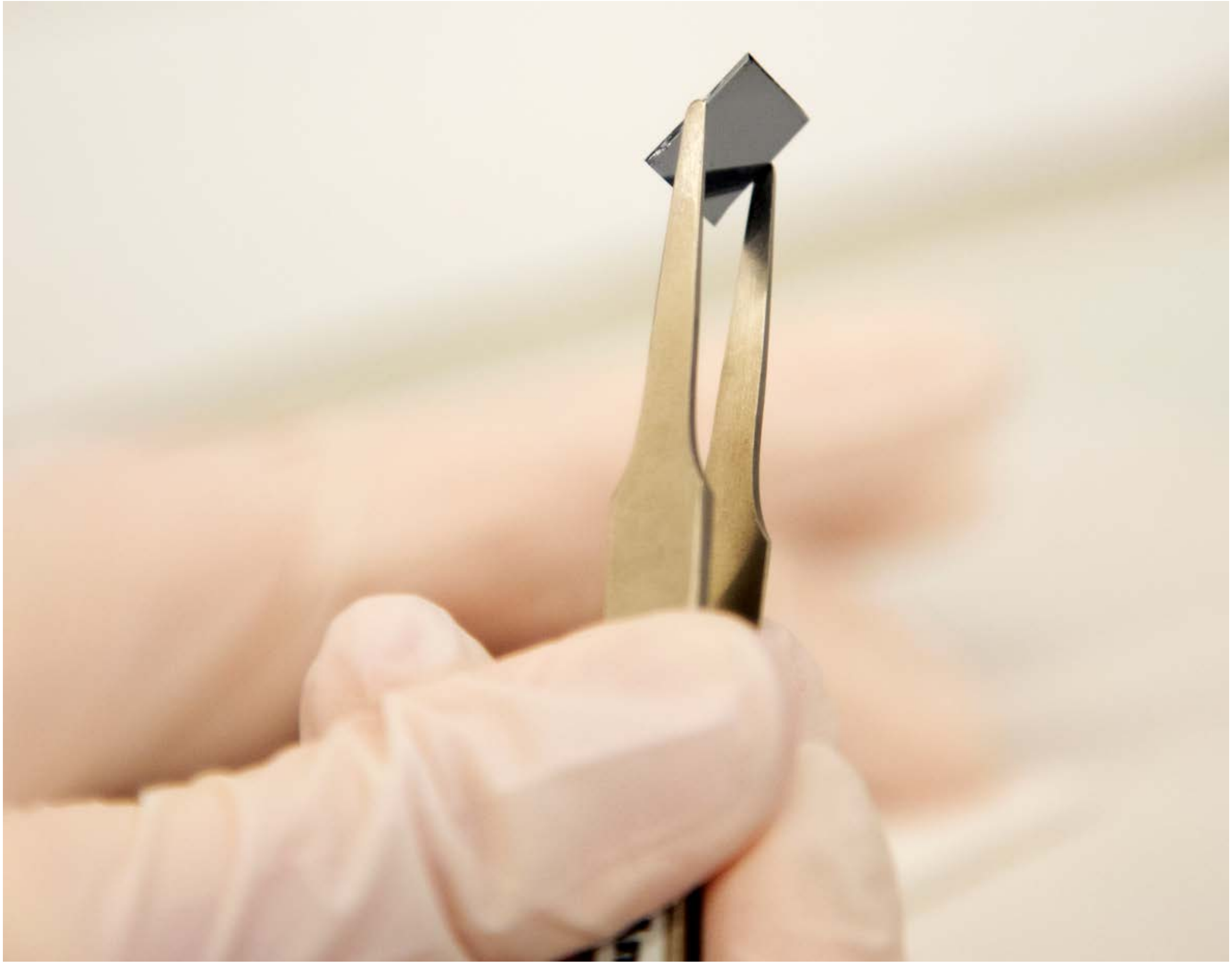
From the Myfab environment 709 publications and 51 doctorial theses were produced during 2023, and during the eight-year period 2016 – 2023, 5986 peer-reviewed publications and 431 PhD students have emerged, which correspond to more than one doctoral thesis per week and more than two peer-reviewed publication per day during eight years! This demonstrates Myfab's capability for the development and fabrication of materials and device structures for advanced research in Sweden.

Business creation and job opportunities are other important outputs from the environment; during the period 2016–2022, 123 innovative companies, mostly small and medium-sized enterprises (SME) and start-ups, have used Myfab. Myfab has often been the launching point for a number of spin-off companies emanating from the research environments using the infrastructure. During a 5-year period, typically 20–30 start-ups emerge from the environment. These spin-offs create an immense societal impact, and we estimate that their total turnover is well beyond one billion SEK per year.



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 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 six other national RIs in Finland, Norway, Ireland, France, Portugal and Latvia, and a cleanroom laboratory in Spain. The system is used by 18 cleanrooms in total, and we have a dozen other lab infrastructures at Swedish Universities that run the system.



New and potentially returning users, with no previous experience from Myfab, are invited to apply for funding for their first project through Myfab Access.

Research at Myfab is often cross disciplinary and covers a wide scientific field. With increasing challenges calling for solutions based on science and innovation, the role of Myfab should be even greater in the years to come. Important initiatives, such as the European Chips Act and the European Green Deal, requires advanced and powerful research infrastructures to reach their goals. Topics addressed by the Chips Act were the initial reason to establish our cleanroom facilities and we are now ready to ramp up our activities in this field. We have updated our investment plan to accommodate for new requirements set by the Chips Act, and we will contribute all the way from education to innovation at high TRL levels. Myfab is absolutely crucial for the position Sweden has in micro- and nanofabrication, and if Sweden is to take a clear role in the European Chip Act.

For the national KAW initiatives WACQT (quantum technology) and the newly *started* WISE (sustainable materials), Myfab is identified as an essential infrastructure. We also support users in new and expanding areas targeting UN's Sustainable Development Goals and provide various types of material for Max IV and ESS users.

GOVERNANCE DURING THE CURRENT PERIOD OF OPERATION 2020 - 2024

Myfab's fifth period of operation started on 1 January 2020 and is promoted by a new model for governing national research infrastructures. Common for all national research infrastructures in Sweden since 2020 is that they have a governing board, the General Assembly (GA or Stämman in Swedish), which oversees general conditions including the consortium agreements and commitments of the participating universities. Myfab's GA thus consists of four members, one each from Chalmers (host), KTH, Lund University and Uppsala University respectively. The GA meets at least once per year.

The Steering group, with members recommended by the General Assembly and appointed by Chalmers University of Technology (Chalmers), consists of seven members. Four of them are representatives proposed by the participating universities, one is an industrial representative, one international representative and finally one from another Swedish university. The steering group oversees Myfab's activities during the current period of operation, which ends on 31 December 2024. The steering group decides on the use of the SRC funding.

The members of Myfab's steering group and appointment periods are presented in Annex B. The steering group normally has four meetings each year, where the director also participates. Through this process we make sure that operations and strategic development are aligned and support the need of our users in the best possible way. The director oversees operations and to implement the decisions by the steering group. The operational management consists of the director and the four laboratory managers and oversees 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 LIMS

We have continued to develop the Myfab LIMS software during 2023. We have launched new functionalities like facility tools where an infrastructure can couple processing tools to a facility system (typically a media provider like cooling water or a gas) where service interventions automatically is propagated as tool status updates on all processing tools connected to that facility system. We have continued the development of the process manager, which still is an alpha version where we need to finish the last third including the run sheet data collection. We have started the development of an updated electronic logbook with much more advanced functionalities such as service triggers and coupling to the process manager. During end of 2023 we also drafted an updated collaboration agreement to be used as a legal framework for the external labs licensing Myfab LIMS.

INTERNATIONAL NETWORKING

Nordic Nanolab Network (NNN)

The Nordic Nanolab Network (NNN) is an established collective of research infrastructures across the Nordic Countries[2]. Through the Nordic Nanolab Network, Myfab benefit from close collaboration between the 12 participation Nordic laboratories on the management, expert and user levels.

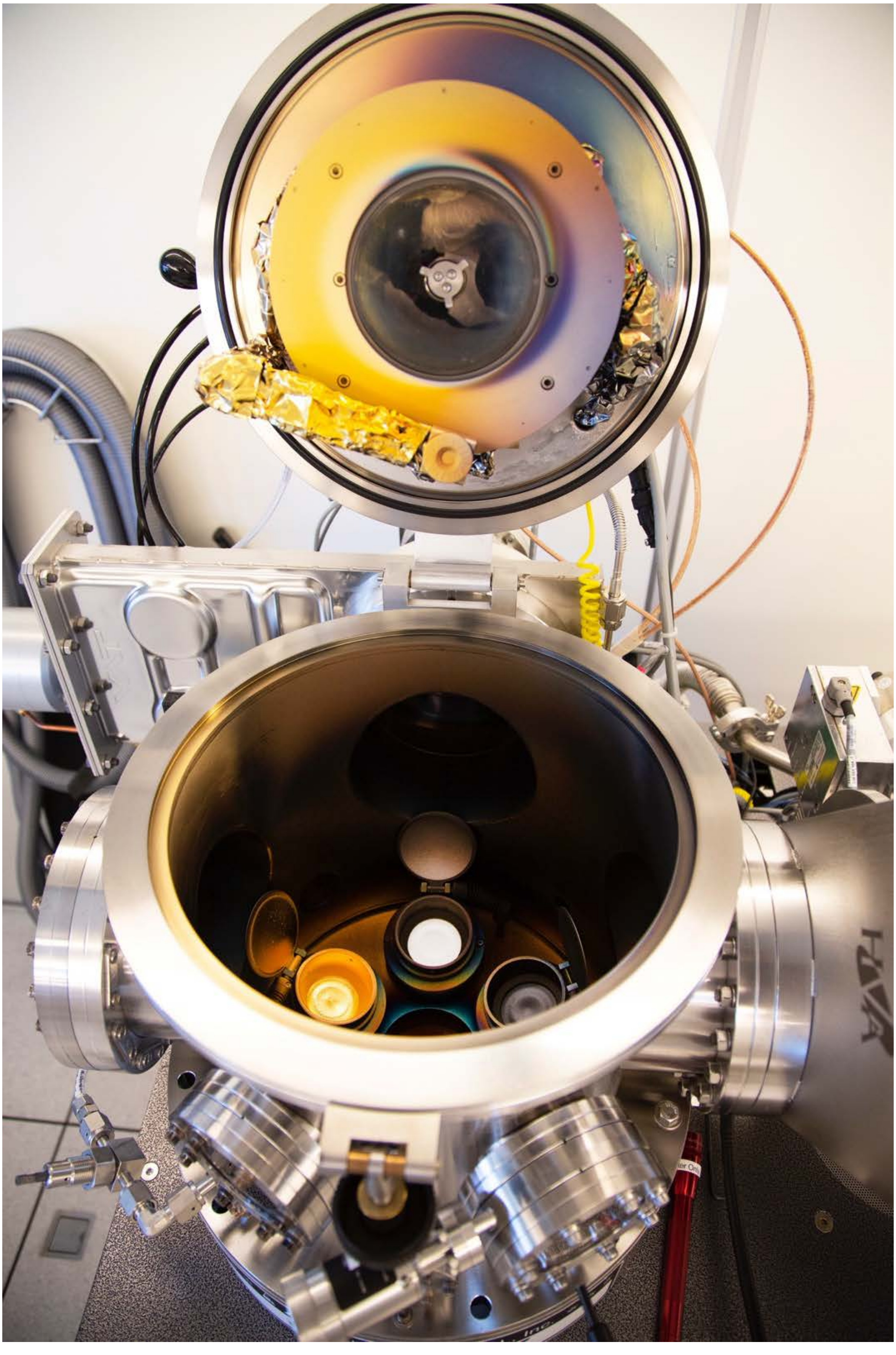
[2] NorFab Norway, DTU Nanolab Denmark, OtaNano /Aalto University and VTT Finland, and the University of Iceland.

At the management level, the NNN partners meet physically typically 2 time per year. NNN arranges the Nordic Nanolab User Meetings (NNUM) every 2:nd year. Last meeting (http://nordicnanolab.se/Home/NordicNanolabUserMeeting2022.aspx) was arranged 5–6 May 2022 in Gothenburg with 300 participants and in 2024, Norway will host the meeting in Oslo during 3–4 June. The target groups for NNUM are current and future users as well as nanofabrication experts and management. Core the program are the tutorials where various fabrication techniques available to the users are presented and explained. Thanks to our international networks, especially NNN and NNEN and the network of Myfab LIMS users, we can assist and propose users with special needs to visit other (national) research infrastructures who also provide open user-access in the Nordic countries.

EuroNanoLab (ENL)

Myfab has actively contributed to the formation of EuroNanoLab (ENL)[3] through the collaboration with its member research infrastructures. Recently, Denmark and Belgium became members to EuroNanoLab, with currently consists of more than 40 cleanroom-based nanotechnology laboratories. ENL is, very much like NNN, inspired by the modus operandi and the user-fee based open access that Myfab has developed. Essential parts of the collaboration are the ENL expert groups and the arrangement of the biennial European Nanofabrication Research Infrastructure Symposium, which was arranged in Paris during 2023 (https://www.enris2023.insight-outside.fr) with record-high participation of about 200. Next ENRIS will be arranged in Bologna 2025 (https://euronanolab.eu/enris-2025-welcome-to-bologna/).

[3] Current members of ENL, in addition to Myfab, are: RENATECH France, NorFab Norway, NanoLab NL the Netherlands, CEITEC the Czech Republic, NCNR Italy, INL Portugal and Spain, DTU Nanolab in Denmark and KU Leuven Belgium.



NODE ACTIVITIES

Myfab Chalmers

In 2023 Myfab Chalmers experienced approximately the same activity in the facility as in last year. We had a small decrease in academic usage (in hours but not in number of users) and a further increase in the commercial use of the lab resulting in a record high commercial income. We saw steep cost increase in for example chemicals and energy but still managed to make a profit of 4,2 MSEK. The profit will as usual go directly to reinvestments.

During the year we have procured a number of tools: a dicing saw (Disco), a film stress measurement system (KLA Tencor), RIE system for oxygen processing (Samco), ICPO/RIE including an atomic layer etching module (Oxford), two SEM systems (Zeiss) and a HF vapour etch (KLA/SPTS). For the facility we have invested in a new control system and a new compressed dry air system (compressor and dryer). We have also initiated a procurement of new ULPA filters for the air handling system and we are investigating how to better handle fluorinated gas residuals from our processing tools.

At the end we also opened for three new positions where two are replacing retirements and one is a final compensation for the staff reduction implemented in 2016 due to the lowered Myfab funding at that time.

Myfab KTH

Myfab KTH consists of two cleanroom facilities, with complementing profiles. Electrum Laboratory in Kista 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 welcome both academic and commercial users.

Electrum Laboratory is equipped for advanced semiconductor processing of complex devices and circuits in Si MEMS and CMOS, SiC power electronics, and InP and GaAs optoelectronics. Most of the tools are intended for industrial production and the process lines are ISO9001 certified, for high quality in complex processing.

All tools financed by the Myfab grant are now in place. The last to arrive were a Dektak XT thin film strain measurement tool and an SPTS ICP deep etcher with a Rapier module for Si and a Synapse module for SiC and SiO2 etching. KTH has financed an Annealsys AS-One RTA system and RISE an Oxford Plasmalab 100 ICP PECVD during the year.

For some years, the cleanroom has been reconstructed, and lab space customized for commercial users and their proprietary tools. This is now finalized, and planning has started to re-organize the wet chemistry in next period.

In the customer satisfaction poll for 2023 Electrum Lab got the highest score ever – 3.3 out of 4.0 – proving that the users are increasingly pleased with the function of the infrastructure.

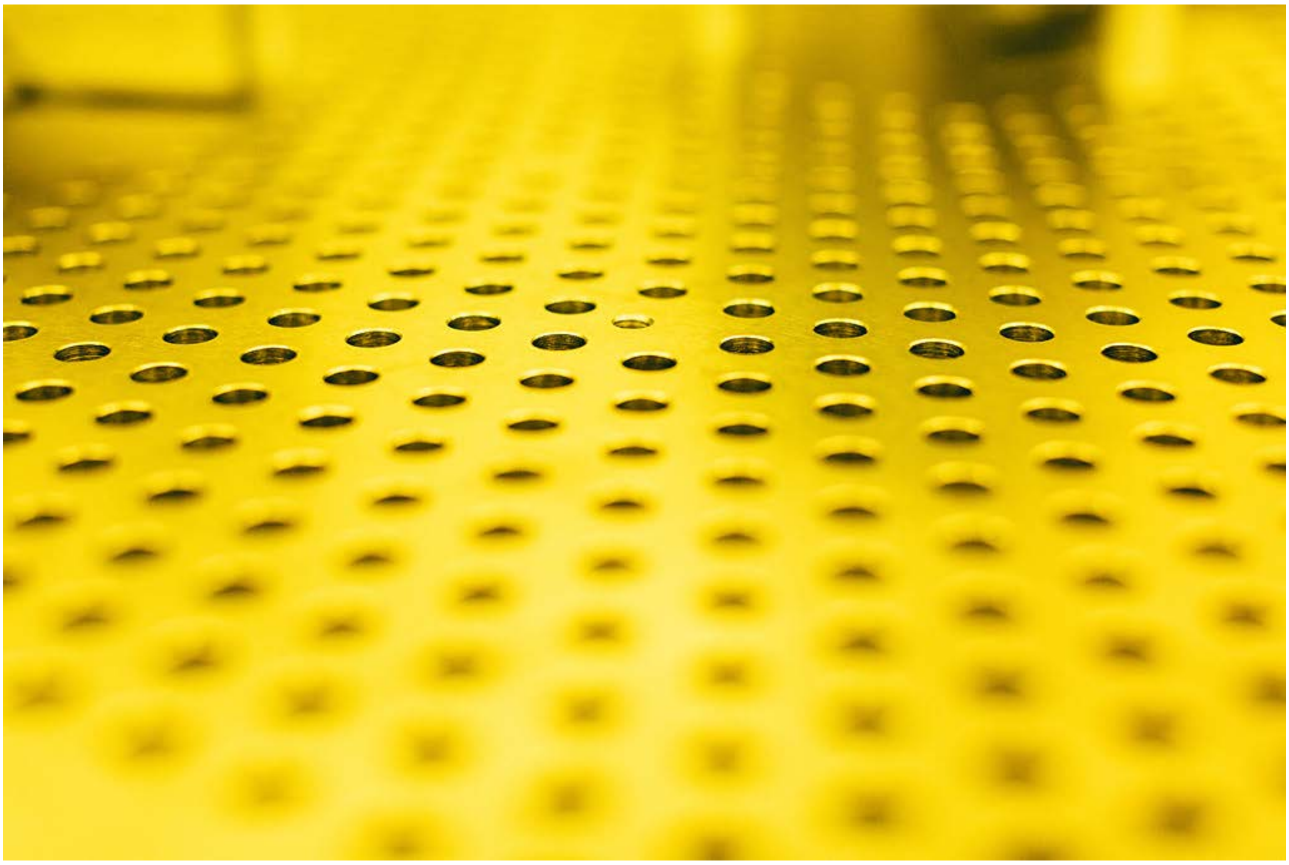
The KTH board of directors decided in November to move all KTH activities in Kista to central campus before end of 2027, except the Electrum Laboratory. The future of the laboratory will be investigated, and in the meantime, the operation will continue unaffected.

Albanova Nano Lab has a focus on materials and quantum physics, allowing a wide flexibility in substrate sizes and materials. Major applications are in the fields of quantum- and nanotechnologies based on e-beam and direct write laser lithography techniques. The facility also comprises an advanced lab for atomic force microscopy.

Albanova Nanolab has received the final chamber of the Myfab funded AJA UHV evaporator, and the tool has been in full operation since the autumn of 2023. The KTH funded Helios 5 UC SEM/FIB from FEI-Thermo Fisher Scientific has been heavily used during the winter. The system is optimized to work at low voltages making it highly suitable to image sensitive materials and insulators. KTH also allocated about 3 MSEK for a new front-door-loading evaporator for dirty and bulky samples. Procurement expected to finish in early 2024. KAW-WISE program has granted 21 MSEK to ANL for ALD-CVD AtomFab cluster for fabrication of advanced materials with atomic mono-layer precision and their device integration.

Due to the steady growth over the past several years, the Albanova Nanolab has a need for extra lab space. Concrete plans have been made to expand by absorbing nearby rooms, available during 2024. Redesign of the new space will be required as well as work on connecting our existing lab space to the new rooms.

The level of activity in 2023 was a new record for Albanova Nanolab, both in terms of tool-hours booked and number of users in the lab, with user fees contributing about three quarters of the running costs of the lab.



Myfab Lund

Myfab Lund serves as an excellent resource at Lund University, playing a crucial role in facilitating research and education in nanoscience and nanotechnology across the faculties of Engineering (LTH), Science (FoS), and Medicine (FoM) at Lund University. Myfab Lund has a clearly defined set of strategic objectives and initiatives aligned with the goals of the Strategic Research Area, NanoLund. In 2023, Myfab Lund had 106 active academic users from 30+ research groups: 66% from the Faculty of Engineering, 31% from the Faculty of Science, and 3% from the Faculty of Medicine. Additionally, 5 institute users and 22 commercial users from 9 companies contributed to the collaborative environment. The lab conducts hands-on courses for around 100 students annually on Processing and Device Technology and a total of 10 diploma students completed their thesis work in Myfab Lund for free. Notably, 38 new users underwent essential introductory training. Beyond these direct users, there exists a broader community of indirect users who leverage the devices, materials, and structures fabricated at Myfab Lund in their own research endeavours.

The research pursuits cover a wide spectrum, ranging from quantum technology and novel materials development to sustainable energy, semiconductor technology, and precision medicine. Myfab Lund has an impressively large research output: in 2023, active users co-authored 137 publications, with authors affiliated with the Faculty of Engineering (LTH), the Faculty of Science, and the Faculty of Medicine. There were 13 Ph.Ds. awarded to Myfab Lund users in 2023. The excellence can also be gauged by several ERC and EIC grants in which the lab plays an important role as well as a large number of VR, VINNOVA, SSF and WISE grants in which the lab facilities are used.

Recognizing its strategic importance, LTH, FoS, FoM, NanoLund, and LU are actively supporting and participating in the plans for the development of a new NanoLab at Science Village (NLSV).

Myfab Uppsala

A shared cleanroom for a broad range of materials science was the principal motivation to establish the Ångström Laboratory. After more than a quarter century and a number of expansions, it has grown into a campus for mathematics, physics, chemistry, technology and computer sciences. The cleanroom is now part of Myfab, bringing the idea about a shared research infrastructure to the national level.

With a user base primarily from the departments of Physics, Chemistry, Materials Science and Electrical Engineering the research activities still cover a wide spectrum from fundamental science to thin film technology, with major applications in sustainable energy (generation and storage), emerging electronics and biomedical engineering. During 2023 the user base was slightly reduced, and the tool bookings did not reach the same level as the year before, which is attributed to periodic fluctuations in combination with some extended technical issues with key equipment. Nevertheless, 85 new users were introduced which substantially improves the future prospects.

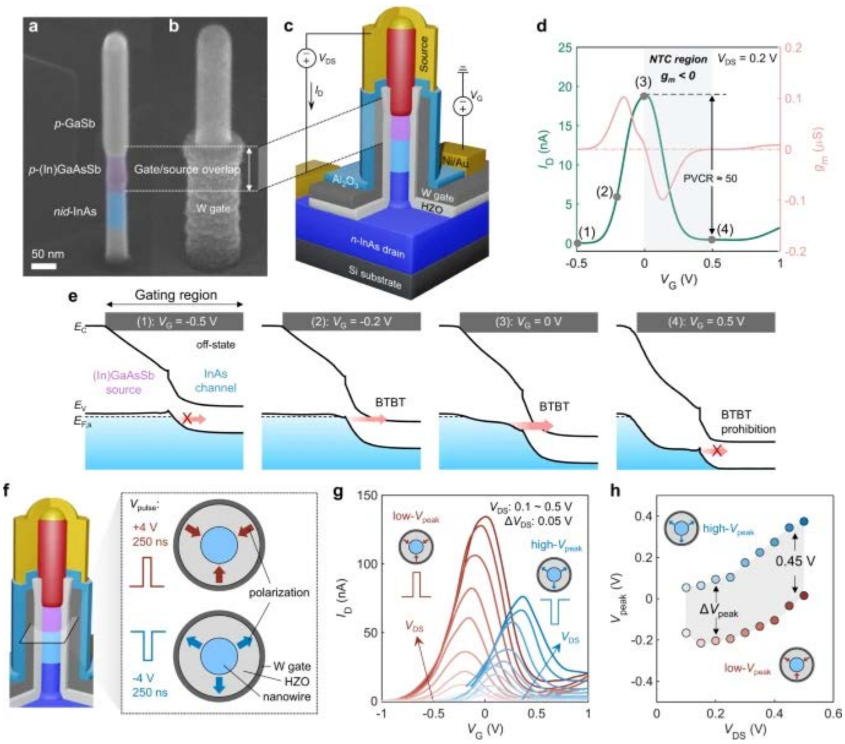
Procurements proceeded with deliveries of the TEM energy filter and the UHV-PVD system. The new EBL and the complementary 3D printer should be delivered in 2024. Testing and final acceptance of the UHV-PVD will also be delayed until next year since there have been some start-up issues. Our investment plan is being revised. This is done in five thematic committees and the result shall be presented in the beginning of 2024.

The general cost increase calls for actions to raise income and cut expenses. One important action has been to install gas flow meters to monitor the consumption of distributed gas. This will improve our ability to track excessive usage and distribute the cost more accurately.

SELECTED USER SUCCESS STORIES

Information and Communication Technologies

Reconfigurable signal modulation in a ferroelectric tunnel field-effect transistor

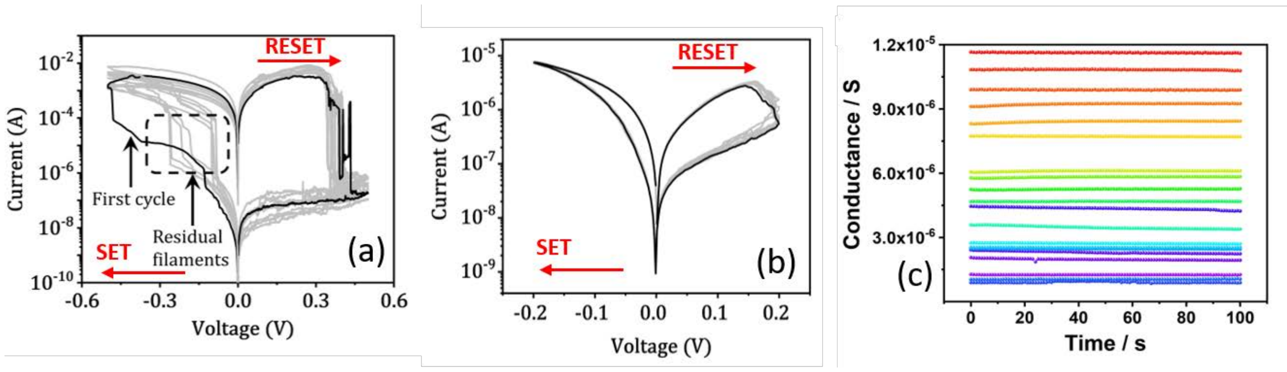


Reconfigurable transistors are an emerging device technology adding new functionalities while lowering the circuit architecture complexity. However, most investigations focus on digital applications. Here, we demonstrate a single vertical nanowire ferroelectric tunnel field-effect transistor (ferro-TFET) that can modulate an input signal with diverse modes including signal transmission, phase shift, frequency doubling, and mixing with significant suppression of undesired harmonics for reconfigurable analogue applications. We realize this by a heterostructure design in which a gate/source overlapped channel enables nearly perfect parabolic transfer characteristics with robust negative transconductance. By using a ferroelectric gate oxide, our ferro-TFET is non-volatilely reconfigurable, enabling various modes of signal modulation. The ferro-TFET shows merits of reconfigurability, reduced footprint, and low supply voltage for signal modulation. This work provides the possibility for monolithic integration of both steep-slope TFETs and reconfigurable ferro-TFETs towards high-density, energy-efficient, and multifunctional digital/analogue hybrid circuits.

Reconfigurable signal modulation in a ferroelectric tunnel field-effect transistor, Zhongyunshen Zhu, Anton E. O. Persson & Lars-Erik Wernersson, Nature Communications volume 14, Article number: 2530 (2023). https://doi.org/10.1038/s41467-023-38242-w

Ag_2S-based Memristors for Energy-Efficient Neuromorphic Computing

Zhen Zhang's group has explored nanoscale memristor devices for energy-efficient neuromorphic computing in Myfab-Uppsala. They have demonstrated a Ag2S-based memristor device with a record high 106 ON/OFF ratio at about ± 0.5 V switching voltage, based on a new interface and filament combined resistance-switching (RS) mechanism (See Fig. 1a)1. They have further achieved RS with significantly reduced variability in the setting/resetting cycles2, and ultra-low switching energy down to ~0.2 fJ (close to that of biological synapses)3, based ONLY on the Schottky-barrier height modification at the contact interface in the Ag2S memristors (see Fig. 1b and c). They currently work on the wafer scale integration of Ag2S-based memristive crossbar array based on the new interface RS mechanism for reliable and energy neuromorphic computing.



Setting/resetting cycles of a single Ag_2S memristor (in thick film) with interface and filament combined RS mechanism. (b) Setting/resetting cycles of the same memristor with solely interface RS. (c) Retention of 20 conductive states set by interface RS in the thick film.

Zhu, Y., et al, High Performance Full-Inorganic Flexible Memristor with Combined Resistance-Switching. ACS Appl. Mater. Interfaces 2022, 14 (18), 21173–21180.

Zhu, Y., et al, Interface Resistance-Switching with Reduced Cyclic Variations for Reliable Neuromorphic Computing, Journal of Physics D: Applied Physics (2023), DOI: 10.1088/1361-6463/ad0b52.

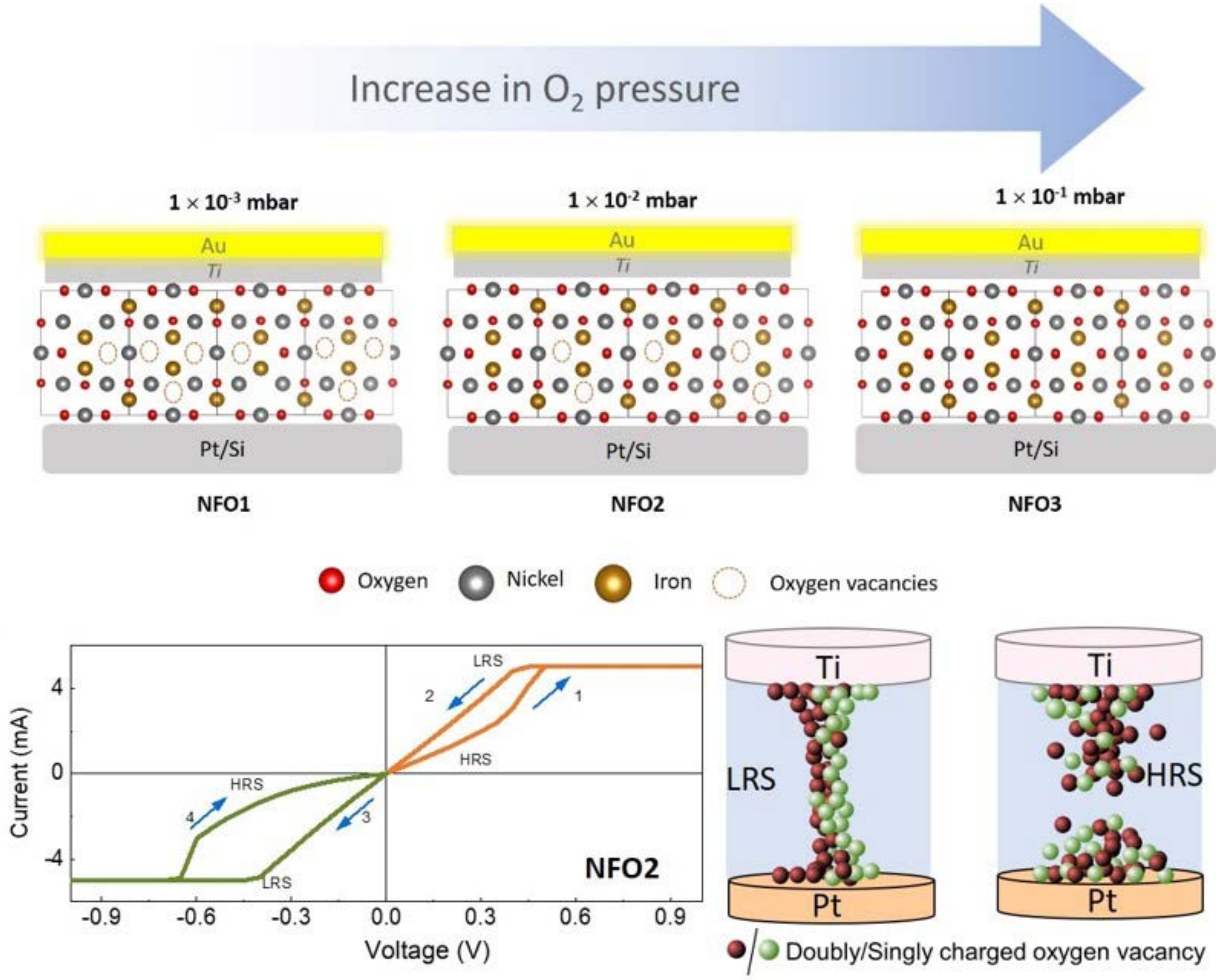
Zhu, Y., et al, Full-Inorganic Flexible Ag2S Memristor with Interface Resistance−Switching for Energy-Efficient Computing. ACS Appl. Mater. Interfaces 2022, 14 (38), 43482–43489.

Silicon JoFET Technology

The demand of large-scale quantum computing for computational tasks such as drug development involving complex molecular interactions among thousands of molecules motivates research on semiconducting quantum bits whose fabrication is compatible with advanced CMOS technology. The research on silicon superconducting transistor led by Shi-Li Zhang and Zhen Zhang at Uppsala University has resulted in a PCT patent application on seamless integration of superconducting source/drain contacts in the transistor structure based on state-of-the-art CMOS process technology. To pave the way for this integration, the group has developed a so-called self-alignment process for the formation of superconducting PtSi films down to 3 nm in thickness with Tc=0.6-0.9 K.

Vacancy Engineered Nickel Ferrite Forming-Free Resistive Switches for Neuromorphic Circuits

Innovations in resistive switching devices constitute a core objective for the development of novel ultralow-power computing devices. Forming-free resistive switching is a type of resistive switching that eliminates the need for initial high voltage for the formation of conductive filaments and offers promising opportunities to overcome the limitations of traditional resistive switching devices. At the Department of Materials Science and Engineering, Uppsala University, the team of Tapati Sarkar has demonstrated mixed charge state oxygen vacancy-engineered electroforming-free resistive switching in NiFe2O4 (NFO) thin films, fabricated as asymmetric Ti/NiFe2O4/Pt heterostructures, for the first time. The NFO films were grown on Pt-coated silicon substrates using pulsed laser deposition in a controlled oxygen atmosphere (at Myfab-Chalmers), while titanium (Ti)/gold (Au) contacts were deposited in a high vacuum e-beam unit using shadow masks at Myfab-Uppsala. The controlled growth using a wide oxygen partial pressure range between 1 × 10-3 mbar to 1 × 10-1 mbar allowed a careful tuning of the oxygen vacancies together with the cationic valence state in the nickel ferrite phase, the latter directly affecting the charge state of the oxygen vacancies. Electrical transport studies revealed that this tuning of the oxygen vacancy concentration and their charge state during the deposition of the films significantly altered the resistive switching characteristics in the films.



The resistive switching mechanism was seen to depend upon the migration of both singly and doubly charged oxygen vacancies formed as a result of changes in the nickel valence state and the consequent formation/rupture of conducting filaments in the switching layer. There exists an optimum oxygen vacancy concentration for efficient low-voltage resistive switching, below or above which the switching process is inhibited. Along with the filamentary switching mechanism, the Ti top electrode also enhanced the resistive switching performance due to interfacial effects. Time-resolved measurements on the devices displayed both long-term and short-term potentiation in the optimized vacancy-engineered NFO resistive switches, ideal for solid-state synapses achieved in a single system.

Rajesh Kumar R, Alexei Kalaboukhov, Yi-Chen Weng, K. N. Rathod, Ted Johansson, Andreas Lindblad, M. Venkata Kamalakar, and Tapati Sarkar, Vacancy engineered nickel ferrite forming-free low-voltage resistive switches for neuromorphic circuits. Accepted in ACS Applied Materials & Interfaces (2024).

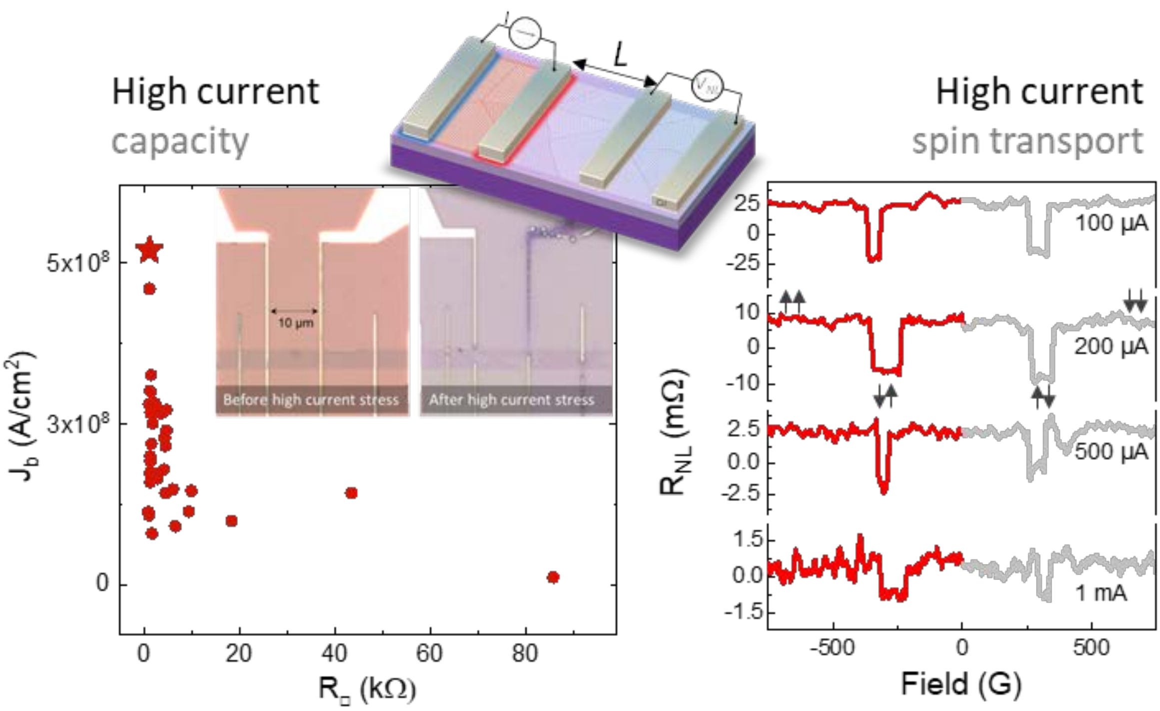
* This work is part of ongoing research in the VR project grant "Novel hybrid structures for new-age resistive memory-logic devices" (Grant number: 2021-03675; PI: Tapati Sarkar).

Enabling Endurance and Novel Platforms for Nanoelectronics and Spintronic Circuits

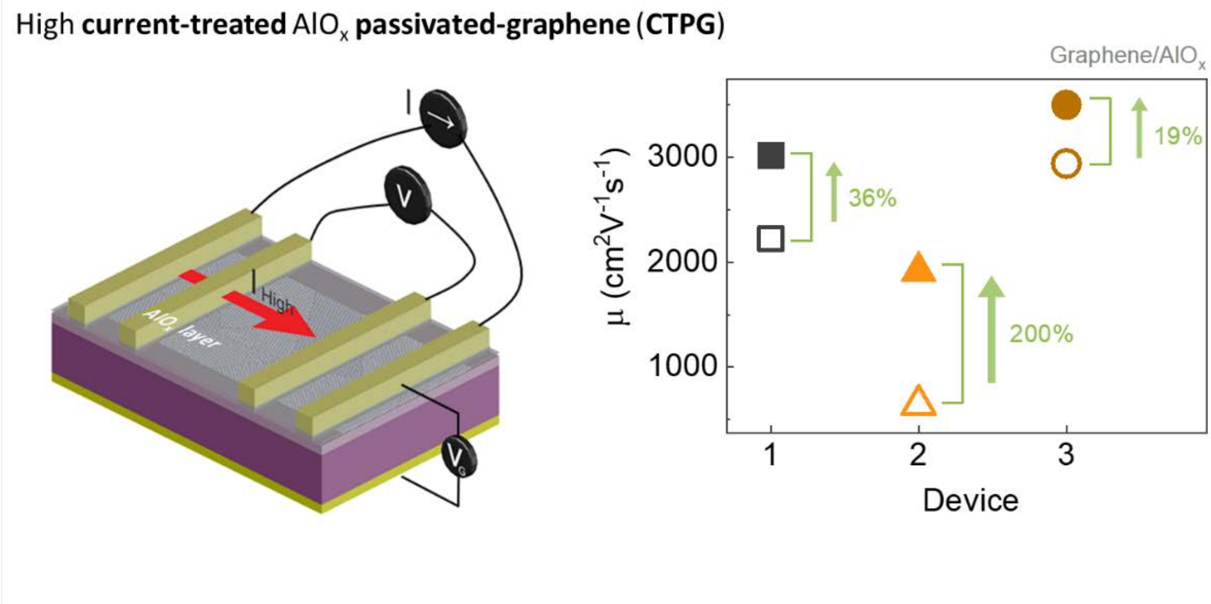
The Quantum Material Device Team (PI: Venkata Kamalakar Mutta) is a rapidly expanding international research group funded by the prestigious European Research Council (ERC consolidator grant 2020), VR, Formas, Olle Engvkist Foundation, and the Knut and Wallenberg Foundation. It is at the forefront of nanodevice research at Uppsala University, specializing in spin and orbital electronics for next-generation ultralow power and neuromorphic components. The team probes the fundamental physics of charge, spin, and orbital dynamics in low-dimensional and atomically thin materials & their heterostructure-based devices, prepared by the state-of-the-art nanofabrication techniques in Myfab at UU. Quantum materials such as two-dimensional crystals with semiconducting, magnetic, and superconductivity and their cutting-edge van der Waal heterostructures are prepared using the group's physical and chemical vapor deposited techniques. The experiments involve low-temperature charge and spin transport phenomena, nano magneto-optic Kerr effect, and precision optoelectronic and spintronic measurements. In 2025, the team will commission the first milli-kelvin dilution refrigerator at Uppsala University with a 10 mK base temperature facility to identify new quantum phases.

One prime aim of the QMD group is to enable a robust platform for building two-dimensional nanoelectronic and spintronic circuits. For this purpose, the core challenges are standardizing a large-scale form of graphene and its integration with state-of-the-art metal oxides that can address reliability at the component and circuit levels in scalable materials and interfaces. The team made two new developments towards endurance and performance enhancement in CVD graphene devices.

Published in Nano Research 2023 [1], the team demonstrated high Current Limits in Chemical Vapor Deposited Graphene Spintronic Devices, where they showed the high current carrying capacity ~ 5×10^{8}A/cm^2 in CVD graphene on Si/SiO_2 and high current spintronic devices for the first time working at current densities ~10^{8}A/cm^2 (Figure below).



Harnessing such extreme current carrying capacity of CVD graphene, they came up with a novel concept to achieve scalable current-treated passive graphene (CTPG), where they passivated graphene with an aluminium oxide layer and applied high current to enhance quality for achieving high-quality materials for scalable applications. This work was published in Nanoscale Horizons **2024** [2] and presents a novel platform for stable nanoelectronic and spintronic applications.

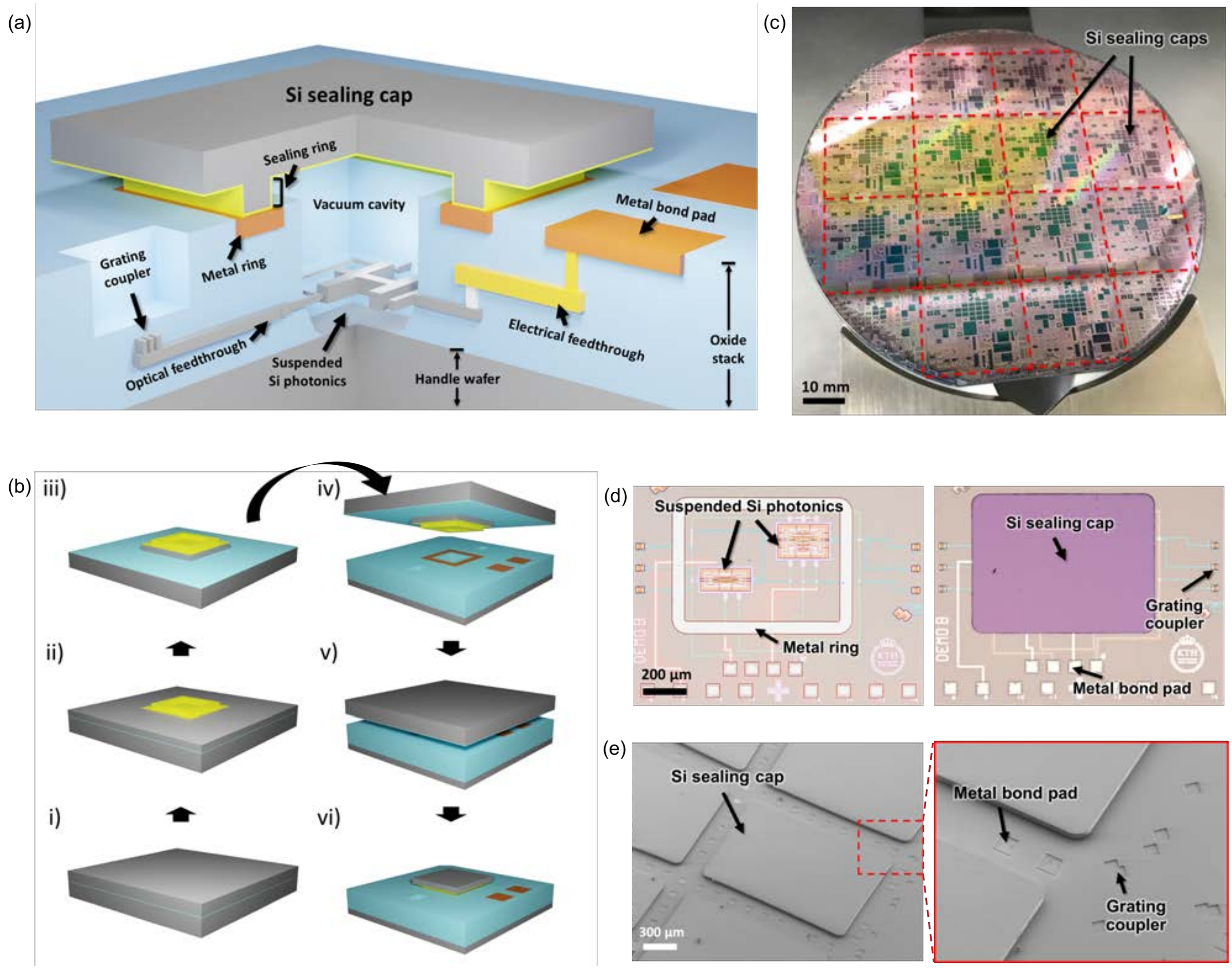


[1] D. Belotcerkovtceva, J. Panda, M. Ramu, T. Sarkar, U. Noumbe, and M. V. Kamalakar, *High Current Limits in Chemical Vapor Deposited Graphene Spintronic Devices*, Nano Res **16**, 4233 (2023).

[2] D. Belotcerkovtceva, H. Nameirakpam, G. Datt, U. Noumbe, and M. Venkata Kamalakar, *High Current Treated-Passivated Graphene (CTPG) towards Stable Nanoelectronic and Spintronic Circuits †*, This Journal Is Cite This: Nanoscale Horiz **9**, 456 (2024).

Wafer-level Hermetically Sealed Silicon Photonic MEMS

The emerging fields of silicon (Si) photonic micro-electromechanical systems (MEMS) and optomechanics enable a wide range of novel high-performance photonic devices with ultra-low power consumption. However, photonic MEMS are susceptible to environmental influences such as exposure to dust, gas composition, and humidity, and, therefore, require a robust packaging to ensure reliable operation over extended time periods. Hermetic sealing in inert gas or vacuum is crucial for their reliable performance and serves as a prerequisite for their commercialization. We have demonstrated wafer-level hermetic sealing of Si photonic MEMS inside cavities with electrical and optical feedthroughs. We validate the feasibility of our approach by sealing Si photonic MEMS devices on foundry wafers from the photonics platform of IMEC, Belgium.



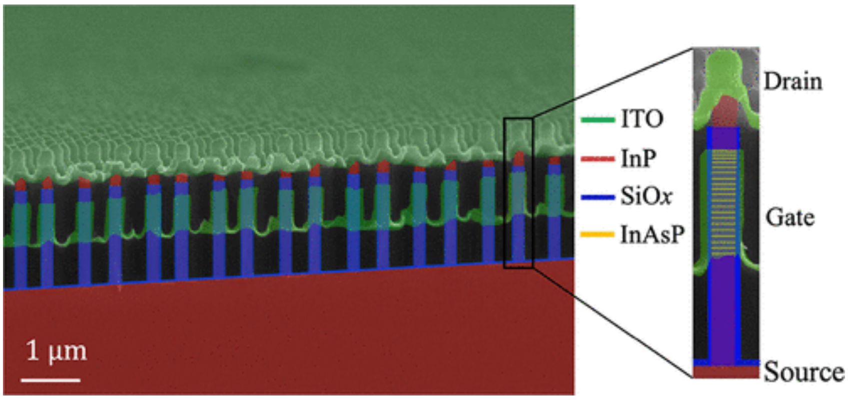
Wafer-level hermetic packaging of Si photonic MEMS. (a) Cut-away 3D illustration of a hermetically sealed suspended photonic MEMS device. (b) Process flow of the hermetic packaging approach by transfer bonding of a Si sealing cap: Step i-ii) Patterning of sealing rings by deep reactive ion etching (DRIE) on the SOI cap wafer, followed by TiW/Au deposition and etching. iii) Etching of the sealing caps. iv-v) Wafer alignment of the SOI wafer containing the caps and the photonic device wafer, and bonding of the wafers inside a vacuum chamber at 250 . vi) Removal of the Si handle (substrate) layer of the SOI cap wafer by DRIE such that only the thin vacuum sealing caps remain on the photonic device wafer. (c) Photograph of a full wafer with sealed Si photonic MEMS. (d) Microscope images before sealing (left), and after sealing (right). (e) SEM images of the bond pads and grating couplers around the thin sealing caps.

Our sealing approach uses low-temperature (250 ℃) thermo-compression wafer bonding that is fully compatible with the Si photonic foundry wafers. We have demonstrated a vacuum sealing yield of 90 %. The vacuum encapsulated photonic devices feature higher mechanical quality factors (Q) and increased mechanical cut-off frequency, due to the elimination of air damping.

Jo, Gaehun, Pierre Edinger, Simon J. Bleiker, Xiaojing Wang, Alain Yuji Takabayashi, Hamed Sattari, Niels Quack Frank Niklaus, et al. "Wafer-level hermetically sealed silicon photonic MEMS." Photonics Research 10, no. 2 (2022): A14-A21.

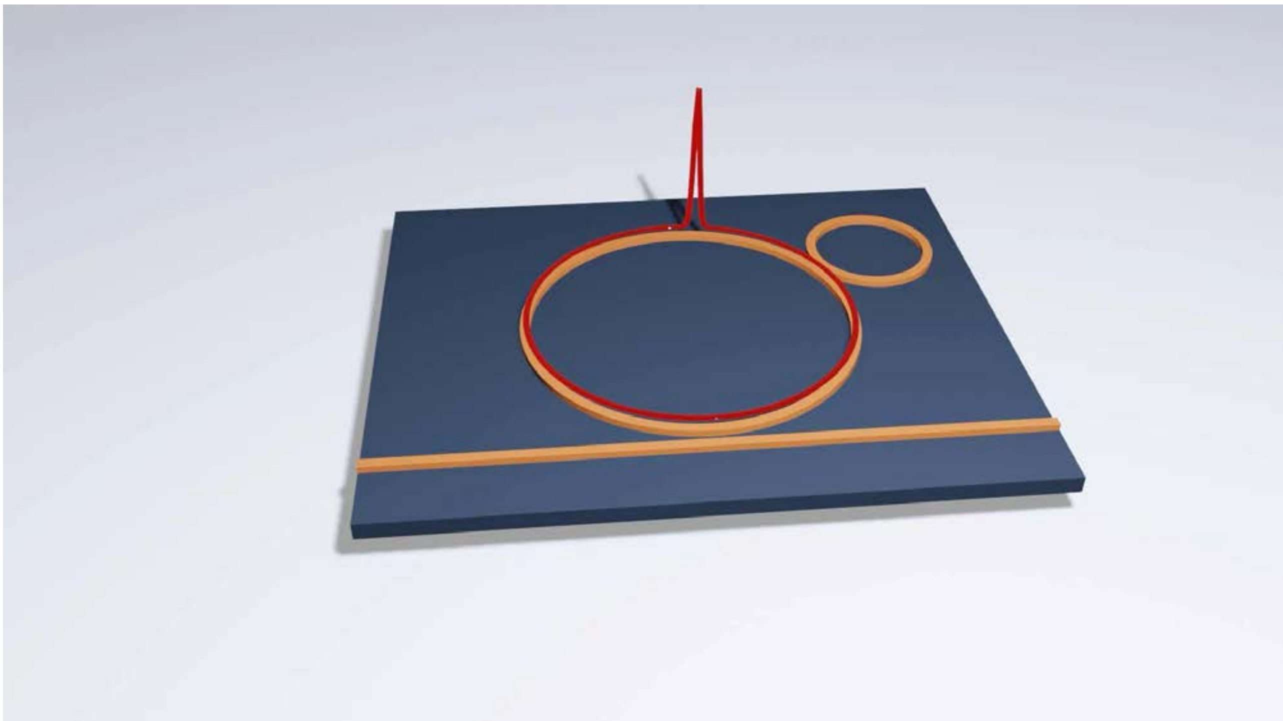
Bogaerts, Wim, Alain Yuji Takabayashi, Pierre Edinger, Gaehun Jo, Iman Zand, Peter Verheyen, Moises Jezzini, Frank Niklaus et al. "Programmable silicon photonic circuits powered by MEMS." In Smart Photonic and Optoelectronic Integrated Circuits 2022, vol. 12005, pp. 55-69. SPIE, 2022.

Spectrally Tuneable Broadband Gate-All-Around InAsP/InP Quantum Discs-in-Nanowire Array Phototransistors with a High Gain-Bandwidth Product



High-performance broadband photodetectors offering spectral tunability and a high gain-bandwidth product are crucial in many applications. Here, we report on a detailed experimental and theoretical study of three-terminal phototransistors comprised of three million InP nanowires with 20 embedded InAsP quantum discs in each nanowire. A global, transparent ITO gate all around the nanowires facilitates a radial control of the carrier concentration by more than two orders of magnitude. The transfer characteristics reveal two different transport regimes. In the subthreshold region, the photodetector operates in a diffusion mode with a distinct onset at the bandgap of InP. At larger gate biases, the phototransistor switches to a drift mode with a strong contribution from the InAsP quantum discs. Besides an unexpected spectral tunability, the detector exhibits a state-of-the-art responsivity, reaching around 100 A/W (638 nm/20 μW) @ VGS = 1.0 V/VDS = 0.5 V with a gain-bandwidth product of around 1 MHz, in excellent agreement with a comprehensive real-device model.

Spectrally Tunable Broadband Gate-All-Around InAsP/InP Quantum Discs-in-Nanowire Array Phototransistors with a High Gain-Bandwidth Product, Jeddi, H., Witzigmann, B., Adham, K., Hrachowina, L., Borgstrom, M. T., & Pettersson, H. (2023). ACS Photonics. (2023) 085003
https://doi.org/10.1021/acsphotonics.2c02024



The two rings in the image are microresonators. The bigger ring is the one where the microcomb is generated. The microcomb is formed by a pulse of light – here illustrated with a red spike and also known as a soliton - that recirculates in the cavity forever. The key aspect is that the smaller ring helps in coupling the light from the straight waveguide, illustrated by the straight orange line at the bottom, into the bigger ring. In other words, it behaves as impedance matching, and therefore the soliton is generated more efficiently.

New method makes microcombs ten times more efficient

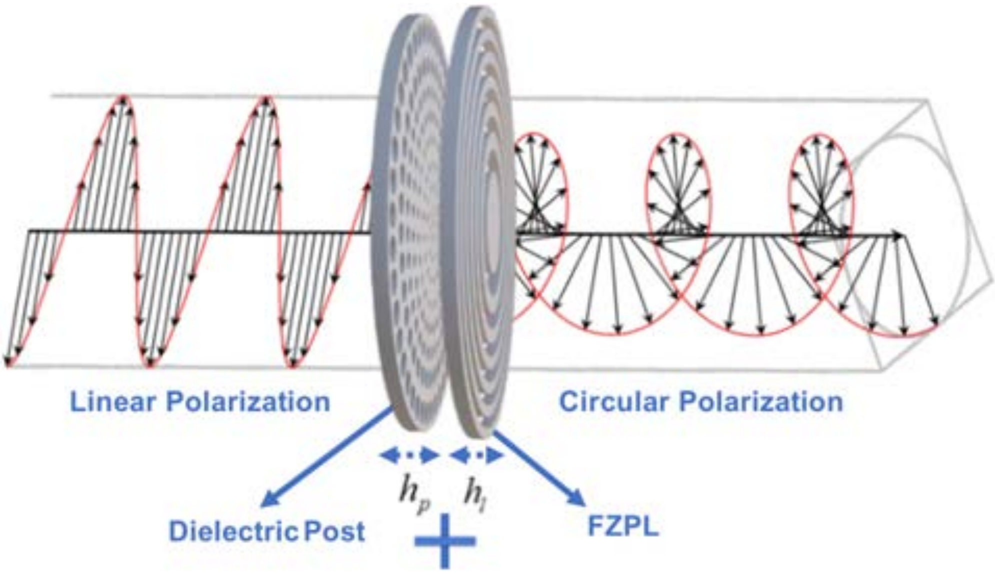
Microcombs can help us discover planets outside our solar system and track new diseases in our bodies. But current microcombs are inefficient and unable to reach their full potential. Now, researchers at Chalmers University of Technology in Sweden have scored a world first with their solution to make microcombs ten times more efficient. Their breakthrough opens the way to new discoveries in space and healthcare and paves the way for high-performance lasers in a range of other technologies. Laser frequency combs can measure frequencies with revolutionary precision and are considered the most disruptive technological advance in the field since the birth of the laser. Simply put, a microcomb is like a ruler made of light. The principle is based on a laser sending photons that circulate inside a small cavity, a so-called microresonator, where the light is divided into a wide range of frequencies. These frequencies are precisely positioned in relation to each other, like the markings on a ruler. Thus, a new kind of light source can be created consisting of hundreds – or even thousands – of frequencies, like lasers beaming in unison. Since virtually all optical measurements are connected to light frequencies, the microcomb has a multitude of applications – from calibrating instruments that measure signals at light-year distances in space in the search for exoplanets, to identifying and keeping track of our health via the air we exhale. "We've developed a new method that breaks what was previously thought to be a fundamental limit for optical conversion efficiency. Our method increases the laser power of the soliton microcomb by ten times and raises its efficiency from around 1 percent to over 50 percent," says Victor Torres Company, Professor of Photonics at Chalmers.

Helgason, Ó.B., Girardi, M., Ye, Z. *et al.* Surpassing the nonlinear conversion efficiency of soliton microcombs. *Nat. Photon.* **17**, 992–999 (2023).

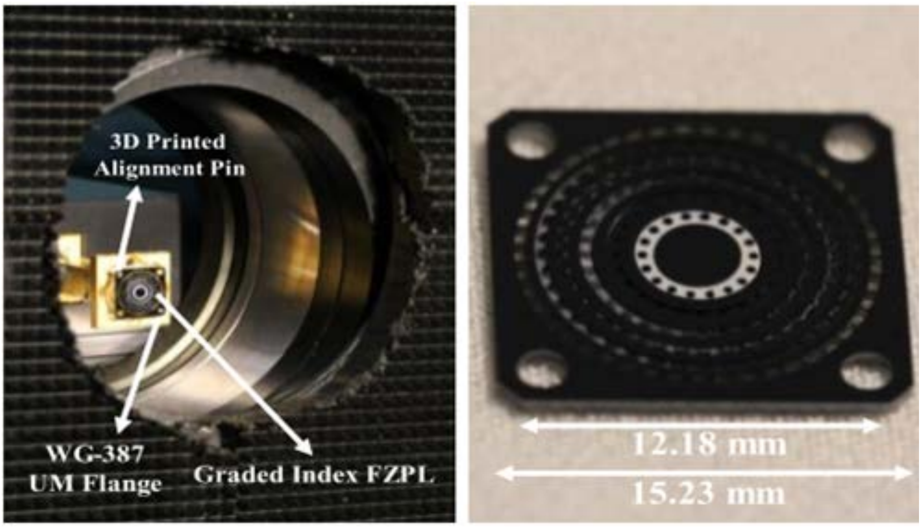
THz antennas

The THz lab at KTH-EECS-IS-MST has developed a compact, 15x15 mm2 micromachined lens antenna for highly directed telecommunication at 500-750 GHz, fabricated at the Electrum Laboratory at KTH. The antenna features an optimized graded-index Fresnel zone planner lens (FZPL) design and radiates a circularly polarized wavefront without the need for additional phase compensation components. The antenna achieves a measured gain of

36 dBi and maintains a return loss better than -15 dB across the whole bandwidth of 500 to 750 GHz. The average measured total efficiency is -1.05 dB for the whole band 500 to 750 GHz, very close to the average simulated total efficiency of -0.73 dB. This antenna efficiency and gain is unparalleled in this frequency range. The circular polarization is achieved by a dual-layer design where the first layer provides the phase shift, and the second layer contains the optimized, graded-index Fresnel zone lens. The bottom layer also facilitates the feeding of the antenna from a standard WM-380 open-ended waveguide port to illuminate the antenna.

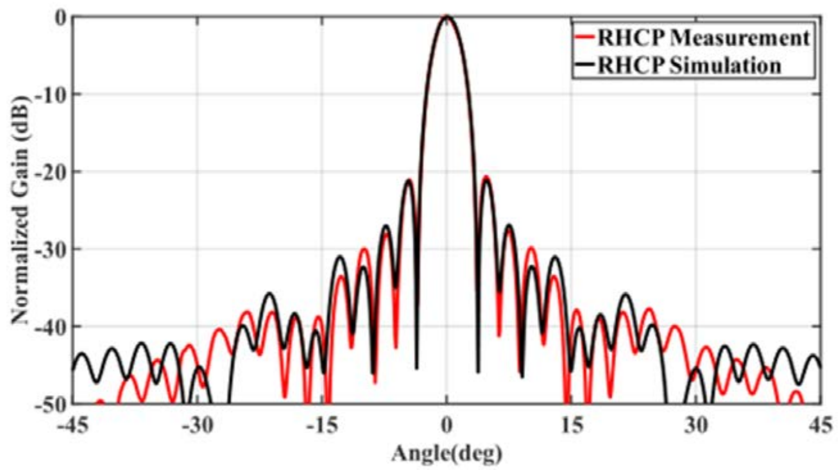


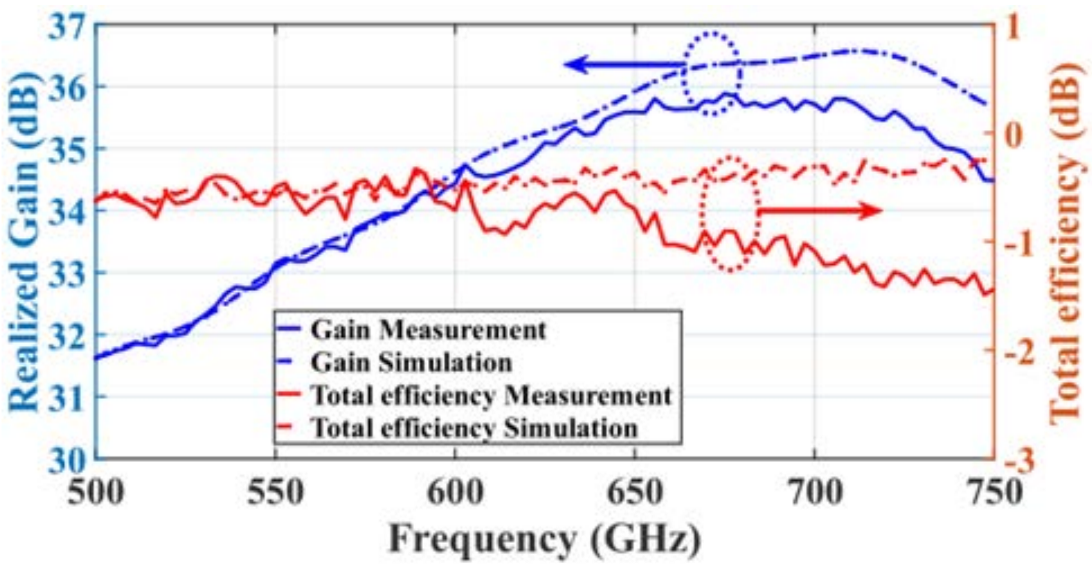
Concept of 500-750 GHz graded-index Fresnel zone planner lens antenna with dielectric feeding and circular-polarization post.



Measurement setup (left) with fabricated micromachined antenna (right).

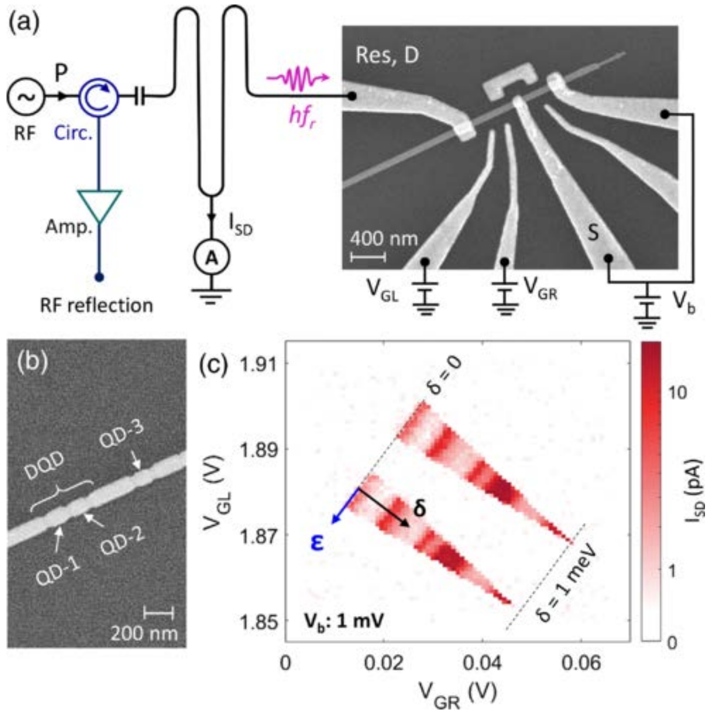
The measured antenna radiation patterns show excellent agreement with the simulation data and were carried out in a far-field setup in the fully automated THz antenna chamber at KTH. This THz antenna characterization facility can be used with calibrated antennas from 75 to 750 GHz. The work was carried out by the PhD student Alireza Madannejad under the supervision of Prof. Joachim Oberhammer. Funding was provided through the SSF project CHI19 -0027.





Characterization results: (top) measured radiation pattern as compared to simulations, at 625 GHz; (bottom) realized gain and total antenna efficiency, measurement data compared to simulation data.

Energetics of Microwaves Probed by Double Quantum Dot Absorption



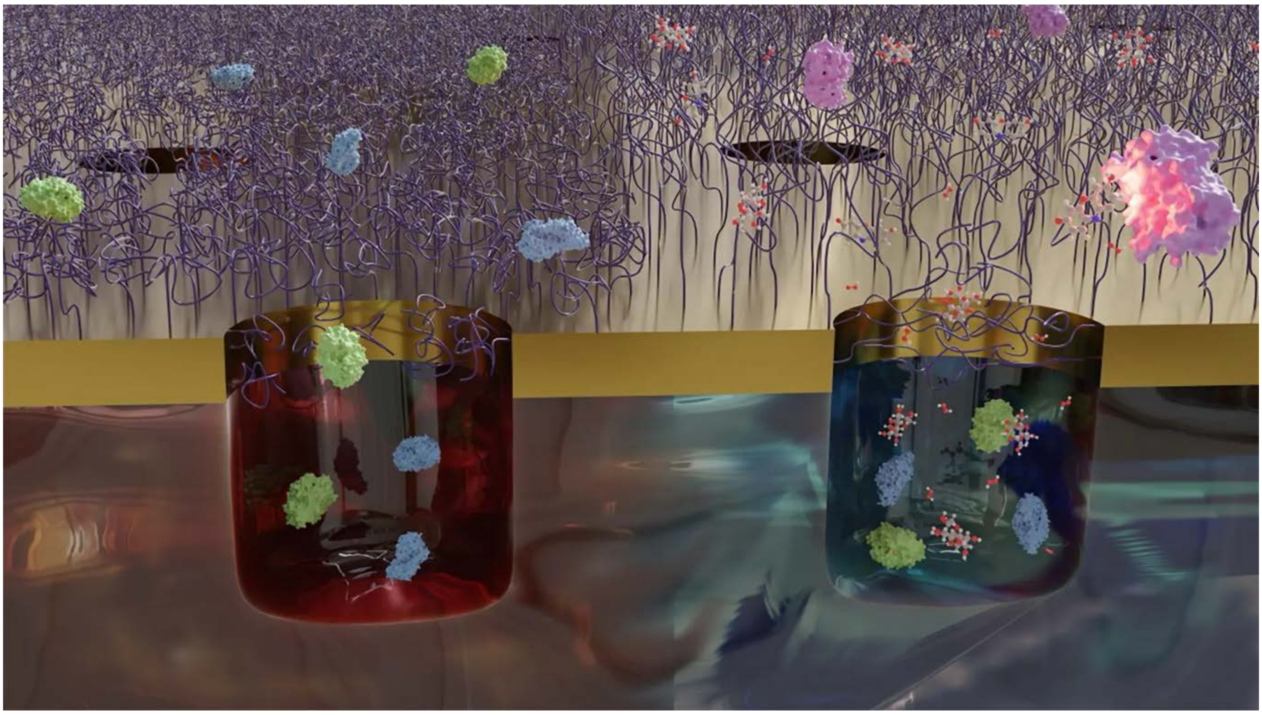
This study probes the relevant energy in a microwave signal with a double quantum dot absorber. The experiments show that the single-photon energy sets the relevant absorption energy in a weak-drive limit, which contrasts the strong-drive limit where the wave amplitude determines the relevant-energy scale and opens up microwave-induced bias triangles. The threshold condition between these two regimes is set by the fine-structure constant of the system. The energetics are determined here with the detuning conditions of the double dot system and stopping-potential measurements that constitute a microwave version of the photoelectric effect.

Energetics of Microwaves Probed by Double Quantum Dot Absorption, Subhomoy Haldar, Harald Havir, Waqar Khan, Sebastian Lehmann, Claes Thelander, Kimberly A. Dick, and Ville F. Maisi. Phys. Rev. Lett. 130, 087003 (2023), https://doi.org/10.1103/PhysRevLett.130.087003

Life Sciences

Tiny traps can provide new knowledge about difficult-to-treat diseases

Proteins that form clumps occur in many difficult-to-treat diseases, such as ALS, Alzheimer's and Parkinson's. The mechanisms behind how the proteins interact with each other are difficult to study, but now researchers at Chalmers University of Technology, Sweden, have discovered a new method for capturing many proteins in nano-sized traps. Inside these traps, the proteins can be studied in a way that has not been possible before. The gates that the researchers have developed consist of so-called polymer brushes positioned at the mouth of nano-sized chambers. The proteins to be studied are contained in a liquid solution and are attracted to the walls of the chambers after a special chemical treatment. When the gates are closed, the proteins can be freed from the walls and start moving towards each other. In the traps, you can study individual clumps of proteins, which provides much more information compared to studying many clumps at the same time. For example, the clumps can be formed by different mechanisms, have different sizes and different structures.



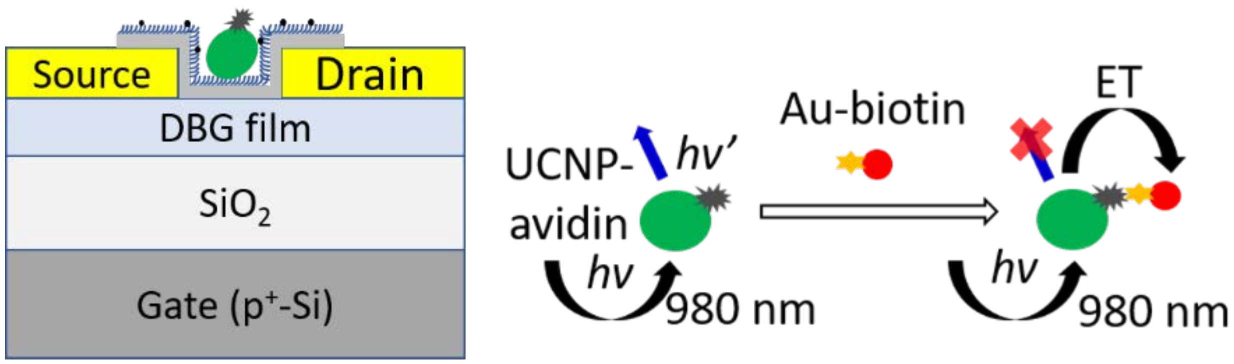
The image shows the protein traps, which consist of nanoscale chambers and polymers that form gates above. These "doors" are opened up by increasing the temperature by about ten degrees, which is done electrically. Then the polymers change their shape to a more compact state so that proteins can pass in and out.

Such differences can only be observed if one analyses them one by one. In practice, the proteins can be retained in the traps for almost any length of time, but at present, the time is limited by how long the chemical marker - which they must be provided with to become visible - remains. In the study, the researchers managed to maintain visibility for up to an hour. "We believe that our method has great potential to increase the understanding ofearly and dangerous processes in a number of different diseases and eventually lead to knowledge about how drugs can counteract them," says Andreas Dahlin, professor at Chalmers, who led the research project.

Svirelis, J., Adali, Z., Emilsson, G. *et al.* Stable trapping of multiple proteins at physiological conditions using nanoscale chambers with macromolecular gates. *Nat Commun* **14**, 5131 (2023).

Thin-Film Phototransistors for Single-Molecule Detection

To explore the potential of chip-technology for single-molecule detection, the research led by Shi-Li Zhang has made proof-of-the-concept demonstration of an integrated solution based on thin-film transistor (TFT) with direct bandgap semiconductor (DBS). With smart engineering, the bandgap of the DBS is reduced from that corresponding to ultraviolet to that for visible. The sensor integrates upconversion nanoparticles (UCNPs) to convert incident infrared excitation to visible emission that can then be altered to a different wavelength by means of Förster resonant energy transfer (FRET) upon specific molecular conjugation. This novel sensor concept with three distinct techniques (UCNP-FRET-TFT) is presented in a forthcoming PhD thesis.

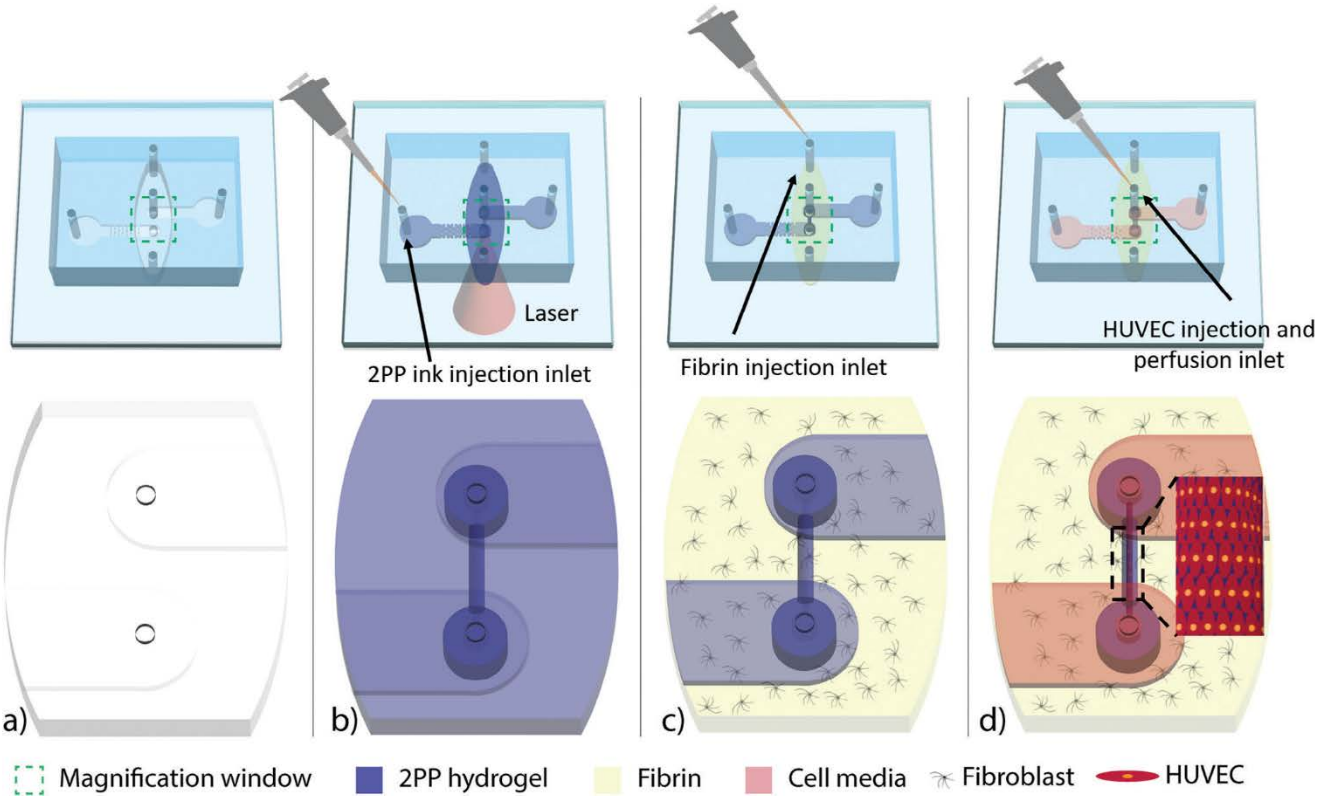


2-Photon3DPrintingtoImproveMicrofabricationFidelityinHydrogels

Engineering vasculature networks in physiologically relevant hydrogels represents a challenge in terms of both fabrication, due to the cell–bioink interactions, as well as the subsequent hydrogel-device interfacing. A new cell-friendly fabrication strategy has been presented by researchers headed by Maria Tenje to realize perfusable multi-hydrogel vasculature models supporting co-culture integrated in a microfluidic chip. The system comprises two different hydrogels to specifically support the growth and proliferation of two different cell types selected for the vessel model. First, the channels are printed in a gelatin-based ink by two-photon polymerization (2PP) inside the microfluidic device. Then, a human lung fibroblast-laden fibrin hydrogel is injected to surround the printed network. Finally, human endothelial cells are seeded inside the printed channels. The printing parameters and fibrin composition are optimized to reduce hydrogel swelling and ensure a stable model that can be perfused with cell media. Fabricating the hydrogel structure in two steps ensures that no cells are exposed to cytotoxic fabrication processes, while still obtaining high fidelity printing. In this work, the possibility to guide the endothelial cell invasion through the 3D printed scaffold and perfusion of the co-culture model for 10 days was successfully demonstrated on a custom-made perfusion system.

Engineering vasculature networks in physiologically relevant hydrogels represents a challenge in terms of both fabrication, due to the cell–bioink interactions, as well as the subsequent hydrogel-device interfacing. In this work, researchers headed by Maria Tenje present a new fabrication strategy for making a dual-hydrogel microvasculature model by combining the precision of 2PP and the cell compatibility of hydrogel casting. In the presented two-step process, a vasculature network is first defined using 2PP inside a microfluidic device. Second, another cell-laden hydrogel is injected around the 2PP-defined structures. The vasculature is finalized by seeding endothelial cells inside the channel network. The study showed that this set-up supports 3D culture of fibroblasts for up to 10 days in a perfusable vascularized hydrogel. The presented strategy not only preserves the cell viability >90% of the 3D culture but also enables the generation of channels with feature sizes down to 10 µm, thus replicating the capillary size of human tissue. The versatility of 2PP allowed the creation of side apertures in the 2PP channel to promote HUVEC migration and sprouting, leading to a defined angiogenesis density for more comparative studies in the future.

By combining the reliable perfusion of the system with a new high-resolution fabrication strategy, there is a unique opportunity to create innovative in vitro models of vascularized multi-hydrogel co-culture microphysiological systems.



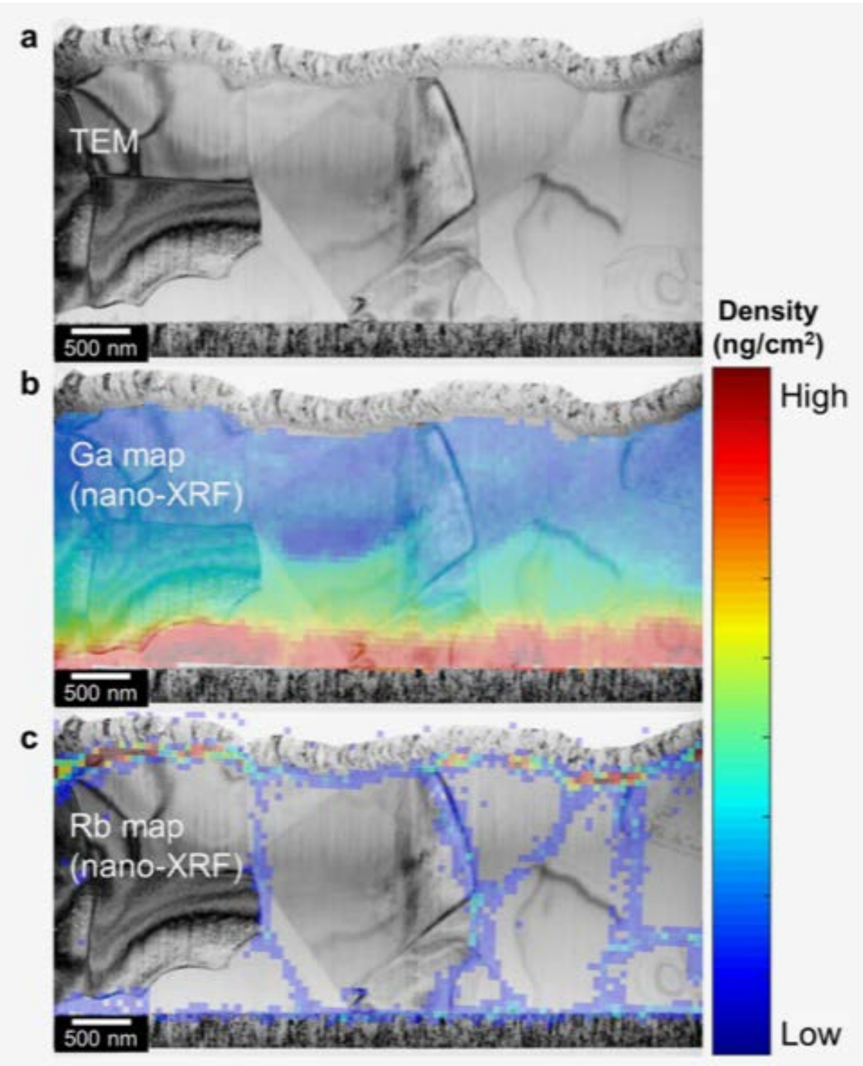
Schematic representation of the cell-friendly fabrication strategy for perfusable co-culture of HUVECs and fibroblasts.

Cantoni, F., Barbe, L., Pohlit, H., & Tenje, M., *A perfusable multi-hydrogel vasculature on-chip engineered by 2-photon 3D printing and scaffold molding to improve microfabrication fidelity in hydrogels*. Adv. Mater. Technol. **9** (2024).

Energy

World Record Solar Cells

Solar cell research is at the heart of the Myfab Uppsala cleanroom, both with a dedicated "solar lab" and by using synthesis and characterization equipment. During 2023 the Solar Cell Technology division collaborated with First Solar ETC, an Uppsala based subsidiary of First Solar (USA), to a world record thin film solar cell with an efficiency of 23.6 %. This result was first published in the NREL chart of solar cell efficiencies in 2023[1].



a) TEM cross section cut out with FIB of the CIGS record thin film solar cell showing the Mo back contact at the base, the CIGS layer in the middle and the transparent front contact at the top.

In b) and c), elemental maps of Ga and Rb as measured by nano-XRF at MAX IV on the same slab are shown.

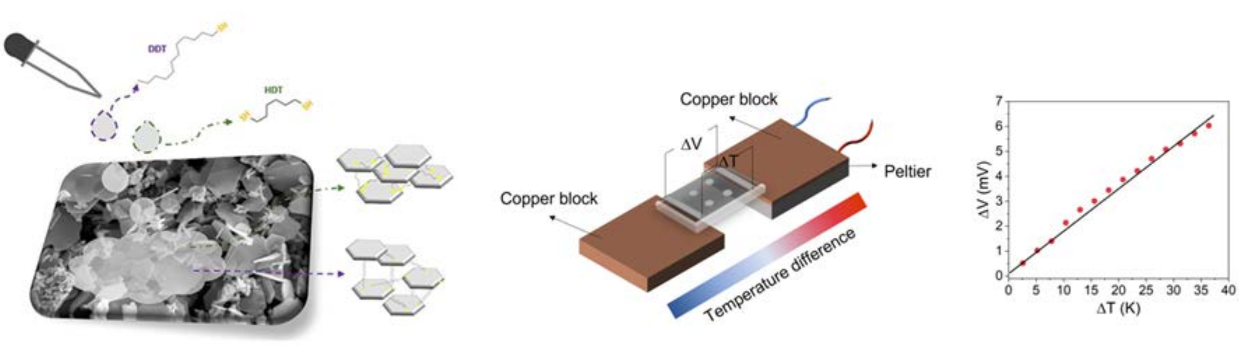
In order to understand the physics of this device and how to improve this kind of solar cells further, we used the Myfab Uppsala focussed ion beam instrument to cut a thin slice of the solar cell and the transmission electron microscope to analyse composition, grain size and defects and texture. We also used complementary techniques such as photoluminescence, glow discharge optical emission and synchrotron analysis at the MAX IV Beamline. One example of the analysis made at Myfab Uppsala can be found below and was published in Nature Energy[2]. The article was accepted in 2023 and published in February 2024.

[1] https://www.nrel.gov/pv/cell-efficiency.html

[2] Keller, J., Kiselman, K., Donzel-Gargand, O. et al. High-concentration silver alloying and steep back-contact gallium grading enabling copper indium gallium selenide solar cell with 23.6% efficiency. Nat Energy (2024). https://doi.org/10.1038/s41560-024-01472-3

Thermoelectric materials for energy solutions

With the recent advances in thermoelectric (TE) technology, there is an increasing demand to develop thick films that would enable large-scale TE devices. Assembly of TE-films from size and morphology-controlled nanoparticles has been a challenging issue that has been addressed by the use of electrophoretic deposition (EPD) technique by KTH Nanochemistry group, led by Muhammet Toprak. The group developed morphology-controlled Sb2Te3 nanoparticles through microwave-assisted chemical synthesis, which were subsequently used for EPD of TE films on specially developed glass-substrates.

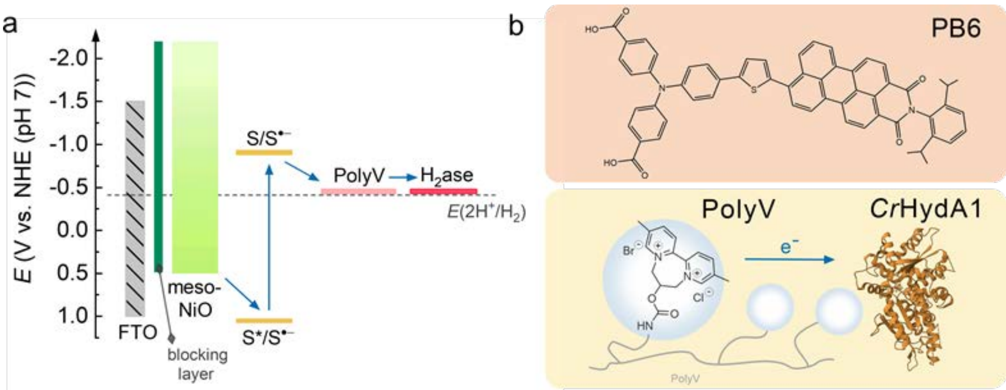


The high interfacial resistance is a well-known problem in porous and hybrid materials, which led to high initial resistance. By the use of small organothiol molecules they demonstrated a significant improvement in the conductivity of the films. The platform developed not only enables successful EPD film fabrication, but also allows for the study of the impact of different nanoparticle morphology and size, and molecular linkers to identify the best performing film formulation for a selected composition of the material. The study provides insights on interfaces and may enable large area TE applications as sustainable energy harvesting coatings, as a complementary source to green transition.

Batili, H.; Hamawandi, B.; Parsa, P.; Björn Ergül, A.; Szukiewicz, R.; Kuchowicz, M.; Toprak, M. S. Electrophoretic Assembly and Electronic Transport Properties of Rapidly Synthesized Sb2Te3 Nanoparticles. Appl. Surf. Sci. 2023, 637, 157930. https://doi.org/10.1016/j.apsusc.2023.157930.

Dye-Sensitized Photocathodes in Bias-free Photoelectrochemical Water Splitting

Converting sunlight into electricity, fuels and chemicals is an important strategy to utilize and store the solar energy. Dye-sensitized photoelectrodes consisting of eco-friendly photosensitizers and molecular catalysts with tuneable structures and adjustable energy levels are attractive for low-cost solar-assisted synthesis of energy rich products. Despite these advantages, dye-sensitized NiO photocathodes suffer from severe electron-hole recombination and facile molecule detachment, limiting photocurrent and stability in photoelectrochemical (PEC) water-splitting devices. Haining Tian's group has developed an efficient and robust biohybrid dye-sensitized NiO photocathode for direct hydrogen production. The sputter deposited NiO compact layer produced at Myfab Uppsala has a significant role in suppressing charge recombination. The photocathode consists of PB6 dye as a photosensitizer, [FeFe]-hydrogenase as a proton reduction catalyst, and 2,2´-viologen-based redox polymer (PolyV) as a redox mediator. Owing to efficient electron transfer from the PB6 dye to [FeFe]-hydrogenase mediated by PolyV, the photocathode showed a photocurrent of 141±17 $\mu A \cdot cm^{-2}$ at neutral pH at 0 V vs. reversible hydrogen electrode (RHE), as well as a stable continuous output for 5 hours. This biohybrid photocathode is capable of driving overall water splitting in combination with a $BiVO_4$ photoanode. With the photocurrent stabilizing at 63.5±0.7 $\mu A \cdot cm^{-2}$ after 10-hour output, the bias-free PEC devices reached 0.124% solar-to-hydrogen efficiency, thus outperforming all reported water-splitting devices based on dye-sensitized photocathodes. These findings demonstrate the opportunity of building green biohybrid systems for artificial photosynthesis.



(a) Energy diagram for the biohybrid dye-sensitized photocathode and (b) molecular structures of PB6, PolyV, and H2ase (CrHydA1). The blocking layer is compact NiO blocking layer. S is short for ground state of PB6, S stands for excited PB6, and $S^{\bullet-}$ is for reduced PB6. The blue arrows show the preferred electron transfer pathway.*

Accepted for publication in Nature Communications.

Materials Science

Metamaterial-based sensors

RISE has an ongoing EU project IFLOWS, which is a 3-years project since 2022-11-01, https://www.ri.se/en/what-we-do/projects/detection-of-illicit-material-for-postal-services-and-courier-flows. It aims to develop advanced technologies for scanning and detection of illicit material for postal services and express courier flows. RISE is primarily involved in two work packages in the project. One of them is to develop new technology for THz sensors based on advanced plasmonic structures and graphene.

The THz sensor design and fabrication for the project are ongoing, which is based on our expertise on both the metasurface/plasmonic IR sensors and the chemical sensors for illicit drug detection that produced at cleanroom facilities at Electrum. The sensors include the designed nano or micro scale plasmonic metamaterial absorbers and the electrodes as shown in Figure 1. The colourful sensor surface is caused by the interaction between the plasmonic structures and visible light, such structural colouring occurs among birds and insects in nature. The desired operating wavelength/frequency can be tuned by the plasmonic feature's geometries and pitches as shown in Figure 2.

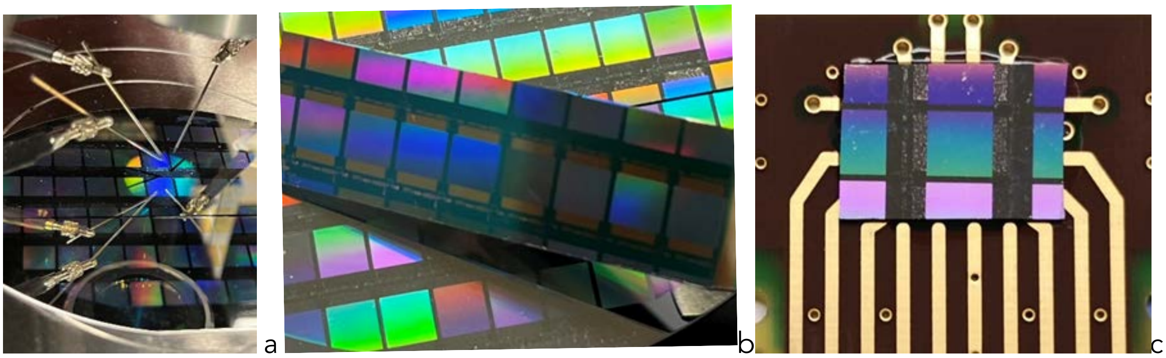


Figure 1 (a): a photo of wafer scale fabricated metamaterial-based sensors under optical microscope on a probe station to verify the sensor's performance. (b): The zoomed the view of the sensor with active sensing area and two electrodes. (c) the sensor mounted on a chip carrier.

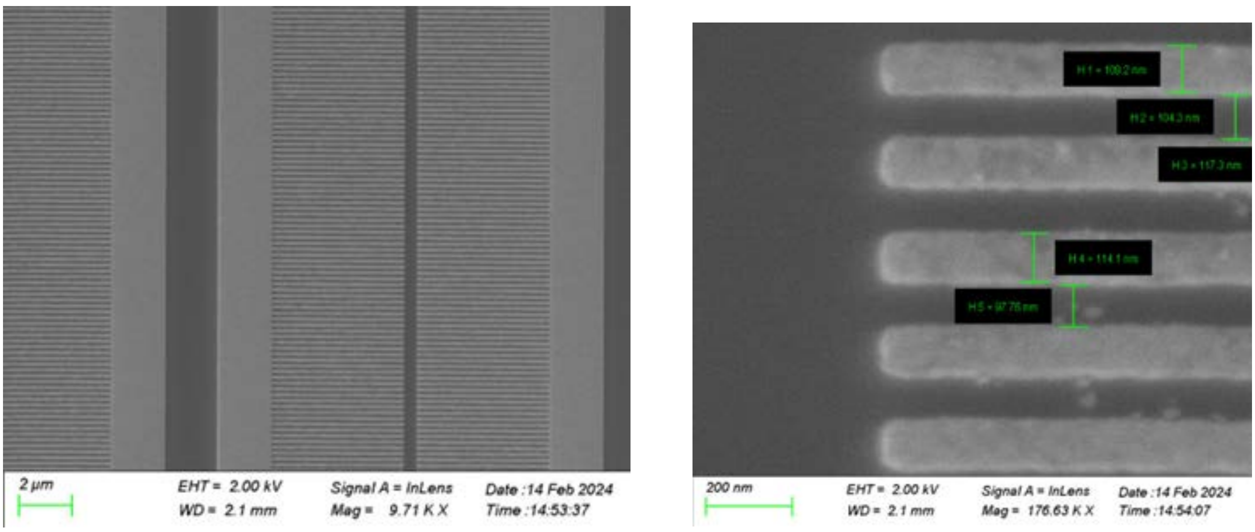
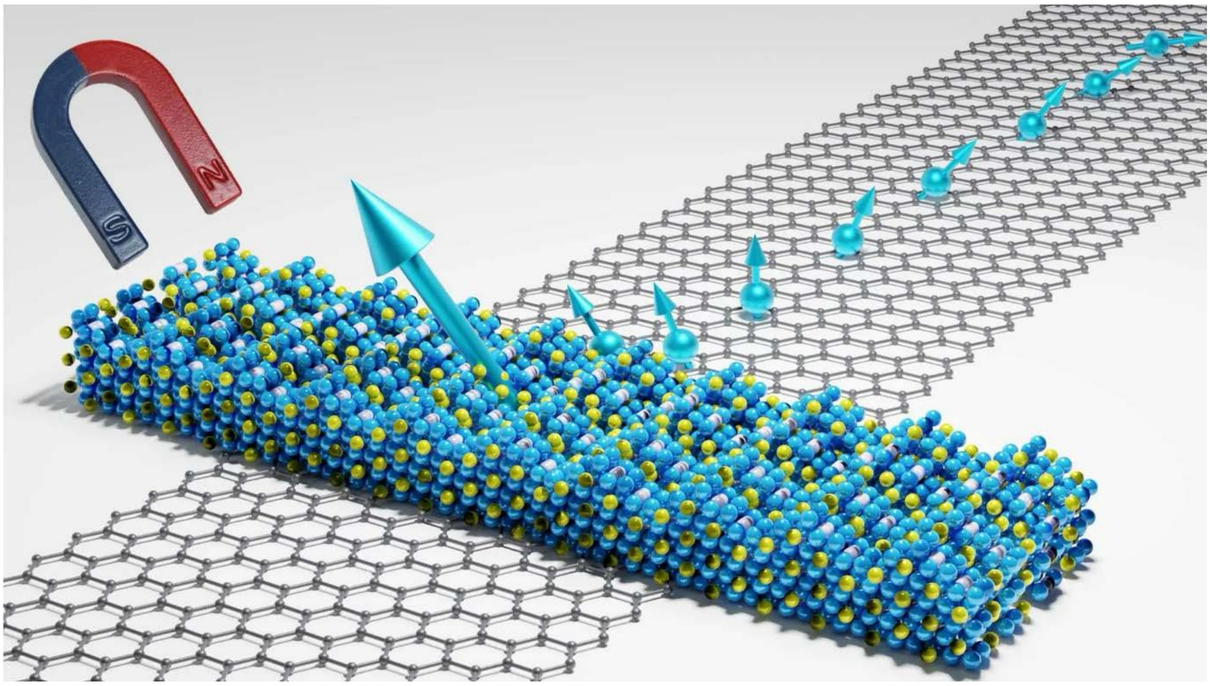


Figure 2: SEM images of the fabricated plasmonic features in the THz sensor.

Hope such developments will lead to our THz sensors being exploited routinely in the security context. But whatever happens, this is a fascinating area that there is still much to be done to understand and exploit its potential in comparison with advanced image legacy systems, e.g. X-Ray and Raman detection systems



The researchers have for the first time succeeded in demonstrating a device, based on a 2D magnetic material, in room temperature. The illustration shows a 2D magnet used as an efficient source and detector for spin polarized electrons on a graphene channel.

Breakthrough in magnetic quantum material paves way for ultra-fast sustainable computers

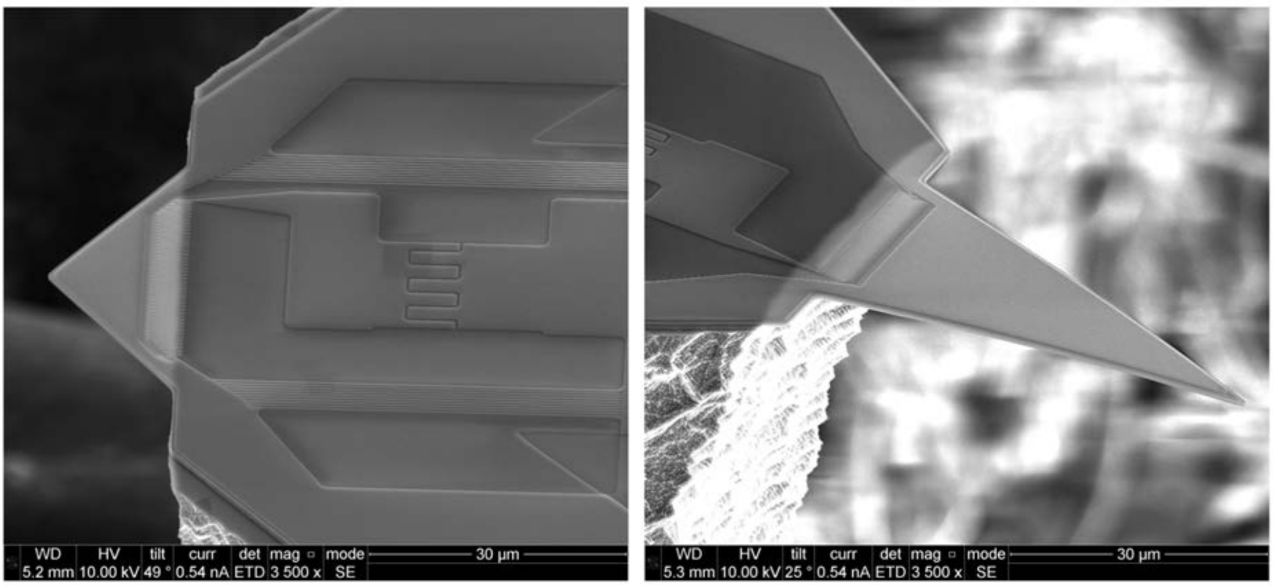
The discovery of new quantum materials with magnetic properties are believed to pave the way for ultra-fast and considerably more energy efficient computers and mobile devices. So far, these types of materials have been shown to work only in extremely cold temperatures. Now, a research team at Chalmers University of Technology in Sweden are the first to make a device made of a two-dimensional magnetic material work at room temperature. The first atomically thin material to be isolated in a laboratory was graphene, a single atom-thick plane of graphite, that resulted in the 2010 Nobel Prize in Physics. And in 2017, two-dimensional materials with magnetic properties were discovered for the first time. Magnets play a fundamental role in our everyday lives, from sensors in our cars and home appliances to computer data storage and memory technologies, and the discovery opened for new and more sustainable solutions for a wide range of technology devices. "Two-dimensional magnetic materials are more sustainable because they are atomically thin and offer unique magnetic properties that make them attractive for developing new energy-efficient and ultra-fast applications for sensors and advanced magnetic memory and computing concepts. This makes them promising candidates for a range of different technologies," says Saroj Dash, Professor in Quantum Device Physics at Chalmers University of Technology.

Zhao, Bing, et al. (2023). A Room-Temperature Spin-Valve with van der Waals Ferromagnet Fe_5GeTe_2 /Graphene Heterostructure. *Advanced Materials*. 35:16

Nanoscience and Nanotechnology

Towards Quantum-limited Atomic Force Microscopy

The atomic force microscope (AFM) is probably the most widely used tool for nanotechnology, imaging all types of materials, insulators, semiconductors and metals, in all sorts of environments. A sharp tip at the free end of an oscillating cantilever is scanned over a surface, detecting minute forces between the tip and surface.



SEM images of two force sensors. When the triangular cantilever bends, strain is induced in a superconducting nanowire which meanders along the clamping line of the cantilever. The strain changes the kinetic inductance of the nanowire, causing a shift a microwave resonant circuit formed by the nanowire inductor and a series interdigital capacitor.

Currently AFMs detect force as bending of the micro-cantilever, using a separate optical system that is cumbersome to align, and requires recalibration with every tip exchange. A recent EU funded project called QAFM worked to develop a force transducer where a superconducting resonant microwave circuit is used to detecting cantilever bending. The participating group at KTH realized a new type of electro-mechanical transduction mechanism, whereby the kinetic inductance of a superconducting nanowire changes under mechanical strain. The mechanism builds on the advantages of cavity opto-mechanical force transduction schemes, which can reach the standard quantum limit of measurement precision.

Reference: A. Roos et al. PHYSICAL REVIEW APPLIED 20, 024022 (2023), DOI:10.1103/PhysRevApplied.20.024022

ECONOMY

Myfab's financial report for 1 January – 31 December 2023 is undersigned by Chalmers financial controller and submitted separately 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 2023.

	Myfab Chalmers	Myfab KTH	Myfab Lund	Myfab Uppsala	Myfab all labs
Faculty grants	35 658 996	17 931 000	21 770 000	11 325 256	86 685 252
Fees, academic	15 524 255	10 540 000	4 268 000	7 203 513	37 535 768
Fees companies incl. RISE	19 338 555	27 496 000	3 926 000	4 069 680	54 830 235
Myfab SRC grant	3 134 000	3 131 000	3 131 000	3 131 000	12 527 000
Financed depr.	7 231 000	7 726 000	1 746 000	3 393 232	20 096 232
Projects SSF, EU		3 569 000			3 569 000
Services		4 208 000	1 101 000		5 309 000
Income Total	**80 886 806**	**74 601 000**	**35 942 000**	**29 122 681**	**220 552 487**
Costs [kSEK]					
Personnel	16 498 802	16 299 000	9 674 000	7 573 643	50 045 445
Rent premises	19 429 170	18 555 000	8 471 000	11 557 193	58 012 363
Operation	22 075 802	19 965 000	9 529 000	6 856 281	58 426 083
Overhead	5 022 748	7 212 000	2 770 000	1 817 709	16 822 457
Financed depr.	7 231 000	7 726 000	1 746 000	2 664 974	19 367 974
Depreciations	6 379 661	4 747 000	7 314 000	186 321	18 626 982
Costs Total	**76 637 183**	**74 504 000**	**39 504 000**	**30 656 121**	**221 301 304**
Result	**4 249 623**	**97 000**	**-3 562 000**	**-1 533 440**	**-748 817**

Myfab Standard report 2023 – key numbers from Myfab LIMS

	Myfab Chalmers	Myfab KTH	Myfab Lund	Myfab Uppsala	2023 Myfab	2022 Myfab	2021 Myfab	2020 Myfab
Active users	203	208	133	276	**820**	835	811	782
-new users	55	51	46	85	**237**	219	-	-
Female active users	44	64	39	110	**257**	241	228	202
Gender balance,	22%	31%	29%	40%	**31%**	29%	28%	26%
University active users	166	144	106	226	**642**	659	660	646
Institutes active users	2	9	5	1	**17**	14	16	17
Commercial active users	35	55	22	49	**161**	162	135	119
Companies w. own personnel	17	19	8	25	**69**	72	65	58
Number of booked	53 232	37 617	29 984	23 010	**143 842**	160 542	170 579	164 830
-from universities	43 458	28 356	25 793	20 848	**118 454**	137 002	147 833	141 417
-from institutes	62	2 915	280	25	**3 282**	4 108	3 038	3 198
-from commercial	9 712	6 346	3 911	2 137	**22 106**	19 432	19 708	20 215

ANNEXES

ANNEX A - MYFAB KEY NUMBERS 2023

Key numbers as specified in Appendix 1 (Bilaga 1) to Myfab's contract (Dnr: 2019-00207)

Table also submitted separately

Infrastrukturens namn: Myfab 5
Diarienummer: 2019-00207
Respondent (namn): Thomas Swahn
Respondent (epost): thomas.swahn@chalmers.se
Respondent (telefon): 0730-744676
Avser år: 2023

Katergorier av nyckeltal
1 Anställda (enskilda individer (eller FTE))
2 Projekt (fakturerade)
3 Användare (enskilda individer)
4 Kvantitet av användning [timmar]
5 Output

1	Anställda vid infrastrukturen	
1.1	*Enskilda individer*	
	Totalt	80
	Ledning (labchefer ingår)	5
	Vid Myfab Chalmers	22
	Vid Myfab KTH	25
	Vid Myfab Lund	15
	Vid Myfab Uppsala	13
1.2	*FTE*	
	Totalt	56,95
	Ledning	1,8
	Vid Myfab Chalmers	18
	Vid Myfab KTH	17,4
	Vid Myfab Lund	11
	Vid Myfab Uppsala	8,75

		a. Alla projekt			b. Typ av hemvist för alla projekt						c. Typ av akademisk hemvist för projekt (endast akademiska hemvister)			
					Akademisk			Kommersiell	Offentlig	Övriga				
2	Projekt	Totalt	Män	Kvinnor	Totalt	Män	Kvinnor	Totalt	Totalt	Totalt	Värdorganisatio	Inom konsortiet, ej vär	Annat svenskt lärosäte	Internationell
2.2	*Genomförda projekt*													
	Totalt													
	Vid Myfab Chalmers	185	165	20	159	141	18	24	2		149	1	9	
	Vid Myfab KTH	164	154	10	104	99	5	41	19		97	3	4	
	Vid Myfab Lund	86	76	10	69	59	10	12	5		65	1	2	1
	Vid Myfab Uppsala	117	70	47	89	53	36	27		1	78	5	6	

		d. Alla användare			e. Typ av hemvist för alla användare						f. Typ av akademisk hemvist för användare (endast akademiska hemvister)			
					Akademisk			Kommersiell	Offentlig	Övriga				
3	Användare	Totalt	Män	Kvinnor	Totalt	Män	Kvinnor	Totalt	Totalt	Totalt	Värdorganisatio	Inom konsortiet, ej vär	Annat svenskt lärosäte	Internationell
3.2	*Genomförda projekt*													
	Totalt	820	545	275	642	443	199	178						
	Vid Myfab Chalmers	203	159	44	166	129	37	35	2		153	1	12	
	Vid Myfab KTH	208	144	64	144	99	45	64			132	4	8	
	Vid Myfab Lund	133	94	39	106	75	31	27			126	2	5	
	Vid Myfab Uppsala	276	166	110	226	136	90	50			219	7		

		g. Total kvantitet per typ av tillgång till		h. Kvantitet av tillgång för akademiska projekt		
		Alla användare		Fysisk tillgång till infrastruktur		
4	Typ och kvantitet av tillgång	Fysisk [antal anv.	timmar	Totalt (timmar)	Män (andel, %)	Kvinnor (andel, %)
4.1	*Användning under året*					
	Totalt	820	143842	118454	69%	31%
	Vid Myfab Chalmers	203	53232	43458	78%	22%
	Vid Myfab KTH	208	37617	28356	69%	31%
	Vid Myfab Lund	133	29984	25793	71%	29%
	Vid Myfab Uppsala	276	23010	20848	60%	40%

5	Output		
5.1	Publikationer	Bifoga lista enl specifikation	
5.2	Antal examinerade doktorer	Som haft en väsentlig verksamhet i Myfab	

ANNEX B – ORGANISATION 2023

General Assembly members (Stämma)

Chair: Lars Börjesson, Senior Advisor to the President, Chalmers
Annika Stensson Trigell, Vice-President KTH
Johan Tysk, Vice-Rector Uppsala University
Victor Öwall, Pro Vice-Chancellor Lund University

International Advisory Board (AB)

Chair: Anna Rissanen Director OtaNano, Aalto University
Jörg Hübner Director DTU Nanolab
Maria Huffman Director UW Washington Nanofabrication Facility
Max Lemme Professor RWTH Aachen University

Steering Group

1 January – 30 April:

Chair:
Mikael Östling, Deputy President KTH

Marcus Aldén, Professor, Lund University
Anne Borg, Rector NTNU Trondheim
Mikael Jonsson, Professor, Uppsala Univ.
Ellen Moons, Professor, Karlstad Univ.
Anna Stenstam, CEO CR Competence
Henrik Thunman, Professor Chalmers

1 November – 31 December:

Chair:
Mikael Östling, Deputy President KTH

Mikael Jonsson, Professor, Uppsala University
Heiner Linke, Professor Lund University
Jane Hvolbaek Nielsen, Professor DTU
Catarina Sahlberg, Dir. Big Science Sweden
Anna Stenstam, CEO CR Competence, Lund
Henrik Thunman, Professor Chalmers

Operational management

Director:
Thomas Swahn, Docent

Laboratory Managers:
Myfab Chalmers: Peter Modh, Ph.D.
Myfab Lund: Luke Hankin, PhD.
Myfab KTH: Nils Nordell, Docent
Myfab Uppsala: Stefan Nygren, PhD.

ANNEX C – MYFAB ACCOUNTING OF PROCUREMENTS 2023

Investment number 1: LPCVD, Myfab Chalmers

Amount paid 2023: 2 910 536 SEK.

Total investment: 852 650 €.

Tool: Tempress TS66603 furnace with three tubes for SiN, Poly Si and, TEOS.

Investment number 3:

Amount paid 2023: 4 273 451 SEK

Total Investment: 734 758 €

Tool: Oxford PlasmaLab 100 ICP/RIE one chamber system with Atomic Layer Etching option and one Samco 10NR RIE.

Investment number 4: ICP-RIE, Deep Si etch, Myfab KTH

Amount paid 2023: 15 436 661 SEK

Total investment: 2 072 330 €

Tool: SPTS Omega c2L cluster tool with one Rapier and one Synapse chamber

Background

Deep silicon etching has enabled ground-breaking research in the past 20 years in very interdisciplinary research fields, including devices for biotechnology (DNA sequencing), biomedical applications (microneedles for transdermal drug delivery), microwave and terahertz frequencies, photonics, sensors and actuators, 2D-material integration (graphene enabled sensors). Examples of current cutting-edge research, relying on deep-silicon micromachining, include for instance single-photon microwave radiation detection at room temperature enabled by nanometre surface-roughness multi-domain waveguides (for radio-astronomy applications), or ultra-high Q-factor terahertz-frequency resonators requiring sub-micrometre precision deep-silicon etched cavities. Myfab KTH has the leading competence within Myfab in deep-silicon etching processes, and Electrum Lab is one of the leading deep etching environments in Northern European public cleanrooms since 1997.

Tool description

The purchased equipment is a state-of-the-art etcher with a central wafer handling robot able to transfer wafers from cassette-to-cassette of different substrate sizes up to 200 mm. The tool is equipped with and two process chambers, for deep-Si etching, and SiC/SiO2 etching, respectively.

The deep-Si etching chamber fulfils tough demands on very low sidewall roughness; high-aspect ratio geometries; verticality of sidewall profiles and low mask undercut; uniformity; endpoint detection towards etch-stop layers; high selectivity towards SiO2 and photoresist masks; and good notching performance on etch stop layers such as SOI BOX layers. The primary application for this chamber is 3-dimensional geometries for microsystems, high-aspect ratio requirements for etches typically 30 µm up to 100 µm deep and feature sizes down to 1 µm, and deep and through-the-wafer etching of 300 µm or 500 µm tall structures, for 3-dimensional MEMS devices, through-Si vias and for chip separation; both types of etches having very low sidewall roughness. Typically, SOI wafers are etched with priority is on switched (BOSCH) processes. The SiC/SiO2 etching chamber, fulfils particular requirements on good profile control; shallow and deep etching capability; high etch rate; high selectivity; high-aspect ratio structures; end-point detection; and uniformity. The primary application is for high power electronics devices in SiC, including deep vias and structures with a vertical profile close to 90°. For deep vias high etch rate combined with high selectivity to the mask is necessary, while for more shallow structures side wall profile and the shape of the trench bottom are the most important features. A secondary purpose of the chamber is silicon dioxide etching, with applications in 3D geometries for microsystems, photonic waveguides, and thick oxide masks for deep-silicon etching.

Investment number 5: HPVE reactor Upgrade, Myfab KTH

Amount paid 2023: 2 737 866 SEK.

Total investment: 2 737 865 SEK

Tool: Agnitron control system upgrade, including software PC and cabling

Background

Hydride vapor phase epitaxy is a unique process that has high growth rate and comparably low gas consumption. It is a technique utmost suitable for selective epitaxy on planar and non-planar substrates. It is used for research on III-V on silicon for silicon photonics, III-V/Si multi-junction solar cells, and for fabricating buried heterostructure lasers (for telecom and quantum cascade lasers (QCL)). The HVPE reactor at KTH was installed in 1997 and now the electronic control system is obsolete. An upgrade will extend the lifetime and enable us to maintain our lead in this technology for fabricating advanced devices and attract international collaborations. The Hydride Vapor Phase Epitaxy process at KTH is unique, as no other suppliers of high quality HVPE exist in open access labs in the world. There is only one home-built reactor in France, but it cannot provide material at the same quality.

Tool description

The control system is configured for the Aixtron HVPE system already installed at KTH (installation date 1997; serial no. 2106), with a reactor designed to grow GaInAsP compounds at aa pressure of 20 mbar and a temperature up to 750 degree celsius. The new upgraded control system is compatible with the analogue devices and the alarm system in the existing HVPE system.

Investment NUMBER 10: CD Overlay Inspection, Myfab KTH

Amount paid 2023: 1 733 916 SEK.

Total Investment: 1 733 916 SEK

Tool: Nikon Eclipse microscope with workstation and software for pattern recognition and image processing.

Background

KTH research is conducted to augment integrated circuits and enables new technologies within wide areas of applications e.g. increasing device packaging densities through 3D monolithic integration, interfacing electronics with biology, enabling electronics operating at T>250 °C, enabling integrated sensors, and photonic – electronic co-integration. As a core for the research a fully depleted Si CMOS technology and a SiC integrated circuit technology have been developed. The process flows to enable the Si and SiC based circuits are complex, rising the research demands on fast and reproducible feedback on the processing results, from state of-the-art in-line metrology, and is also strongly motivated by the ISO9001 quality system.

Tool description

The tool is based on an optical microscope equipped with a semi-automatic, motorized stage and an integrated workstation with software for pattern recognition and image processing. It is capable for measurements of critical dimensions (CD) and overlay on patterned wafers as well as well as automatic scanning of wafers (patterned and non-patterned) for defect detection and classification in the process line. This is a new metrology capability at Electrum lab for fast and reproducible feedback on the processing results enabling the Si and SiC based circuits and 3D integration for interfacing electronics with devices and structures.

ANNEX D – MYFAB PUBLICATIONS AND DOCTORAL THESES 2023

Peer-reviewed publication lists Doctoral Theses from

Myfab Chalmers:	177 publications, 8 doctoral theses
Myfab KTH:	167 publications, 8 doctoral theses
Myfab Lund:	137 publications, 13 doctoral theses
Myfab Uppsala:	226 publications, 22 doctoral theses

In total 707 peer-reviewed publications and 51 doctoral theses during 2023.

Myfab Chalmers Peer Reviewed Journal and Conference Papers

1. Andersson, John, Järlebark, Julia, Kesarimangalam, Sriram, Schaefer, Andreas, Hailes, Rebekah, Palasingh, Chonnipa, Santoso, Bagus, Vu, Van Truc, Huang, Chun Jun, Westerlund, Fredrik & Dahlin, Andreas, 'Polymer Brushes on Silica Nanostructures Prepared by Aminopropylsilatrane Click Chemistry: Superior Antifouling and Biofunctionality', ACS Applied Materials & Interfaces., 15:7, s. 10228-10239, 2023
2. Järlebark, Julia, Andersson, John & Dahlin, Andreas, 'Chemically functionalised nanopores for protein trapping', European Biophysics Journal., 52:SUPPL 1, s. S187-S187, 2023
3. Svirelis, Justas, Adali, Zeynep, Emilsson, Gustav, Medin, Jesper, Andersson, John, Vattikunta, Radhika, Hulander, Mats, Järlebark, Julia, Kolman, Krzysztof, Olsson, Oliver, Sakiyama, Yusuke, Lim, Roderick Y H & Dahlin, Andreas, 'Stable trapping of multiple proteins at physiological conditions using nanoscale chambers with macromolecular gates', Nature Communications., 14:1, 2023

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4. Mone, Mariza, Kim, Youngseok, Darabi, Sozan, Zokaei, Sepideh, Karlsson, Lovisa, Craighero, Mariavittoria, Fabiano, Simone, Kroon, Renee & Müller, Christian (2023). Mechanically Adaptive Mixed Ionic-Electronic Conductors Based on a Polar Polythiophene Reinforced with Cellulose Nanofibrils. ACS Applied Materials & Interfaces. 15:23, s. 28300-28309
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7. Sasanian, Nima, Kesarimangalam, Sriram, Ghaeidamini, Marziyeh, Dorfman, Kevin, Esbjörner Winters, Elin & Westerlund, Fredrik (2023). Probing physical properties of single amyloid fibrils using nanofluidic channels. European Biophysics Journal. 52:SUPPL 1, s. S205-S205
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9. Luneau, Mathilde, Strandberg, Linnéa, Montserrat Siso, Gerard, Shokhen, Victor, Mohan, Roopathy, Grönbeck, Henrik & Wickman, Björn (2023). Fundamental insight into enhanced activity of Pd/CeO 2 thin films in hydrogen oxidation reaction in alkaline media. Journal of Materials Chemistry A. 11:30, s. 16370-16382
10. Reza Bilesan, Mohammad, Yazdani, Meghdad, Luneau, Mathilde, Montserrat Siso, Gerard, Wickman, Björn & Repo, Eveliina (2023). Electrochemical Approach for Advanced Flow Reactors via Additive Manufacturing of High Surface Area Ti-6Al-4V Anode. ChemElectroChem. 10:20

11. Shokhen, Victor, Strandberg, Linnéa, Skoglundh, Magnus & Wickman, Björn (2023). Fuel cell electrode degradation followed by identical location transmission electron microscopy. Journal of Materials Chemistry A. 11:39, s. 21029-21035
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15. Andersson, Carl, Serebrennikova, Olga, Tiburski, Christopher, Alekseeva, Svetlana, Fritzsche, Joachim & Langhammer, Christoph (2023). A Microshutter for the Nanofabrication of Plasmonic Metal Alloys with Single Nanoparticle Composition Control. ACS Nano. 17:16, s. 15978-15988
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21. Shaner, Sebastian, Savelyeva, Anna, Kvartuh, Anja, Jedrusik, Nicole, Matter, Lukas, Leal, José & Asplund, Maria (2023). Bioelectronic microfluidic wound healing: a platform for investigating direct current stimulation of injured cell collectives. Lab on a Chip. 23:6, s. 1531-1546
22. Ghanbari, Reza, Pashazadehgaznagh, Sajjad, Sekar, Kesavan, Nygård, Kim, Terry, Ann, Liebi, Marianne, Matic, Aleksandar & Kádár, Roland (2023). Painting Taylor vortices with cellulose nanocrystals: supercritical spectral dynamics.
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