ANNUAL REPORT 2021

Department of
MICROTECHNOLOGY AND NANOSCIENCE

CHALMERS
UNIVERSITY OF TECHNOLOGY

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ISSN 1652-0769
Technical Report MC2-449
www.chalmers.se/mc2

Publisher: Mikael Fogelström
Editor: Susannah Carlsson
Contributing photographers: Matteo Acciai, Riccardo Arpaia, Muhammad Asad, Kamanasish Debnath, Yifeng Fu, Lovisa Håkansson, Divya Jayasankar, Kerstin Jönsson, Robert Karlsson, Krantz Nanoart, Hang-Xi Li, Johan Liu, Anna-Lena Lundqvist, Pixabay, Zhizhao Ye.

Print: Ale Tryckteam AB, 2022

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HEAD OF DEPARTMENT DIALOGUE

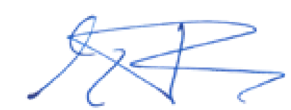
Dear reader,

another year, 2021, is to be accounted for. In our annual report we summarise our activities in a year still marked by the pandemic with all that has meant in terms of online teaching, working from home, and general restrictions in travel and normal interaction with colleagues. Despite special circumstances we have managed to carry out work at MC2 in a close to usual pace. I sincerely would like to thank all my colleagues for their efforts and contributions.

Our research is mainly geared to deliver the best scientific output. It also aims at providing a basis for innovations that can be progressed to a technology in our collaborations with institutes and industry. During 2021 our various research programs have continued to deliver. There are several results and breakthroughs that stand out and are reported here under 2021-at-a-glance. While research and innovations may be our largest focus, we are working continuously and determined to become more involved in undergraduate education. In the graduate education, I'm happy to see that no less than 18 new doctors have graduated from our PhD program. Our excellent students are key enablers for the research and teaching that we do at the department.

At MC2 we are committed to establish a good working environment that attracts talent to come and join us in study, teaching, and research. One step along this path we have done was to open a family room to make life easier for parents. The family room is supported by the GENIE initiative at Chalmers, and you can read more about it in the report.

I, as Head of Department, thank you all for your very hard work and endurance making MC2 probably the best place to work at,



Mikael Fogelström
Head of Department

APPLIED QUANTUM PHYSICS LABORATORY

Head of Laboratory Göran Johansson
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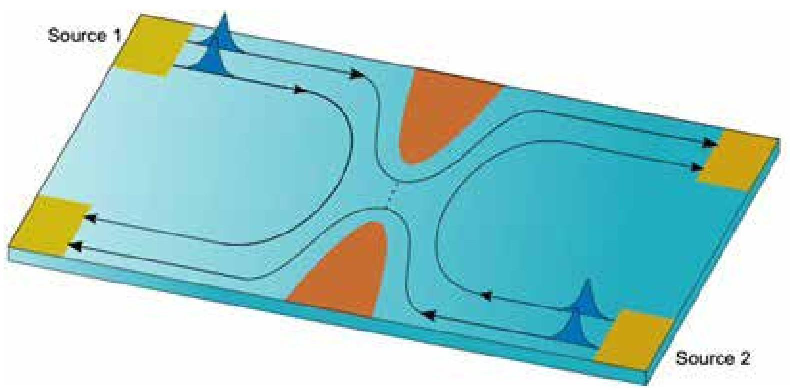
The Applied Quantum Physics Laboratory (AQP) is despite its name a home for theoretical physicists only. AQP has been growing in the past few years and at the end of 2021 AQP employed 34 theorists, with a gender balance female/male approaching 40/60. We have a strong interest in device-related aspects and we often work on applying our theoretical tools to present and potential future solid-state physics experiments. Our current activities span from quantum thermodynamics, exotic phases in HTc superconductors, heat, spin and charge transport in nanostructures, graphene and other 2D materials, quantum information in continuous variables and superconducting circuits, quantum algorithms, quantum machine learning, waveguide QED, quantum acoustics and quantum plasmonics.

Research high-lights in 2021 include that post-doc Matteo Acciai and professor Janine Splettstößer initiated a collaboration with the experimental team of C. Glattli at CEA-Saclay on the topic of quantum Hall interferometry. Expoiting quantum Hall edge states (see Figure below), acting as waveguides for electrons, quantum optics-like experiments can be performed, with potential future applications for flying-qubit architectures. A recent experiment performed at CEA and successfully modelled by the theory group at AQP demonstrated that electronic states injected in a two-particle interferometer retain a high degree of coherence, even in the fractional quantum Hall regime, where the elementary excitations are exotic quasiparticles with fractional charge and statistics (arXiv:2201.09553 and arXiv:2201.06833).

In 2021, we are also very happy that assistant professor Giulia Ferrini was promoted to associate professor and is now a permanent member of the AQP Faculty!



A quantum Hall interferometer. Electronic states are injected into the waveguides (edge channels) by the two sources and interfere at the central beamsplitter.

ELECTRONICS MATERIALS AND SYSTEMS LABORATORY

Head of Laboratory Johan Liu
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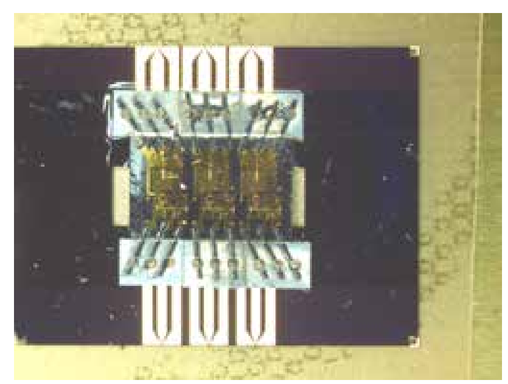
At the Electronics Materials and Systems Laboratory (EMSL), research is focused on materials, including DNA, polymers and liquid crystals, on computing, and on electronics packaging as well as microsystem designs. We combine carbon and silicon-based materials to achieve superior device and system performance, and we develop processes and tools, including first-principle materials theory and algorithms, to reach those ends. As a strong focus, the research at EMSL addresses scientific issues within current CMOS and beyond CMOS integration technology using novel concepts such as carbon-based electronics systems and neuromorphic based computing. EMSL belongs to a selected group of academic labs in the world that combines design, fabrication and integration into a packaged system and having the capability to characterize those devices, including reliability testing. In EMSL, we run several, VR, SSF and European grants within Horizon 2020 program such as GreEnergy and Nanosmart, that reflect strong international recognition. We are the coordinator of the EU project GreEnergy, showing the significance of our role and impact. The vision of the laboratory is to conduct world-class research and education in new carbon-based functional materials and systems for a sustainable society and a joyful life.

This year, we have demonstrated fabrication of high-power density energy storage devices using alkylamino functionalized reduced graphene oxide (rGO). Here, by utilizing conventional clean-room technologies such as spin-coating, lithography and reactive ion etching, we have demonstrated fabrication of complementary-metal-oxide semiconductor (CMOS) compatible on-chip energy storage devices called micro-supercapacitors (MSCs). The concept of using on-chip CMOS compatible micro-supercapacitors along-side an energy harvester such as a solar cell can potentially demonstrate a more or less infinite lifetime of power supply. The study is published in Basic Solid State Physics.

After 6 years intensive research with the funding support of SSF (and enhanced in U.S. DOE user grants), we have also a) successfully made a first demonstrator of a complete all carbon-based electronics system using CNT, 3D integration (via stacking and inkjet printing) and graphene-based devices, and b) released several theory methods that enhance the reach of the primary materials theory tool, demonstrating enhanced predictive power in systems ranging from perovskites and cutting tools, over carbon capture, and to DNA assembly and polymers.

We have studied combined effects of confinement and intrinsic chirality in lyotropic liquid crystals leading to complex, periodic, chiral superstructures (study published in Langmuir). Additionally, we have in an article in Scientific Reports demonstrated a simple method that reveals the polar nature of the recently found ferroelectric nematic phase. In addition, we have written the chapter on smectic liquid crystal modes in the forthcoming 3rd edition "Handbook of visual display technology" (Springer).

In addition to this, we have also shown that it is possible to classify protein sequences are toxic or non-toxic using a combination of the state-of-the-art pattern recognition methods based on an implementation of the reservoir computing paradigm. As the reservoir we used several cellular automata networks. It has been shown that these systems generalize well on the unseen data sets.



A complete all carbon-based electronics system using 3D CNT based via stacking, graphene enhanced inkjet printing as well as graphene devices.

MICROWAVE ELECTRONICS LABORATORY

Head of Laboratory Christian Fager
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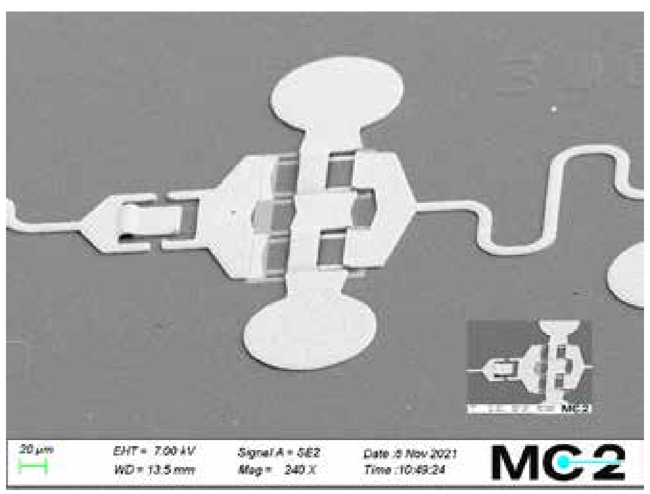
At the Microwave Electronics Laboratory (MEL) we perform application-relevant research on active high-speed electronic components, circuits, and subsystems. Our research is performed in close collaboration with industrial partners and contributes to improved energy and spectrum efficiency, higher data capacity, improved reliability and accuracy in new and emerging wireless communication and sensor applications.

Millimeter-wave integrated circuit design
A chipset for high data rate communication and radar sensing in the D-band, 110-170 GHz is developed in the EU project Car2tera. Building on Infineon's 130 nm B11HFC BiCMOS-process featuring a maximum frequency oscillation frequency of 380 GHz. In 2021, the chipset enabled a record high datarate exceeding 100 Gbps in a lab setup including a 1 m plastic waveguide. The excellent scalability of this technology makes it feasible to integrate many parallel channels in one chip and build, for instance, phased array systems and MIMO communication systems with several 100 Gbps in a near future. Our next goal is to package the chips for further wireless communication and radar sensing tests.

Energy-efficient wireless communication transmitters
The urge for increased energy efficiency and bandwidth in mobile communication applications is driving our research on innovative power amplifier circuit solutions co-designed with tailored signal processing algorithms antenna arrays. We collaborate closely with the CSE department on mixed-signal designs in 22 nm FDSOI CMOS. In 2021, this resulted in the demonstration of a fully integrated 20-26 GHz RFDAC that transmits a 256-QAM signal up to 8 Gbit/s with low distortion. For our research on beyond-5G/6G systems, we have extended our digital radio-over-fiber distributed MIMO testbed with a robot car which has enabled groundbreaking communication and localization experiments in 2021.

Electronics based on wide bandgap semiconductors
In our research, we explore new findings in material, device and circuit design, as well as characterization and modelling to improve the performance of electronics based on the AlGaN/GaN, and InAlN/GaN material systems. This semiconductor technology is of large interest in wireless communication and different types of sensor systems, where efficient power generation at high frequencies is essential. During 2021, we fabricated integrated circuits working up to 100 GHz and continued to explore the ultimate frequency performance by aggressive scaling of the transistor layout and the semiconductor layers. We have also explored a commercial GaN HEMT MMIC process in the H2020 CleanSky project GRACE, realizing an W band (93-100 GHz) LO VCO-multiplier chain with state-of-the art phase noise.



SEM-images of a simple GaN-based MMIC and a close-up of the transistor fabricated in cleanroom at MC2

NANOFABRICATION LABORATORY

Head of Laboratory Peter Modh
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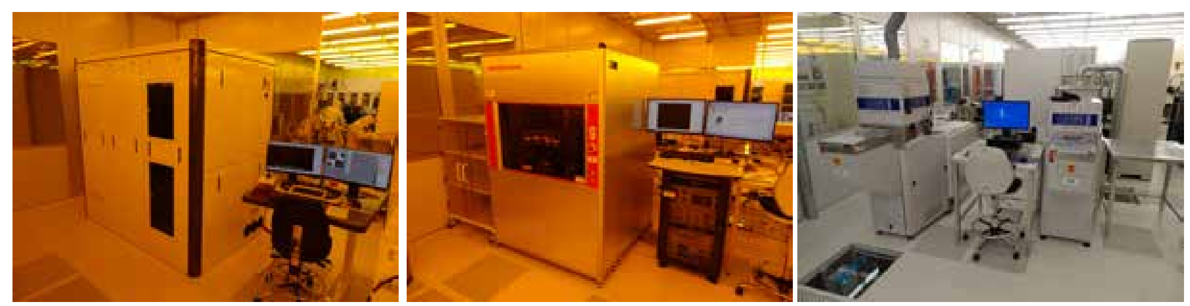
The Nanofabrication Laboratory (NFL) is a world-class university cleanroom for research into, and fabrication of, micro and nanotechnology. The laboratory is run by MC2, as an open user facility for external as well as internal academic and industrial interested parties. The laboratory offers a broad platform of process tools for the development and testing of new ideas in micro and nanotechnology. Two strategic focus areas in the cleanroom are within quantum devices and microwave/photonic devices. Both rely on our strength and strong heritage within nanolithography.

NFL runs and maintains the cleanroom, trains the users, supports researchers with process development and problem solving, and offers advanced process services to external customers. The NFL research infrastructure is a key-enabling laboratory for the whole of MC2. Its leading role in national micro- and nanofabrication initiatives, is widely recognised both domestically and in Europe. It is an inherently capital-intensive research infrastructure, required to support strategic goals both internally at Chalmers and globally. The laboratory is one of four nodes within the Swedish national research infrastructure for micro and nano fabrication, Myfab, with financing from the Swedish Research Council.

During 2021 we continued with the planned reinvestments, and we have procured a dry etch for Bosch process etching of Silicon, a PECVD for the deposition of Silicon Nitrides and Oxides, a laser lithography system, an SEM for automated analysis, and a new ellipsometer. All systems will be commissioned early 2022.

Cleanroom usage 2021
- 194 users that booked equipment
- 60344 booked hours
- 32 customers
  - 22 Swedish companies where 14 used own personnel in the cleanroom
  - 2 foreign companies where 1 used own personnel in the cleanroom
  - 5 Swedish universities or institutes where 4 used own personnel in the cleanroom
  - 3 foreign universities or institutes where 2 used own personnel in the cleanroom



From left to right the new tools delivered in the end of 2021:
Raith Chipscanner 150, Heidelberg MLA 150, and Oxford Estrelas and PECVD systems.

PHOTONICS LABORATORY

Head of Laboratory Peter Andrekson
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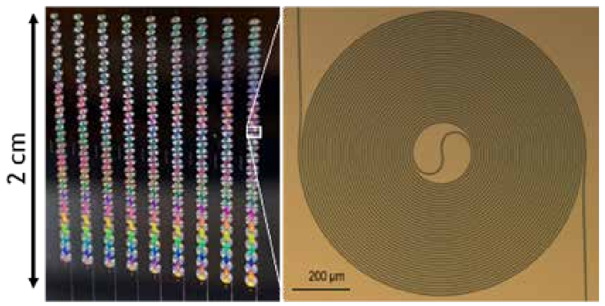
We conduct application-oriented research on opto-electronic materials and devices, photonic integrated circuits, ultrafast optics, and fibre optical communication. Optical communication is a high-visibility area of research, with efforts on system, circuit, and device technologies for applications ranging from long-haul fibre transmission and short-reach interconnects to free-space optical communication.

The research on coherent fibre optic transmission systems deals with spatial division multiplexing, energy-efficient transmission, and novel transmission schemes for improving spectral efficiency and data transfer capacity. A current research focus is on the optimization of utilizing all dimensions of light to increase the overall throughput. In addition, laser frequency comb technologies are developed for applications in fibre optic communication systems and ultrafast metrology.

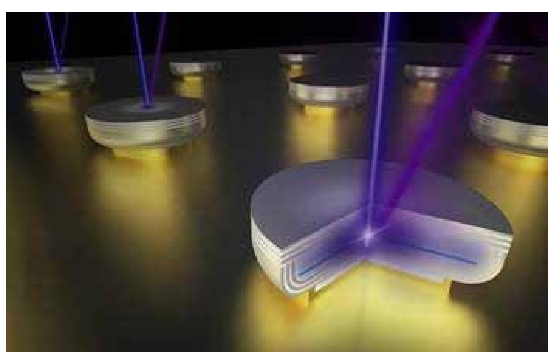
The research on phase-sensitive optical amplifiers aims at improving performance of fibre optic and free-space optical transmission systems by utilizing their excess-noise-free amplification and ability to mitigate fibre nonlinearities. A highlight this year is the first demonstration of continuous-wave parametric amplification in a compact chip. This was enabled by record low loss integrated dispersion-engineered silicon nitride waveguides of 1.4 dB/m.



Photograph of a silicon-nitride spiral waveguide structure used to demonstrate the first CW optical parametric amplifier

Our research on vertical-cavity surface-emitting lasers (VCSELs) led to the demonstration of monolithic multi-wavelength VCSEL arrays with precise channel spacing, intended for co-packaged high-bandwidth-density wavelength-multiplexed optical transceivers for short-reach interconnects including in harsh environments. Intensity noise was added to our physics-based VCSEL equivalent circuit model to accurately predict RIN-induced penalties in VCSEL-based optical interconnects.

Ultraviolet (UV) light-emitting diodes (LEDs) and visible and UV-emitting VCSELs are developed for applications in sterilization, solid-state lighting and medical diagnosis and treatment. Highlights include the first GaN high contrast grating VCSEL and the world's shortest emission wavelength VCSEL at 310 nm.



Artist illustration of an optically pumped UV VCSEL

QUANTUM DEVICE PHYSICS LABORATORY

Head of Laboratory Dag Winkler
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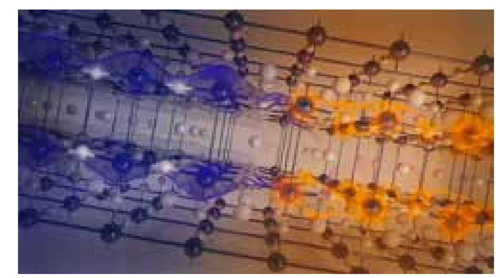
The Quantum Device Physics Laboratory (QDP) performs state-of-the-art research, education, and innovation in the field of nanoscale device physics exploiting the quantized charge and spin degrees of freedom in emerging materials that we tailor down to the atomic scale. The research extends over a variety of topics at the forefront of 2D materials and van der Waals heterostructures, topological Dirac and Weyl materials, semiconductors, oxide heterostructures, nanomagnets, and superconductors. Our mission is to develop novel nanoelectronic quantum devices for future generations of information and sensing technology, which can be smaller, faster, more sensitive and energy-efficient for a sustainable society. Applications are found, e.g., in quantum metrology, topological quantum technology, thermoelectrics, quantum theory, radio astronomy, medical instrumentation, and spintronics.

In 2021, QDP published 36 scientific papers (including 2 in Science) in internationally recognized journals, 2 review articles and 3 PhD theses. QDP was awarded 3 new research grants from the Swedish Research Council (VR). Samuel Lara was appointed new director of 2D-tech and graphene centre and Hans He together with Samuel Brem were given the GCC/2D-tech PhD Award for the best doctoral theses on graphene and related materials at Chalmers in 2020. The project SSF FLU-ID, which spun off the company Videm AB was recognized on IVA's 100-list. A few more highlights below:

Nanoparticles coated with graphene flakes loaded with new, very promising antibiotics. These drugs are unfortunately insoluble in water, making them difficult to transport in the bodies to bacterial cells. The graphene coated nanoparticles could be a solution to this problem. The sharp edges of graphene can damage the cell membrane and gradually release the deadly payload. This antibacterial nano-weapon is the goal of a new Nordic interdisciplinary research project coordinated by Prof. Ivan Mijakovic [1].

New insights into the strange metal phase of YBCO. Transport and X-ray scattering measurements were combined to study ultrathin films made of cuprate high-Tc superconductors. The strain induced by the substrate induces changes in the strange metal phase, in the charge modulations and in the superconducting order, which establish a clear hierarchy and intertwining between these phenomena. In conjunction with the suppression of long-ranged charge density waves, the strange metal flourishes and is restored in a large portion of the phase diagram [2]; vice versa, short-ranged charge density fluctuations might represent the long-sought microscopic mechanism underlying the peculiarities of this phase, that has evaded theoretical understanding for so long [3] .



The appearance of charge density waves (on the left) breaks the strange metal phase (on the right), where a "quantum entanglement", strong interaction between electrons, occurs.

A new type of spin quantum bit. In an international collaboration, we demonstrated the coherent behavior of a single electronic spin trapped in a superconducting weak link. This confinement is the result of phase coherent Andreev reflection processes, which strongly couple the trapped electron to the surrounding superconducting quantum circuit [4]. In 2003, our MC2 colleagues Göran Wendin and Vitaly Shumeiko took part in establishing the principle of this kind of qubit.

[1] https://www.chalmers.se/en/departments/bio/news/Pages/New-nano-weapon-against-resistant-bacteria.aspx.
[2] Wahlberg E, Arpaia R, Seibold G, Rossi M, Fumagalli R, Trabaldo E, et al., Science 373, 1506 (2021).
[3] Seibold G, Arpaia R, Peng YY, Fumagalli R, Braicovich L, Di Castro C, et al., Commun. Phys. 4, 7 (2021).
[4] Hays M, Fatemi V, Bouman D, Cerrillo J, Diamond S, Serniak K, et al., Science 373, 430 (2021).

QUANTUM TECHNOLOGY LABORATORY

Head of Laboratory Jonas Bylander / Per Delsing (until 31 January 2021)
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The research within the Quantum Technology Laboratory (QTL) is dominated by the big efforts within the Wallenberg Centre for Quantum Technology, WACQT (see separate article), led by Prof. Per Delsing. Profs. Göran Wendin and Jonas Bylander are active within the EU Flagship on Quantum Technology to help organise the consortium on superconducting quantum computers, OpenSuperQ.

In 2021, QTL welcomed Raphaël Van Laer as a new tenure-track assistant professor funded by WACQT and the ERC Starting Grant. Prof. Van Laer is coming from a postdoctoral fellowship at Stanford University and is now setting up a laboratory, Quantum Photonics Lab, at the intersection of quantum photonics and superconducting quantum technology.

The group led by Jonas Bylander is developing superconducting quantum computers, encompassing quantum-processor design and technology, the physics of qubits, quantum computer software infrastructure, and control methods enabling the implementation of quantum algorithms. One highlight from 2021 is a new method for reproducibly making Josephson junctions – the most important component of superconducting quantum processors – of sufficient quality for scaling up these processors to larger numbers of qubits (*A. Osman et al., Simplified Josephson-junction fabrication process for reproducibly high-performance superconducting qubits, Applied Physics Letters vol. 118, 064002 (2021). Editor's pick).* Other results include our first 3d integrated quantum circuit (S. Kosen et al.) and a discovery about the behaviour of the major sources of noise in superconducting quantum circuits (D. Niepce et al.)

The Wieczorek group demonstrated a superconducting chip that is capable of levitating a 50 µm diameter superconducting sphere at millikelvin temperatures. The next step is to fully characterize the centre-of-mass motion of the levitated sphere and to cool it to the quantum ground state, which would be the starting point to explore macroscopic quantum states. *(M G Latorre et al., A chip-based superconducting magnetic trap for levitating superconducting microparticles, arXiv:2109.15071 (2021)).*

The 202Q-lab, led by Simone Gasparinetti, performed state-of-the art experiments in measurement and control of a harmonic oscillator deep in the quantum regime. Their system consists of a high-quality microwave cavity made of aluminum, integrated with a planar superconducting qubit circuit. They demonstrated the high-fidelity generation of a range of Wigner-negative states useful for quantum computation, such as Schrödinger-cat states, binomial states, Gottesman-Kitaev-Preskill (GKP) states, and cubic phase states. *(M Kudra et al., Robust Preparation of Wigner-Negative States with Optimized SNAP-Displacement Sequences, ArXiv:2111.07965 (2021)).*

Researchers in the group of Per Delsing have demonstrated a new way to generate propagating nonclassical states that are useful for quantum computation. *(Y Lu et al, Propagating Wigner-Negative States Generated from the Steady-State Emission of a Superconducting Qubit, Physical Review Letters, 126, 253602 (2021)).*

TERAHERTZ AND MILLIMETRE WAVE LABORATORY

Head of Laboratory Jan Stake
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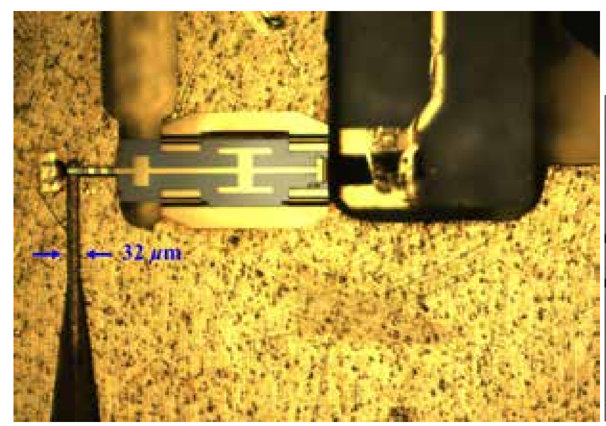
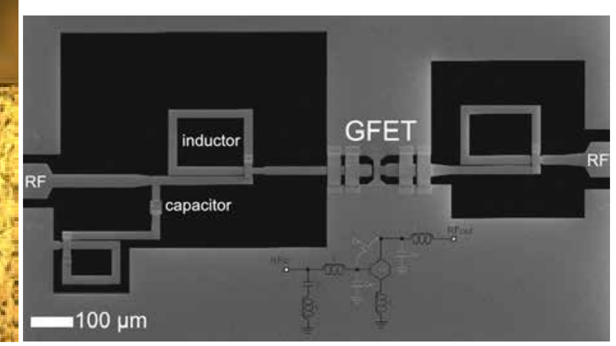
We demonstrate innovating technologies within the terahertz (0.3 – 10 THz) spectra with applications ranging from basic science to future wireless sensors and communication systems. Today, terahertz technology is an indispensable tool for space science, hoping to gain fundamental knowledge of the origin of our universe and for atmospheric science, which is directly related to the environmental challenge and climate change effects. Sandwiched between the visible light on the short wavelength side and radio waves on the long wavelength extreme, the sub-millimetre wave radiation or terahertz wave radiation has long been considered the last uncharted scientific gap in the electromagnetic spectrum. This is the part of the spectrum where optical and microwave techniques meet. Our research aims to close the THz-gap and light up the last dark region of the electromagnetic spectrum.

With a strong heritage in instrumentation for radio astronomy, we focus our research on the following main topics: graphene electronics; low noise devices and circuits; superconducting electronics; terahertz techniques for life science applications; and terahertz electronics and systems.

We benefit from two state-of-the-art facilities: the nanofabrication cleanroom at MC2, where we fabricate unique terahertz components, and our top-class terahertz characterisation laboratory (Kollberg lab). The group has a fruitful history of close collaboration with industry and academia. The laboratory members have knowledge and experience from material science, via device physics to microwave, millimetre wave and terahertz systems. Highlights from 2021 include a demonstration of compact, supra-terahertz mixers for frequency stabilisation of quantum cascade lasers carried out with Paul Drude Institute and German aerospace centre, Berlin, supported by the European space agency, Noordwijk. In collaboration with the Massachusetts Institute of Technology, a breakthrough in infrared single-photon detection at temperatures as high as 20 K was achieved. Our research collaborator at the German Aerospace Center (DLR), Professor Heinz-Wilhelm Hübers, was awarded honorary doctor at Chalmers for his outstanding contribution to the fundamental and applied research in terahertz components and instrumentation for space science applications. Former PhD student Muhammad Asad successfully presented his doctoral thesis on the impact of adjacent dielectrics on the high-frequency performance of graphene field-effect transistors – a research work carried out within the European graphene flagship. Our educational activities include circuit theory, microwave engineering, physics, microelectronics, and semiconductor device physics courses at undergraduate and graduate levels.



A 3.5-THz, ×6-harmonic Schottky diode mixer published in IEEE Transactions on Terahertz Science and Technology, 2021.



An integrated 10-GHz graphene FET amplifier published in Journal of microwaves, 2021.

FORCE

FIBRE OPTIC COMMUNICATIONS RESEARCH CENTRE

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Fibre-optic systems are essential for communication and is an integral part of our Internet-based society. FORCE was established in May 2010 with the aim to coordinate research at Chalmers and to generate more visibility of the research.

The core of the centre is the Photonics Laboratory at MC2, the Communication Systems Group at the Department of Electrical Engineering, and the VLSI Research Group at the Department of Computer Science and Engineering. The collaboration bridges traditional discipline boundaries and includes the chain from components to system, including photonic devices and electronics, and from analysis to experiments. FORCE is open to everyone at Chalmers who has interest in contributing.

While FORCE is a centre with no direct funding, it relies on sizeable external project grants from for example the Swedish Research Council (VR), The Swedish Foundation for Strategic Research (SSF), the K.A. Wallenberg Foundation (KAW), and the European Research Council (ERC).

We conduct inter-disciplinary research on energy-efficient optical communication, in which teams from all three departments join to address the challenge to co-optimise the hardware, algorithms and system with not only performance, but also energy efficiency as a key metric.

Our largest inter-disciplinary project is currently DIMENSIONS, funded by KAW, with the goal to explore the full-dimensional capacity of an optical fibre and to develop a spatial-spectral super-channel demonstrator to show significant throughput gains over current approaches. This involves aspects such as joint coding, advanced constellation formations and machine-learning approaches.

GIGAHERTZ CENTRE

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GigaHertz Centre (GHz Centre) was a research collaboration 2017-2021 in microwave engineering between Chalmers and industry, hosted by MC2. We involved 70 researchers at 14 companies and Chalmers in four joint projects during five years. The major achievements were:

- The development of energy-efficient 5G transceivers, from single transistor power amplifiers to advanced MIMO transmitters. This have required the integration of circuits, antennas, signals, and RF systems in the projects. The holistic approach developed in GHz Centre will become even more important in future transmitter research for 6G where very high frequencies (>100 GHz) and advanced distributed antenna systems are anticipated.
- The pioneering collaborative research on wide bandgap transistors in GHz Centre (starting > 20 years ago) from transistors to full systems such as AESA radar systems. This has helped Sweden to gain a leading position within GaN HEMT research and development building up a value chain of technologies which is now well-positioned in Europe. Several industries witness that the commercialization was accelerated thanks to our collaboration. This will be even more important when GaN HEMT technology now is commercialized in large markets such as consumer electronics.
- Sweden has established a solid reputation in Schottky diode THz technology, e.g., the delivery of 600 GHz mixers for the JUICE instrumentation planned for Jupiter. Also, the THz sensors can be used for weather prediction and climate research.
- The best cryogenic microwave low-noise amplifier performance during the past decade reducing the noise by a factor of 2.5. The products have come to usage in Google's quantum computer system, radio telescope arrays and, more recently, in CubeSats for weather monitoring of hurricanes.

The results have been materialized and documented in 70 scientific publications (60% co-authorship Chalmers and companies), seven PhDs (six PhDs hired by wireless industry), and nine documented stories of industrial impact originating from research carried out in GHz Centre.

Sponsors:
Chalmers University of Technology, company partners, Swedish Governmental Agency for Innovation Systems (Vinnova) in the Competence Centre Programme 2017-2021

Company partners 2017-2021:
Ericsson, Gotmic, Infineon Technologies, Keysight Technologies, Low Noise Factory, National Instruments, Omnisys Instruments, Qamcom Research and Technology, RISE Research Institutes of Sweden, Ruag Space, Saab, United Monolithic Semiconductors, Virginia Diodes, Wasa Millimeter Wave

2D-TECH/GRAPHENE CENTRE

Centre Director Samuel Lara Avila
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With all recruitments in place for its 17 projects, the Vinnova Competence Centre 2D-TECH is now on its way at full speed towards becoming an internationally visible Swedish hub for excellent research and industrial utilization of 2D materials.

The Competence Centre "2D-material based technology for industrial applications" (2D-TECH) is a joint research and innovation centre between Chalmers University of Technology and several industrial partners, and it is part of the Competence Centre program run by the Swedish Governmental Agency for Innovation (VINNOVA). Nearly 50 researchers and engineers are involved in the centre, with about 40% of them working in Chalmers across 6 different departments, and the rest in industry. 2D-TECH research and innovation activities encompass four strategic areas:

- Multifunctional composites
- Sustainable energy
- Electronics
- Emerging materials

During the second year of operations, 2D TECH entered its first, two-year Phase 1, of operations (2021-2022) with a total of 17 projects up and running. In November 16th, 2D-TECH organized its first centre day having Peter Böggild (DTU Denmark), Jari Kinaret (Chalmers), Fredrik Edgren (Volvo Car corporation) and Erik Khranovskyy (Grafren AB) as key note speakers. The event occurred in hybrid format, giving the opportunity, to over 50 attendees, to physically interact and discuss the research results and plans.

2D-TECH and the Graphene center at Chalmers (GCC) continue running networking activities including the biweekly seminar series, the PhD course on advances and challenges of 2D materials, and the PhD Award for 2D material research. The two recipients of the 2021 2DTECH/GCC PhD awards were Dmitrii Khokhriakov and Muhammad Asad, for their work on on spintronics and high frequency transistors, respectively.

Sponsors:
Swedish Governmental Agency for Innovation, (Vinnova), Chalmers University of Technology: Areas of Advance Materials and Energy, Excellence Initiative Nano, Gender Initiative for Excellence (GENIE)

Company partners
2D fab, APR Technologies, BillerudKorsnäs, Biopetrolia, Elitkomposit, Gapwaves, GKN Aerospace, Grafren, Graphensic, Graphmatech, Saab, SHT Smart High Tech, Superstate, Talga, Volvo Personvagnar, and Wellspect

WACQT
WALLENBERG CENTRE FOR QUANTUM TECHNOLOGY

Centre Director Per Delsing
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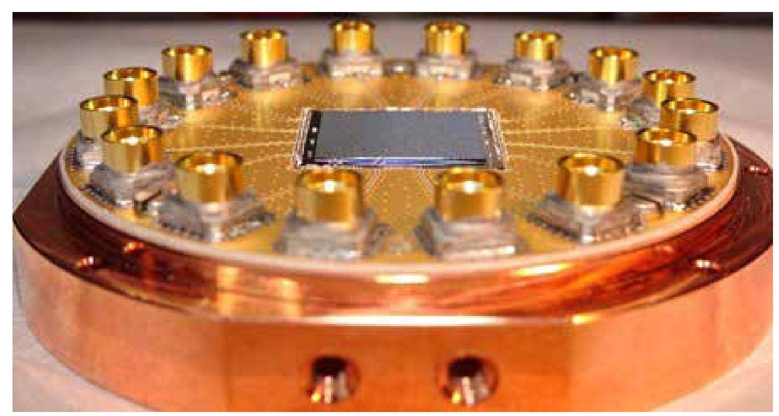
The Wallenberg Centre for Quantum Technology (WACQT) is a twelve-year (2018-2029), billion-SEK, nation-wide project coordinated from Chalmers. The Centre is funded by the Knut and Alice Wallenberg foundation (KAW); the Chalmers research effort is co-financed by the Chalmers foundation. At Chalmers, most WACQT research is carried out at MC2, in the Quantum Technology Laboratory (experiments) and the Applied Quantum Physics Laboratory (theory).

The Centre aims to develop and secure Swedish expertise within quantum technology, both in academia, industry, and society. To this end, the Centre spans all areas of quantum technology: quantum computing and simulation (Chalmers), quantum communication (KTH), and quantum sensing (Lund). The core project of WACQT is to build a Swedish quantum computer with 100 superconducting quantum bits (qubits) at Chalmers. Chalmers is part of OpenSuperQ, a project in the EU quantum technology flagship with goals aligned with the core project.

In 2021, WACQT's annual budget was almost doubled, and the Centre grew to involve around 120 researchers. In addition to the research agenda, the Centre has three instruments to help increase and spread knowledge in quantum technology:

- A graduate school for all PhD students in the Centre.
- A guest researcher program, through which in 2021 the former head of Google's quantum-computing development, John Martinis, visited Chalmers for one month.
- An industrial collaboration program with support for industrial PhD students. Six large Swedish companies have joined WACQT as industrial partners: Ericsson, SAAB, Volvo Group, Astra Zeneca, Jeppesen, and ABB.

Highlights from 2021 include theoretical development of faster and more powerful operations on a quantum computer using its existing components, experimental work on reducing the sensitivity of qubits to noise, the use of machine learning to swiftly characterize and construct quantum states, and the fabrication of a 25-qubit quantum processor.



Quantum computer chip mounted in a sample holder before measurement

INDUSTRIAL COLLABORATION

Vice Head of Department resonsible for Utilisation Cristina Andersson
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We leave 2021 behind us and enter 2022 with white winter landscapes and a society still marked by a pandemic that back and forth has forced us to keep apart. But, despite Covid restrictions, and thanks to both digital solutions and a fantastic personal ability to adjust and find new innovative ways to work, the staff at the department of Microtechnology and Nanoscience - MC2 continued to deliver fantastic results.

The Wallenberg Centre for Quantum Technology, WACQT, with its six industrial partners and four enabling technology partners, organised an industry workshop addressing questions of special interest to industry. The Vinnova Competence Centre GHz Centre, a long-term successful collaboration hub between academic partners and industry in the field of high frequency electronics ended its Vinnova financed activities at the end of the year. A dialogue between Chalmers and industry was started to form a possible continuation. The VINNOVA competence centre 2D-TECH welcomed a new partner, Grafren AB, resulting in a total of 17 industrial partners. The centre organised its first centre day, in a hybrid format, and a series of webinars where high profile speakers presented their 2D-materials' activities. MC2 was also engaged in the VINNOVA competence centre for III-nitride technology, C3NiT, in collaboration with Linköping Univ. and 10 industrial partners.

Two spin-off companies, based on research results from the department, were started in 2021. Videm AB (www.videm.se), a company originating from the Quantum Device Physics Laboratory is developing a small, automated diagnostic device for quick and accurate detection of infectious diseases directly at the point of care. Their technology is applicable to all pathogens enables multiplex testing. Iloomina AB (www.iloomina.com), a company originating from the Photonics Laboratory, is aiming at the commercialization of state of the art ultra-low-loss silicon nitride technology and unique microcomb technology.

Industry was also present at MC2 in the form of adjunct professors, in total 7 during 2021, of which one new adjunct professor and one new adjunct associated professor from Ericsson. Industry continued also to use the state-of-the-art infrastructure at the department and especially the nano fabrication laboratory that showed an all-time high in industrial activities.

All the above, together with everything else not mentioned here, contributed to fantastic results in the form of joint publications, students, increased industrial competitiveness and societal value, all comprising across borders win-win relations, with transfer of technology, knowledge, and knowhow, between MC2 and its industrial partners.

KOLLBERG LABORATORY

Laboratory Director Dan Kuylenstierna
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The Kollberg Laboratory is an open access Chalmers infrastructure for microwave and terahertz measurement technology. The vision of the laboratory is to offer access to unique instrumentation for the generation, detection, and analysis of electromagnetic signals in a wide spectrum, ranging from radio waves far into infrared light. Interesting applications in this spectrum are space science, medical research, wireless communication and radar systems, autonomous vehicles, security and defense. 2021 has been a successful year for the Kollberg laboratory in many perspectives.

The infrastructure has received a 23.2 MSEK grant from Vetenskapsrådet. The funding is allocated for the upgrade of equipment for a Wideband real-time terahertz transceiver testbed for communication and sensing and for Supraterahertz spectroscopy. Some specific instruments that will be procured are: a 110 GHz four-channel real-time oscilloscope, a signal analyzer for spectrum and phase noise analysis up to 500 GHz, a modular tunable source for 1.7-3.2 THz, a three-band (2.5, 3.5 and 4.7 THz) quantum cascade laser system, and two cryostats. During 2021 procurement of equipment in the 7.8 MSEK grant "Accessibility to infrastructure" received from Vetenskapsrådet in 2020 has been started. Equipment for reliability testing has been installed. The CNC milling machine and equipment for on-wafer THz characterization will be installed during 2022.

The Kollberg Laboratory has also invested in upgrade and renewal of Vector Network Analyzers (VNAs). Four existing Keysight PNA-X have been upgraded with new low-phase noise sources and new software. In addition, a new four-port 67 GHz PNA-X has been purchased as a replacement for an old two-port VNA that was decommissioned after more than 15 years of use. Furthermore, a 220 GHz VectorStar VNA from Anritsu is being procured. This instrument is replacing the old 145 GHz VectorStar in the set-up for wideband on-wafer characterization. The 145 GHz VectorStar will remain in the laboratory as a more flexible instrument not locked to a fixed set-up. For instance, this instrument will be available for coaxial characterization up to 145 GHz, a need expressed from users at the Quantum Technology Laboratory.

On notice of daily operations, 2021 has been another challenging year with the pandemic, but we have managed to maintain full accessibility for both internal and external users. The number of hours booked has been somewhat lower, which is natural as all users have been encouraged to plan measurements and increase efficiency to reduce the occupancy in the facilities. On the positive side, we have seen an increased interest from other divisions at Chalmers. In particular, we have seen more users from the Quantum Technology Laboratory.

We are now looking forward to 2022, which promise to be a very good year with a hopefully declining pandemic impact and many new state-of-the-art instruments arriving to the infrastructure!

Vice Head of Department resonsible for Undergraduate Education Per Rudquist
per.rudquist@chalmers.se

MC2 deliver undergraduate courses, on advanced level foremost within two master´s programmes: Nanotechnology (MPNAT) and Wireless Photonics and Space Engineering (MPWPS), and on bachelor level foremost within the subject areas of Engineering Physics, Electrical Engineering, and Biomedical Engineering. The master level courses as well as our bachelor and master thesis projects are often closely related to the research at the department.

The number of undergraduate courses delivered by MC2, spanning over the preparatory year, and both bachelor and master levels, and the contributions of MC2 faculty to courses in educational programmes at other departments, steadily increase. Many courses delivered by MC2 give the students extensive hands-on experience of designing and manufacturing of micro- and nanodevices.

I would like to thank all teachers at MC2 for their contributions and efforts during the last year. Despite the challenging times we in principle have delivered our courses as agreed, and the students are generally very satisfied with the teaching.

Two years with the corona pandemic has in many ways also changed our mindset about teaching. Even if most students and teachers at the department want to go back to normal campus teaching when the pandemic is under control, we know that some of the elements introduced with on-line teaching will be used also after the pandemic.

A wide range of courses
The department of MC2 now delivers core courses in physics, mechanics, optics, mathematics and electrical engineering in several bachelor programmes. The wide range of topics within our advanced level courses includes quantum physics, micro- and nanofabrication, microelectronics, microwave technology, materials science, low-temperature physics, quantum computing, photonics, and telecommunication.

MC2 has also delivered two project courses within TRACKS; Digitalization in sports (Dan Kuylenstierna, Microwave Electronics) within Health and sports technology and the new course Building and programming a quantum computer (Attila Geresdi, and Smone Gasparinetti, Quantum Device Physics) within the theme Emerging technologies - from science to innovation. Already in its first year the latter course had 11 students finishing a total of four group projects ranging from the investigation of quantum limited amplifiers to the development of a new quantum functional language, and the reports are all available open access at the Chalmers Open Digital Repository.

New professor of education
Per Lundgren (Electronic Materials and Systems) was promoted to Professor of Electronic Materials Education. His vital contribution with collegial support in implementing constructive alignment for courses and programmes has been highly appreciated and resulted in e g the shaping of new programmes in civil engineering. He has furthermore been responsible for Chalmers doctoral school for high school teachers and Chalmers complementary education for engineers with a non-European engineering degree.

International collaboration on master level teaching
The MPNAT programme is also part of the European Master Programme in Nanoscience and Nanotechnology (EMM-nano) run by KU Leuven (Belgium), Chalmers, University Grenoble Alpes (France), TU Dresden (Germany), and University of Barcelona (Spain). Within EMM-nano second year students come to MC2 for courses and Master thesis projects.

Missions of trust
Hans Hjelmgren, (Microwave Electronics Laboratory), in December 2021 stepped down as Programme Director for the Electrical Engineering programme, after more than 5 years. He is highly appreciated by the students and the teachers, as was thanked with a diploma from the Student Division at Electric Engineering. During his time as Programme Director he also initiated and further developed the project course MCC145, introducing the first year students to electric engineering applications, working hands-on with typical devices such as radar modules. These radar modules have later been used during Camp Vera, where Hans has been involved and active from the start. We thank Hans for his invaluable contributions to the programme and to courses developed and delivered by MC2 teachers.

Several MC2 faculty members are programme directors for educational programmes; August Yurgens (Quantum Device Physics) for MPNAT, and Zoran Konkoli (Electronics Materials Systems) for Computer Engineering 180p, and Chalmers coordinator for the EMM-nano programme is Thilo Bauch (Quantum Device Physics).

Dag Winkler (Quantum Device Physics) and Åsa Haglund (Photonics) are members of the advisory boards for the Medical Engineering and Engineering Physics programmes, respectively.

Per Lundgren is "PEDUL" - Collegial Pedagogical Developer" for the EDITI educational area. Furthermore, he has been a very active member of the Chalmers working groups formed to provide support for the transfer of teaching and examination into digital format.

Per Rudquist (Electronics Materials and Systems) is convener of the group of deputy heads of departments for undergraduate education at Chalmers.

Pedagogical and teaching developent
During 2021, with support from WACQT, a new "Quantum track" for master students in physics, has been proposed and created. It will be launched in 2022. Part of this track is the new master course "Open quantum systems" (Göran Johanson, Applied Quantum Physics, and WACQT).

Jonas Bylander and Magnus Gustafsson, Quantum Technology published the article: "Improved content mastery and written communication through a lab-report assignment with peer review: an example from a quantum engineering course." European Journal of Physics vol. 42, 025701 (2021).

Industry collaboration
MC2 courses regularly have guest lecturers from several companies such as Ericsson, Veoneer, Qamcom, Acconeer, Micronic, and Saab.

GRADUATE EDUCATION

Deputy Head of Department responsible for Graduate Education Magnus Karlsson
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The bulk of the research work at MC2 is carried out by our PhD (or graduate) students. Around 80 PhD students are enlisted in our graduate school, and most of those are full-time employees at Chalmers, with a smaller number being industrial PhD students, or double degree students who have an employment in industry or at another university.

The graduate school in Microtechnology and Nanoscience is a 4-year educational program, comprising three years of research and one year of course work. In addition, our graduate students also perform teaching and other departmental duties that may amount of up to an additional year, so that the total study time may be up to five years. An optional Licentiate degree can be awarded for students who write such a thesis at approximately half-ways to the PhD degree.

The last 2 years have been marked by the pandemic, and it has made on-site work (such as experiments or clean-room processing) more difficult, and some student have experienced reduced progress rate as a result. It is my hope that we later in 2022 we can come back to more normal operations, but students who feel they need more time to complete their theses than the allotted 5 years should first discuss the situation with their supervisors and second with me to form a reasonable plan for the remaining time.

In preparation for the PhD, the department puts particular value on the scientific quality of the research reported in the thesis. Therefore, an internal committee, the thesis review committee (TRC), consisting of three professors from the department reviews the content of the thesis six months prior to the planned defense. A thesis is given green light to go up for defense only if TRC finds the scientific quality sufficient. If not, the student will be given more time to complete the work. During 2021, TRC consisted of the following three professors: Tomas Löfwander, Christian Fager and Sergey Kubatkin. I would like to take this opportunity to thank them for their work, which significantly contributes to the maintained high scientific quality of the theses produced at our department.

MC2 awarded 18 PhDs and 8 Licentiate degrees during 2021. The theses are available electronically on our webpage. I would like to thank all the department's staff contributing to the PhD education during the year; examiners, main and co-supervisors, research staff, administrative and technical support personnel, and, last but not least, our ambitious students.

THESES 2021

DOCTORAL THESES

Sining An, Millimeter-wave communication and radar sensing – Opportunities, challenges, and solutions.

Muhammad Asad, Impact of adjacent dielectrics on the high-frequency performance of graphene field-effect transistors.

Stavros Giannakopoulos, Wideband integrated circuits for optical communication systems.

Mohammad Mazharul Haque, Electrolyte evaluation and engineering for the performance enhancement of electrochemical capacitors.

Filip Hjort, Ultraviolet vertical-cavity surface-emitting lasers and vertical microcavities for blue lasers.

Mehdi Jahed, VCSEL and integration techniques for wavelength-multiplexed optical interconnects.

Andreas Josefsson Ask, Quantum electro- and acoustodynamics in waveguides.

Bogdan Karpiak, Spin and magneto transport in van der Waals heterostructures of graphene with ferromagnets.

Dmitrii Khokhriakov, Graphene spin circuits and spin-orbit phenomena in van der Waals heterostructures with topological insulators.

Ya Liu, Exploration of Graphene-like 2D materials for energy management and interface enhancement applications.

Andreas Nylander, Fundamental characterization of low dimensional carbon nanomaterials for 3D electronics packaging.

Marco Scigliuzzo, Effects of the environment on quantum systems: decoherence, bound states and high impedance in superconducting circuits.

Parastoo Taghikhani, Modeling approaches for active antenna transmitters.

Kovendhan Vijayan, Phase-sensitive amplifiers for nonlinearity impairment mitigation in optical fiber transmission links.

Eric Wahlberg, Reshaping the phase diagram of $YBa_2Cu_3O_{7-\delta}$ through strain in ultrathin films and nanowires.

Emely Wiegand, Quantum optics and waveguide quantum electrodynamics in superconducting circuits.

Zhichao Ye, Ultralow-loss silicon nitride waveguides for nonlinear optics.

Abdelhafid Zehri, Characterization of multifunctional nanomaterials for electronics thermal management and sintering applications.

LICENTIATE THESES

Shahnawaz Ahmed, Quantum state characterization with deep neural networks.

Sadia Farjana, Polymer-based low-cost micromachining of gap waveguide components.

Halil Volkan Hünerli, Transmitter linearization for mm-wave communications systems.

Divya Jayasankar, Design and characterisation of terahertz Schottky diode harmonic mixers.

Ali Mirani, Constellation shaping in optical communication systems.

Frida Strömbeck, Integrated circuit solutions for high datarate polymer fiber communication.

Yu Zheng, Gaussian conversion protocols for cubic phase state generation.

Han Zhou, Theory and design of efficient active load modulation power amplifiers.

MC2 PHD STUDENT COUNCIL

Chair of the MC2 PhD Student Council Martí Gutierrez Latorre
marti.gutierrez@chalmers.se / aask@chalmers.se

The main purpose and task of the PhD student council is to help PhD students with all questions and problems they may have. The council is composed of students of each of the divisions in MC2, and has representatives on the Executive board, the MC2 advisory council, the Doctoral Student Guild (DS), and the Graduate Student Association for Physics (FFF). This is to be most aware of developments at MC2 and at Chalmers, and to be easily reachable by any PhD student in MC2.

This year, the council has been active in the areas of undergraduate teaching, the effects of the pandemic in PhD education and incremental improvements in the PhD graduate schools at Chalmers.

The teaching load on MC2 as a department has been rising in the last year, and it will rise more. This is due to the mandate from central Chalmers to even the teaching to research activities in its departments. This means that PhD students at MC2 will be asked to teach more often both in undergraduate courses (in Swedish) and master projects. The council is attempting to either streamline the minimum hour compensation or to establish guidelines/policy for how many hours should be awarded for what teaching at MC2.

The effects of the Economy in Balance and the shutdown of travel and logistical chains during the pandemic have significantly hampered the ability to recruit and bring in specialists, such as postdocs and technicians, and to get necessary research material and do maintenance and repairs on broken equipment. This has led to significant delays in many projects, especially experimental ones. The council has brought this up and established a consensus that, while requirements for PhD students will not change, contract extensions can be agreed upon on a case-to-case basis, within reason.

Further, the council has contributed the digital version of the study plan, a document containing the planned research and the progress over the duration of a PhD program, has been completed and should be released this year.

The council has also been attempting to keep PhD students up to date with the changes in the Generic Transferable Skills (GTS) courses, that is still in progress.

Finally, there has been a lot of discussions with other organizations about the recently implemented aliens act, about how to best weather the problems that it is causing and how to ultimately modify or remove it from law.

The Council meets in a monthly basis and we invite anyone interested in what is done or with some issue to bring up to join one of them.

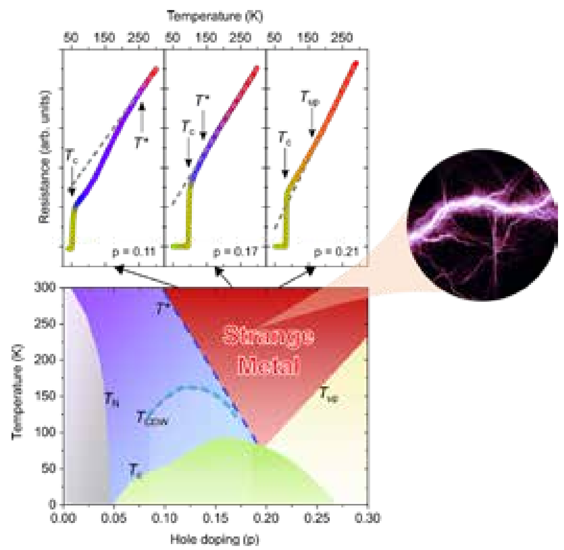
MC2 PhD student council 2021

QDP: Ivo Cools, Nermin Trnjanin
AQP: Hanna Linn, Ariadna Soro Álvarez
QT: Joey Frey, Martí Gutierrez Latorre
EMSL: Agin Vyas
TML: Junjie Li
MEL: Ragnar Ferrand-Drake del Castillo
Photonics: Israel Rebolledo Salgado

Shedding light on the strange metal regime of the cuprate superconductors

MC2 researcher Riccardo Arpaia, Quantum Device Physics Laboratory, is one of the authors of a recently published article in Communications Physics – a new open access journal from Nature Research. The paper Strange metal behaviour from charge density fluctuations in cuprates is a result of a collaboration between Chalmers, Politecnico di Milano, Brandenburg University of Technology and a group of theoreticians at La Sapienza University in Rome. The new findings are based on Riccardo Arpaia's research published in Science in 2019, within the framework of the "VR International Postdoc" carried out in Milan, Italy.

In the work published in Communication Physics, the researchers have presented a theoretical proposal, which has been developed by a group of theoreticians at La Sapienza University in Rome and at Brandenburg University of Technology. They have investigated the consequences of charge density fluctuations on the electron and transport properties of cuprates. The unforeseen discovery is that the charge density fluctuations allow them to explain one of the 'strange' (the use of such adjective is no coincidence!) characteristics of cuprates: the fact that, above the superconducting critical temperature, they have such a different behavior of the electrical resistance with respect to conventional metals. Which is indeed named 'strange metal behavior', and whose most evident benchmark is represented by the linear behaviour of the electrical resistivity as a function of the temperature T up to the highest attained temperatures.

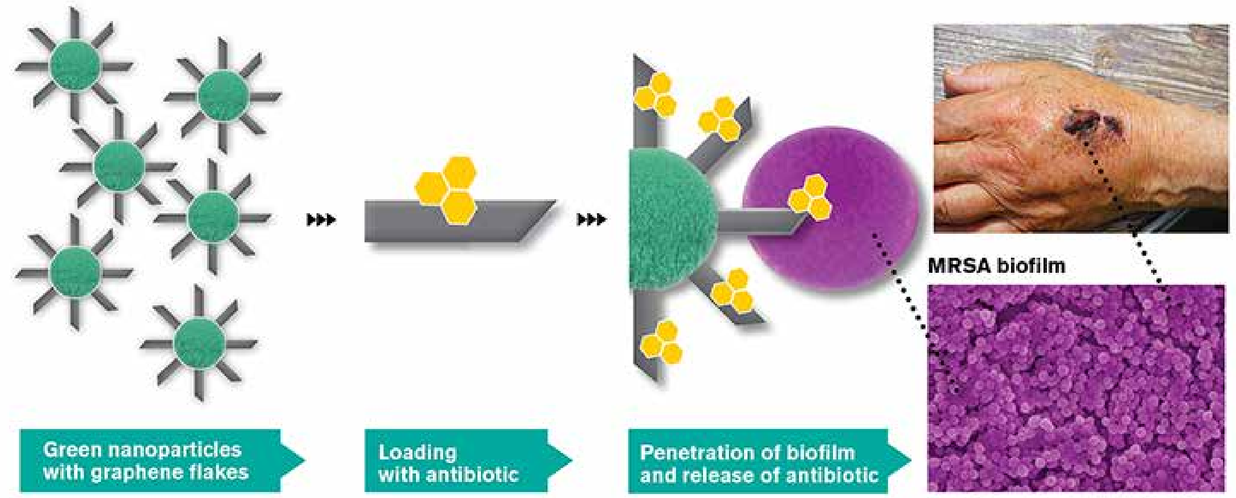


Strange metal behaviour from charge density fluctuations in cuprates. Commun Phys 4, 7 (2021). Seibold, G., Arpaia, R., Peng, Y. Y. et al.

Quantum physicist elected member of the Royal Swedish Academy of Sciences

Göran Johansson, professor at the Department of Microtechnology and Nanoscience, Applide Physics Laboratory, has been elected member of the Royal Swedish Academy of Sciences. He thus becomes the seventh Chalmers professor in the class of physics, and the third from our department.

"I feel honored and actually I'm a bit shocked. I hope that I will be able to contribute with my expertise in quantum technology and my curiosity in other research areas. The Royal Swedish Academy of Sciences is a heavy referral body in the Swedish research community and, among other things, does a very important work with the Nobel Prizes."



New nano-weapon against resistant bacteria

Nanoparticles coated with graphene flakes and antibiotics. This antibacterial nano-weapon is the goal of a Nordic interdisciplinary research project co-ordinated by Prof. Ivan Mijakovic, Chalmers. The project aims to deliver the next generation of treatments against antibiotic-resistant bacteria.

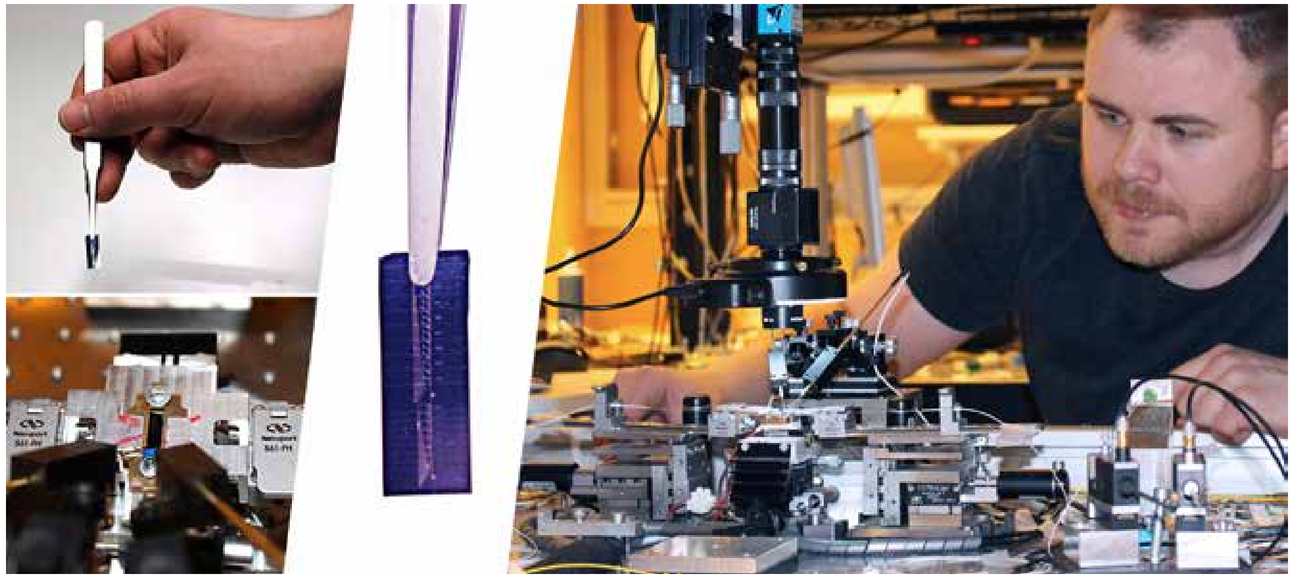
The research project will run for three years, and in January 2021 it was awarded 15 MSEK by Nordforsk. The researchers will specifically be focusing on treatment of methicillin-resistant Staphylococcus aureus (MRSA), which, among other things, causes chronic skin infections and sepsis.

The idea of the project is to combine three already established techniques in a completely new way to create a new system for drug delivery. Metal nanoparticles, graphene flakes and antibiotics all have antibacterial properties. Combined they would be even more powerful, as these particles most likely can penetrate the bacterial biofilm formed at the area of infection and release the antibiotic there.

Chalmers is one of the world leading universities in the research field of graphene. The idea of using graphene for medical treatments is relatively young but has great potential. Professor August Yurgens, Quantum Device Physics Laboratory, and his research group is developing the process where the nanoparticles are coated axially with graphene flakes.

"Sharp edges of graphene flakes placed vertically on a surface cut through the membrane of cells of a certain size, which research from Ivan and other scientists at Chalmers already has shown. Small bacterial cells are killed when they are cut by the sharp graphene edges, but human cells, which are bigger, are not harmed. The graphene flakes will be coated with the drug for transporting it deeper into the infected tissue. The antibiotics will then be released in the infected tissue gradually, "says August Yurgens and continues:

"Since some chemicals used as drugs are non-soluble in water, the main constituent of our bodies, we must find other ways of transporting the drugs within the body. The graphene coated nanoparticles could be a solution to this problem."



New microcomb could detect exoplanets and diseases

Tiny photonic devices could be used to find new exoplanets, monitor our health, and make the internet more energy efficient. Researchers from MC2, Photonics Laboratory, have presented a game changing microcomb that could bring advanced applications closer to reality.

A microcomb is a photonic device capable of generating a myriad of optical frequencies – colours – on a tiny cavity known as microresonator. These colours are uniformly distributed so the microcomb behaves like a 'ruler made of light'. The device can be used to measure or generate frequencies with extreme precision.

In a Nature Photonics article, eight Chalmers researchers describe a new kind of microcomb on a chip, based on two microresonators, instead of one. The new microcomb is a coherent, tunable and reproducible device with up to ten times higher net conversion efficiency than the current state of the art. Placed on a chip, the newly developed microcomb is so small that it would fit on the end of a human hair. The gaps between the teeth of the comb are very wide, which opens great opportunities for both researchers and engineers.

Since almost any measurement can be linked to frequency, the microcombs offer a wide range of potential applications. They could, for example, radically decrease the power consumption in optical communication systems, with tens of lasers being replaced by a single chip-scale microcomb in data centre interconnects. They could also be used in lidar for autonomous driving vehicles, for measuring distances. Another exciting area where microcombs could be utilised is for the calibration of the spectrographs used in astronomical observatories devoted to the discovery of Earth-like exoplanets. Extremely accurate optical clocks and health-monitoring apps for our mobile phones are further possibilities. By analysing the composition of our exhaled air, one could potentially diagnose diseases at earlier stages.

Helgason, Ó.B., Arteaga-Sierra, F.R., Ye, Z. et al. Dissipative solitons in photonic molecules. Nat. Photonics 15, 305–310 (2021).

Recipients of the annual PhD award

Hans He

Samuel Brem

Molecular doping of epigraphene and excitons in two-dimensional materials – those are the topics of the day as Samuel Brem and Hans He receive the GCC/2D-tech PhD Award for best doctoral thesis on graphene and related materials at Chalmers in 2020.

"I'm honored that Graphene Center has recognized my PhD work, and I am grateful to be the recipient of the 2D-Tech award. I am very happy that my research on applications of epigraphene has garnered some interest", says Hans He, former PhD student at the quantum device laboratory at MC2.

And his co-award-winner Samuel Brem, who carried out his PhD work at Condensed Matter and Materials Theory at the Physics department, joins in: "This award means a lot to me and I am very proud of it. It motivates me to continue my path in the academic world and to keep working hard on myself."

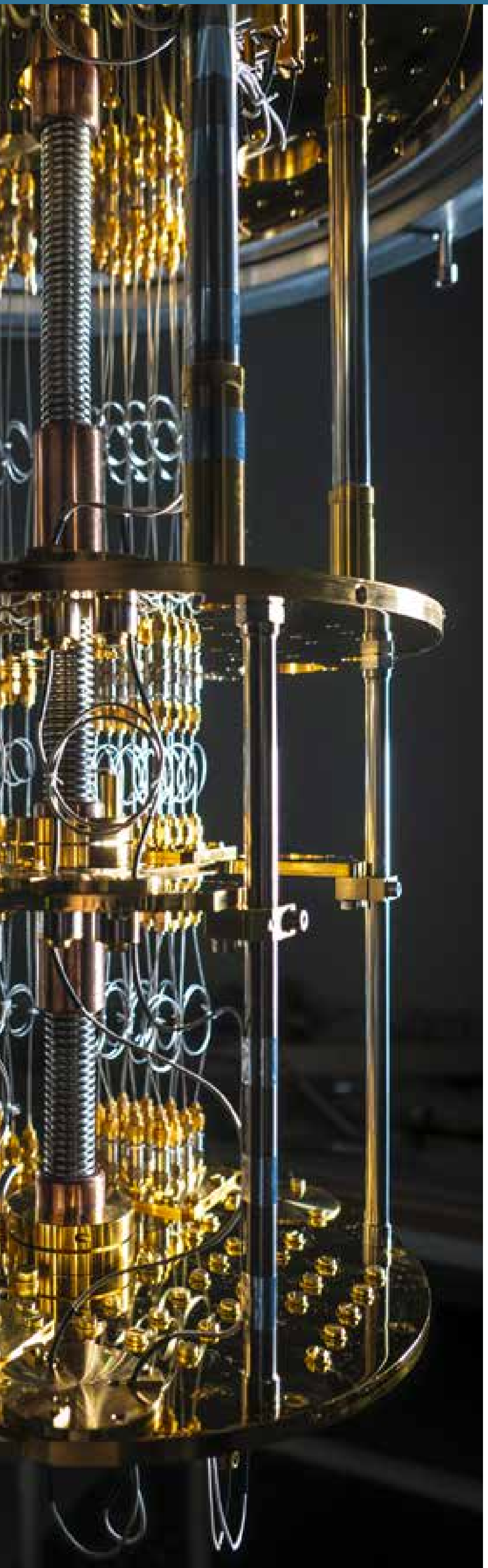
New head of Quantum Technology

A culture that benefits good teamwork and makes sure everyone is noticed in their work. That's the atmosphere Jonas Bylander is looking for as he takes on the role as new head of division of Quantum Technology at the department of Microtechnology and Nanoscience.

Jonas Bylander has been working with qubits for almost his entire career, starting the year after he got his PhD at the department of Microtechnology and Nanoscience at Chalmers in 2007. After a five years' research get-away to MIT, Massachusetts, he returned to his home department in 2013 where Jonas since then has been advancing from assistant professor to his current position as associate professor. Today, his research keeps focusing on qubits and the development of the quantum computer system as a whole. A track-record that quite naturally leads up to Jonas taking on the role as new head of the Quantum Technology Laboratory at MC2.

"QT is a well-working lab that spun out of QDP when we started Wallenberg Center for Quantum Technology, WACQT. I've had a big role in the research at QT, and now I am looking forward to also take a wider view of the department as a whole".

Jonas stepped into the role as head of the QT laboratory as of 1 February 2021, and will be managing a team that is expected to grow from 36 to an estimated 50 by the end of the year.



Sweden's quantum computer project shifts up a gear

Knut and Alice Wallenberg Foundation is almost doubling the annual budget of the research initiative Wallenberg Centre for Quantum Technology, based at MC2, Chalmers. This will allow the centre to shift up a gear and set even higher goals – especially in its development of a quantum computer. Two international workshops kick-started this new phase.

”Quantum technology has enormous potential and it is important that Sweden has the necessary skills in the area. During the short time since the center was founded, WACQT has built up a qualified research environment, established collaborations with Swedish industry and succeeded in developing qubits with proven problem-solving ability. We can look ahead with great confidence at what they will go on to achieve," says Peter Wallenberg Jr, Chair of the Knut and Alice Wallenberg Foundation.

Now comes the time to significantly scale up the number of qubits and increase the efforts to develop software and algorithms. At the same time, the entire research initiative is being scaled up, with the Knut and Alice Wallenberg Foundation, KAW, deciding to almost double WACQT's annual budget, from SEK 45 to 80 million per year for the coming four years. The investment has previously also been extended from its original ten years to twelve, and has a total funding of at least SEK 1.3 billion including contributions from industry and the participating universities.

With the additional funding, the number of researchers working in the quantum computer project can now be significantly increased. For example, a new team will be formed to study nanophotonic devices that can enable the interconnection of several smaller quantum processors into a large quantum computer. Within the next two years, the research force will be expanded by 40 people, almost double the current number. In a first step, fifteen new postdocs will be recruited.

“These are very exciting times in quantum computing. New steps are being taken all the time and the competition is rapidly increasing, with many countries making major investments. This investment will ensure that Sweden and Chalmers remain at the global forefront," says Per Delsing, director of WACQT and Professor at Chalmers.

2021 at-a-glance

Fast, sensitive and reliable test of viral infections on this year's IVA-list

A super-fast influenza test that provides reliable results within an hour. The Royal Swedish Academy of Engineering Sciences (IVA) is now turning the spotlight on a portable small device that is predicted to become an important tool in the fight against pandemics. The technology is developed through a research collaboration between Chalmers, Uppsala University, RISE, KI and SciLifeLab and is coordinated by Dag Winkler at the Quantum Device Physics Laboratory, MC2, Chalmers.

In May, the Royal Swedish Academy of Engineers presented their 2021 100-list of research projects from Swedish universities that have the potential to change the world. With the aim of building bridges between the business community and academia, and thus translating research into actual use, just under a hundred projects have been nominated and selected on this year's theme: emergency preparedness.

One of the projects making it to the list this year is FLU-ID, a research project that has developed a portable small device that enables fast and super sensitive diagnostics of infectious diseases. A near-patient diagnostic tool that provides reliable test results within an hour, enabling on-site analysis instead of via centralized laboratories.

The need for fast, simple and safe diagnosis of infectious diseases has become increasingly urgent during the Corona pandemic. And although the project primarily focuses on flu diagnostics, the method can also be used to detect other diseases, such as malaria, SARS or Covid-19. The technique is based on magnetic analysis of samples from nasal mucosa, blood or urine and enables testing of several different diseases at the same time.

Fast multi-qubit gates enhance the performance of quantum computers

Available quantum computers struggle with noise that causes the qubits to quickly forget their values. Therefore, it is desirable to execute the algorithms swiftly. A team of WACQT researchers have now shown how two-qubit gates can be run simultaneously to create multi-qubit gates, which are more powerful – but still take less time to execute – than the constituent two-qubit gates.

Quantum algorithms may outperform classical ones on important computational tasks in chemistry, optimization, and many other fields. However, to run on current quantum computers, these algorithms must be compiled into long sequences of elementary operations (gates) on one or two qubits.

Since the available quantum hardware still struggles to protect qubits from noise, it is desirable to execute the algorithms as swiftly as possible. In a PRX Quantum publication, a team of WACQT researchers at Chalmers shows how two-qubit gates on existing quantum hardware can be run simultaneously to create new, powerful multi-qubit gates, which surprisingly take less time to execute than the two-qubit gates from which they are constructed.

Xiu Gu, Jorge Fernández-Pendás, Pontus Vikstål, Tahereh Abad, Christopher Warren, Andreas Bengtsson, Giovanna Tancredi, Vitaly Shumeiko, Jonas Bylander, Göran Johansson, and Anton Frisk Kockum. PRX Quantum 2, 040348

New director of 2D-tech and graphene centre

Entrepreneurship, pro-activity, and interaction with the industry – three crucial ingredients when making Chalmers the Swedish epicenter of atomically thin materials and quantum materials. At least if you ask Samuel Lara-Avila who now takes the lead as new director of 2D-TECH and Graphene centre at Chalmers University.

Samuel Lara-Avila, associate professor of physics, was appointed new director of 2D-TECH and Graphene Centre at the 2D-TECH assembly on 3 March. And with more than ten years' experience working on graphene and an academic history at Chalmers that took off already in 2006, it's safe to say he's in familiar territories.

"I know for a fact that graphene can bring something to the table and solve real-world problems that other materials cannot. I see GCC and 2D-TECH as two tools to consolidate Chalmers as the Swedish epicenter of atomically thin materials and quantum materials", says Samuel.

Samuel succeeds Ermin Malic who has been director of Graphene Centre since 2017 and of 2D-TECH since its birth in February 2020. And to Ermin stepping down doesn't mean slowing down. New challenges await in the same country where he once got his PhD 13 years ago.

New research on how to reduce the interference in superconducting components

In an article in Science Advances, researchers from Quantum Technology Laboratory at MC2, present experiments and models that explain how to reduce the interference from defects in materials for superconducting electronic components. The interference is reduced by exposing the materials to a radio frequency electric field. The new results may in particular play an important role in the production of quantum computers.

Superconducting materials contain defects that generate disturbing noise. Today, no one knows for sure exactly what these defects consist of. In the newly published research, Jonas Bylander and his colleagues show how it is possible to reduce the noise in the materials by exposing them to a radio-frequency electric field.

The researchers discovered that the defects display so-called "motional narrowing" when they are exposed to the radio-frequency electric field, something that has not been previously detected in dielectric materials. Bylander compares the effect that occurs with that of reduced motion blur in a photograph.

The published research increases the understanding of how materials used to build superconducting circuits work – when reducing the noise, the components perform better.

"We try to build better components from better materials and design the components so that they are not so sensitive to noise, and if we understand the materials better, we will also be able to build better quantum computers."

Niepce et al., Sci. Adv. 2021; vol 7, Issue 39

With a mind set on nano

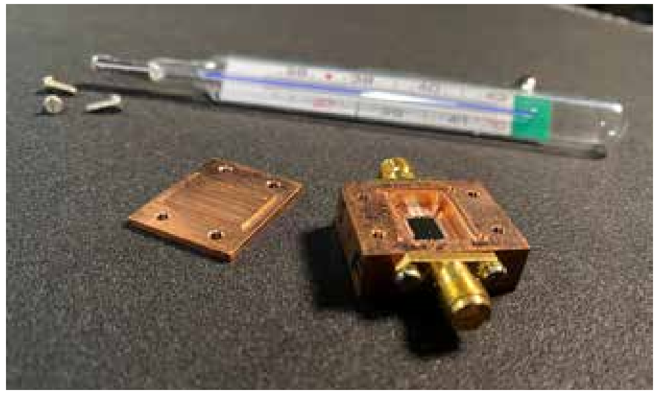
She's a professor of applied quantum physics, a mother of three and speaks five languages. As the leader of the interdisciplinary Nano Excellence Initiative, Janine Splettstoesser now wants to create one of Europe's top nanocenters with the goal of addressing the biggest challenges facing the society. But when it comes to the proudest career moments, she'd rather speak about her students. "When a PhD student gives a really good defense on their dissertation and can continue to work on what they really like and subsequently grow as a researcher. That makes me really proud."

We meet in the department's family room. It's Easter break and Janine's 6-year-old son Paolo has come along. He immediately starts pulling out building kits and tricky games from the shelves while Janine takes a seat at a designated workplace across the room. An empty desk and an ordinary laptop. A mind-blowing thought to an outsider that this is all that is needed for a professor of applied quantum physics when trying to juggle lectures, seminars, conferences and supervision of PhD students. Not to mention her own research.

Janine's many engagements at the department of Microtechnology and Nanoscience become clear within minutes. We've already touched on her teaching, PhD supervision and research. But as of 2021 she's also the new Director of the Nano Excellence Initiative, a government-funded and interdisciplinary initiative, that includes three other departments besides her own - chemistry, physics, biology - with the joint ambition to promote research and development of nanotechnology at the university.

"My goal is to create a meeting place for nano-researchers at all levels, junior as well as senior. A kind of incubator for building collaborations, sharing ideas and networking," Janine explains.

Novel thermometer can accelerate quantum computer development



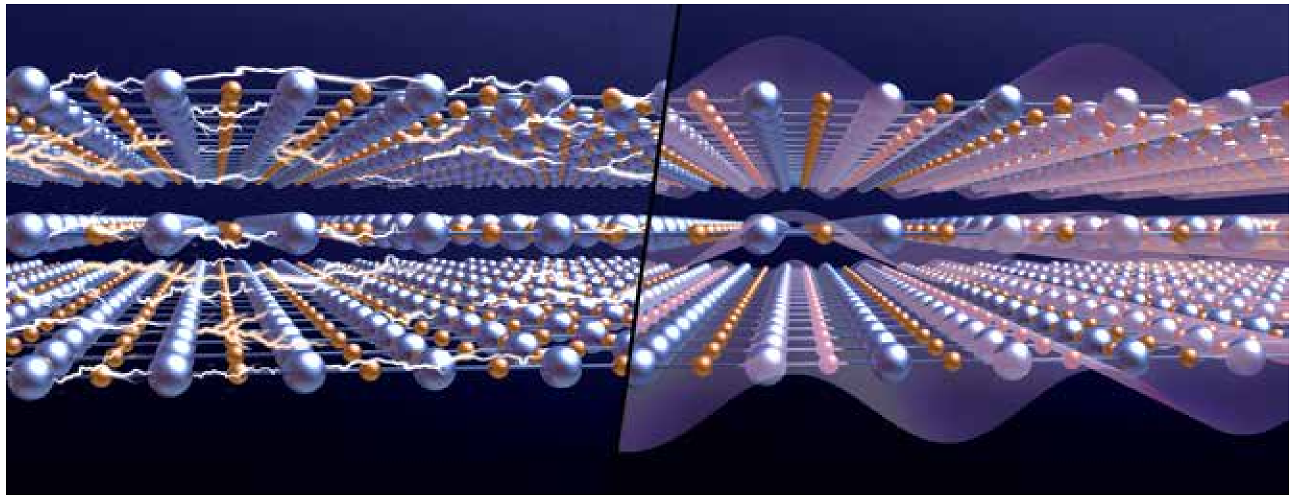
Researchers at Quantum Technology Laboratory, MC2 have developed a novel type of thermometer that can simply and quickly measure temperatures during quantum calculations with extremely high accuracy. The breakthrough provides a benchmarking tool for quantum computing of great value – and opens up for experiments in the exciting field of quantum thermodynamics.

A key component in quantum computers are coaxial cables and waveguides – structures which guide waveforms, and act as the vital connection between the quantum processor, and the classical electronics which control it. Microwave pulses travel along the waveguides to the quantum processor, and are cooled down to extremely low temperatures along the way. The waveguide also attenuates and filters the pulses, enabling the extremely sensitive quantum computer to work with stable quantum states.

In order to have maximum control over this mechanism, the researchers need to be sure that these waveguides are not carrying noise due to thermal motion of electrons on top of the pulses that they send. In other words, they have to measure the temperature of the electromagnetic fields at the cold end of the microwave waveguides, the point where the controlling pulses are delivered to the computer's qubits. Working at the lowest possible temperature minimises the risk of introducing errors in the qubits.

Until now, researchers have only been able to measure this temperature indirectly, with relatively large delay. Now, with the Chalmers researchers' novel thermometer, very low temperatures can be measured directly at the receiving end of the waveguide – very accurately and with extremely high time resolution.

Marco Scigliuzzo, Andreas Bengtsson, Jean-Claude Besse, Andreas Wallraff, Per Delsing, and Simone Gasparinetti. Phys. Rev. X 10, 041054



Making the strange metal state in high temperature superconductors even stranger

Researchers from Quantum Device Physics Laboratory at MC2 have uncovered a striking new behavior of the 'strange metal' state of high temperature superconductors. The discovery represents an important piece of the puzzle for understanding these materials, and the findings have been published in the highly prestigious journal Science.

Superconductivity, where an electric current is transported without any losses, holds enormous potential for green technologies. For example, if it could be made to work at high enough temperatures, it could allow for lossless transport of renewable energy over great distances. Investigating this phenomenon is the aim of the research field of high temperature superconductivity. The current record stands at −130 degrees celsius, which might not seem like a high temperature, but it is when compared to standard superconductors which only work below −230 degrees celsius. While standard superconductivity is well understood, several aspects of high temperature superconductivity are still a puzzle to be solved. The newly published research focusses on the least understood property – the so called 'strange metal' state, appearing at temperatures higher than those that allow for superconductivity.

The key finding of the paper is that the authors discovered what kills the strange metal state. In high temperature superconductors, charge density waves (CDW), which are ripples of electric charge generated by patterns of electrons in the material lattice, occur when the strange metal phase breaks down. To explore this connection, nanoscale samples of the superconducting metal yttrium barium copper oxide were put under strain to suppress the charge density waves. This then led to the re-emergence of the strange metal state. By straining the metal, the researchers were able to thereby expand the strange metal state into the region previously dominated by CDW – making the 'strange metal' even stranger.

The researchers' work indicates a close connection between the emergence of charge density waves and the breaking of the strange metal state – a potentially vital clue to understand the latter phenomenon, and which might represent one of the most striking evidence of quantum mechanical principles at the macro scale. The results also suggest a promising new avenue of research, using strain control to manipulate quantum materials.

Wahlberg E, Arpaia R et al. Restored strange metal phase through suppression of charge density waves in underdoped YBa. Science,vol. 373, number 6562, pages 1506-1510 (2021)

Unique radar components for more sustainable aviation

More efficient air traffic control systems could make a significant contribution to reducing the climate impacts of aviation. But to achieve this, new and more advanced radar systems are required for more accurate navigation. Now, a Chalmers-led research project has developed radar components with a unique level of performance that can contribute to reducing the climate impact.

A European target for reducing the climate impact of aviation states that aircraft that are put into operation after 2020 should have 50 percent lower carbon dioxide emissions compared to those that put into operation in 2000. Of this improvement, more efficient air traffic management systems are estimated to be able to contribute about 10 percentage points. Newer, more efficient systems, which can facilitate better flying in rain and fog, are an important measure to reduce carbon dioxide emissions and achieve the goal. When aircraft can fly more directly towards their destination and avoid interrupted landing attempts due to bad weather, unnecessary emissions can be reduced.

A precondition for this is to upgrade the air traffic control systems with better radars on the aircraft themselves. Now, after almost three years of research, the Chalmers-led, European project is the first in the world to demonstrate precisely this type of component. "Aviation has a major climate impact and so it is important to work with as many measures in parallel to reduce this impact. It feels great to be able to contribute to more sustainable flying in the future," says Dan Kuylenstierna, Associate Professor at MC2 and leader of the project.

The radar components developed through the project are similar to those in self-driving cars. But to be able to be used in aircraft, especially in rain and bad weather, the transmitter power needs to increase significantly. To solve this problem, the research project developed new circuits and encapsulation methods. This means that the technology can now be integrated into the new aircraft's air traffic control system in a way that is both cost-effective and reliable.

2021 at-a-glance

Quantum computer project boosted by superstar

In 2019, a research team at Google made a big breakthrough: their quantum computer managed to surpass the world's best supercomputers in solving a computational task.

The chief scientist behind Google's quantum computer, world-famous Professor John Martinis, left Google the following year and returned to his university, University of California, Santa Barbara. However, he 2021 spent one month in Gothenburg as a guest researcher in Chalmers' quantum computing team where Per Delsing and Jonas Bylander lead the engineering of a Swedish quantum computer. The focus has mainly been on the basic building blocks of the quantum computer – the qubits.

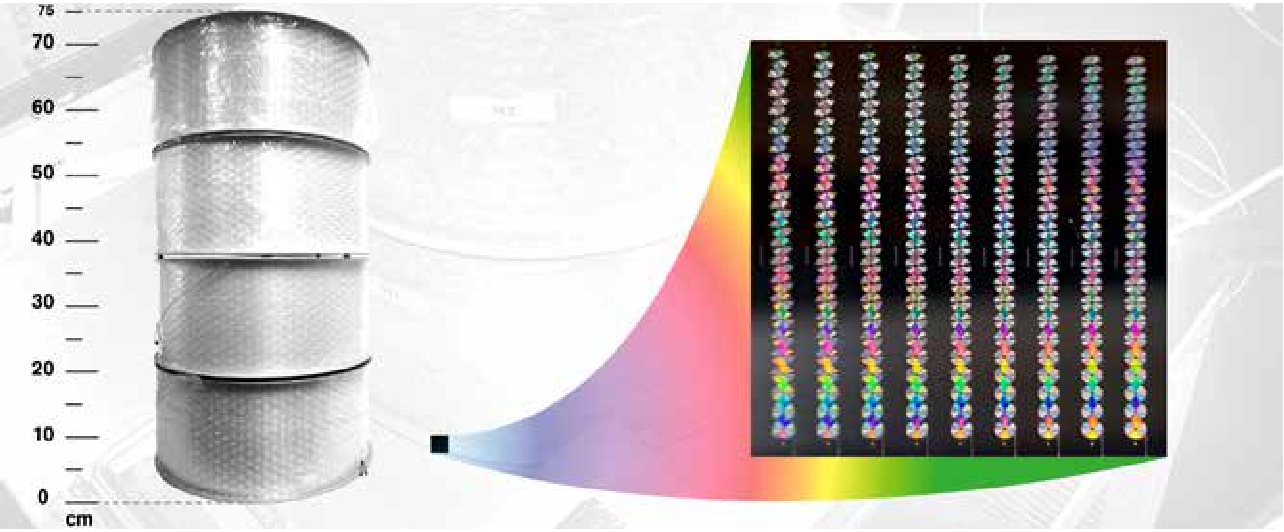
Per Delsing describes John Martinis' visit as a shot in the arm:
"The entire group looks up to him, like a hero. The fact that we all got to spend time with him and his deep interest in what everyone is doing has been like a huge shot. John is extremely skilled and experienced and has given us many valuable suggestions on how to continue our work."
The plan now is to stay in touch, to share results, thoughts and ideas.
"I think that really good things will come out of this," says John Martinis.

New project for future supercomputers

Researchers from Quantum Technology Laboratory, MC2 will now take part in launching an international research project to create an interface between superconductors and semiconductors for future supercomputers.

As a participant of the international research network SuperGate (Gate Tuneable Superconducting Quantum Electronics), researchers from Chalmers are now taking part in an EU-funded project to create a new basis for the super-computers of tomorrow: to develop a bridging technology that combines superconductor technology with semiconductor technology, using an approach that was considered physically impossible until just a few years ago. The two technology systems have up till then been considered incompatible in the sense that semiconductors are controlled by voltage and operate at room temperature, while superconductors, on the other hand, are based on current and operate at temperatures of around minus 270 degree Celsius, near absolute zero. Combining the more powerful and more energy-efficient superconductor technology with existing semiconductor technology is of great interest in high-performance computer development.

"This project will shed some light on a physical effect that we do not fully understand, and, at the same, it provides a clear pathway to utilization," says Simone Gasparinetti, project leader of the research team from the department of Microtechnology and Nanoscience at Chalmers University of Technology.



Unique amplifier could change optical communication

Researchers from Photonics Laboratory, MC2 present a unique optical amplifier that is expected to revolutionise both space and fiber communication. The new amplifier offers high performance, is compact enough to integrate into a chip just millimeters in size, and – crucially – does not generate excess noise.

With communication based on light, rather than radio waves, we could, for example, quickly send high-resolution images from Mars. The information, carried by laser beams, could be sent with high speed from a transmitter on the planet to a receiver on Earth or on the Moon. Optical communication also allows us to use the internet around the world – whether the signal is transferred in optical fiber cables under the seabed or transmitted wirelessly.

Because the light – carrying the information between two distant points – loses power along the way, a large number of optical amplifiers are needed. Without amplifiers, up to 99 percent of the signal in an optical fiber cable would disappear within 100 kilometers. A well-known problem in optical communication, however, is that these amplifiers add excess noise that significantly impairs the quality of the signal you want to send or receive. Now, the Chalmers researchers present an extremely promising solution to an obstacle that has existed for decades.

The light amplification in the project is based on a principle known as the Kerr effect, which so far is the only known approach that amplifies light without causing significant excess noise. The principle has been demonstrated before, but never in such a compact format– previous versions were too bulky to be useful. The new amplifier fits in a small chip just a few millimeters in size, compared to previous amplifiers that have been several thousand times larger.

Additionally, the new amplifiers offer a level of performance high enough that they can be placed more sparingly, making them a more cost-effective option. They also work in a continuous wave (CW) operation rather than a pulsed operation only.

Overcoming the quantum limit of optical amplification in monolithic waveguides. Ye et al., Science Advances. 2021; 7 : eabi8150

Family room at MC2

Working as a researcher is a challenge. Working as a researcher and at the same time being a parent of young children is an even greater challenge.

At the Department of Microtechnology and Nanoscience, a family room has been built for staff to make it easier to manage their everyday lives. The staff can book the room, bring their children there, and work there while the children hopefully entertain themself with toys and books.

Janine Splettstößer is professor of theoretical physics and the one who initiated the family room.

"Both my husband and I are researchers, and at the same time being parents of young children sometimes make it difficult to organize everyday life," she says.

When Chalmers' foundation initiative for gender equality, Genie, made an internal call for projects that would strengthen gender equality at Chalmers, Janine Splettstößer seized the opportunity.

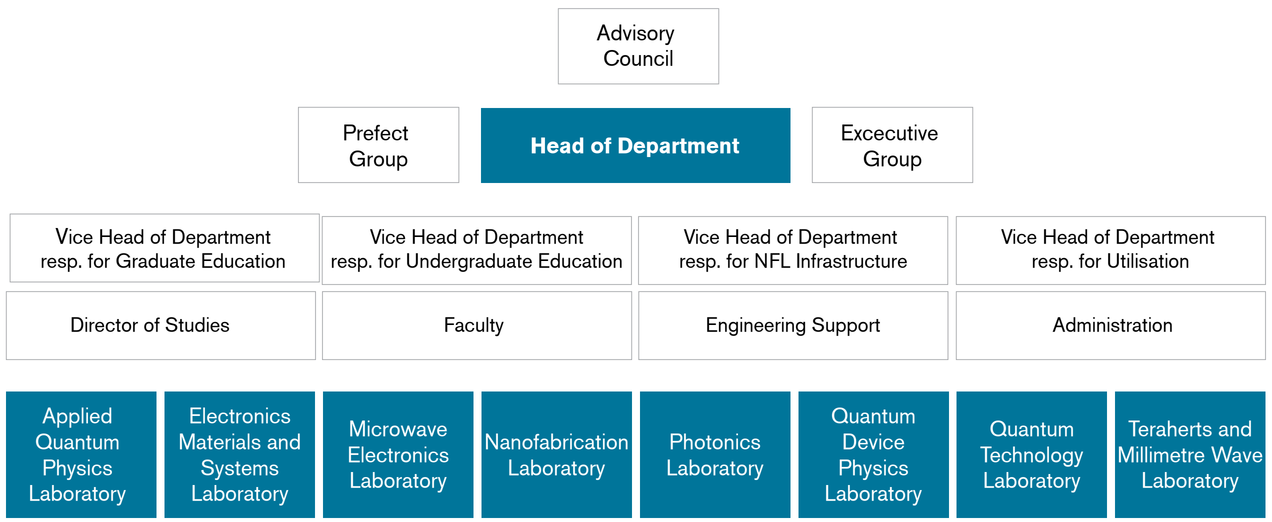
"I asked the head of my department, Mikael, if he thought it was a good idea to do if we could find a room, and he said yes. I went ahead, got money from Genie, and then we found a suitable room. Mikael has supported me a lot in this work – without him there would have been nothing with the family room", she says.

Heinz-Wilhelm Hübers is 2021's honorary doctor at Chalmers

Researcher Heinz-Wilhelm Hübers, professor at Humboldt-University Berlin and the director of the Institute of Optical Sensor Systems at Deutsches Zentrum für Luft und Raumfart, DLR (German Aerospace Center), is awarded an honorary doctorate to recognize his outstanding contribution to the fundamental and applied research in the field of terahertz components and instrumentation for space science applications, and his persisting leading work towards strengthening and expanding international collaborations across countries and continents. His role has been crucial in forming and enabling high spectral resolution terahertz astronomy through such renowned projects like the Herschel Space Observatory and SOFIA (Stratospheric Observatory for Infrared Astronomy), as well as in forming concepts for future terahertz remote sensing space missions.

Professor Hübers has a long history of collaboration with researchers at Chalmers, starting more than two decades ago, through a large number of joint research ventures, supported by various EU Framework Programs as well as the European Space Agency (ESA). This fruitful collaboration had contributed to forming Chalmers as an international node in terahertz technology and instrumentation – stretching through several departments and laboratories and finding applications from biology and communication to space and environmental sciences.

ORGANISATION



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FINANCIAL REVIEW

Distribution of incomes to MC2 from different sources. (in 1000 SEK)	2021
Ministry of Education & Science / Research	102 939
Other state funding	90 857
Public foundations	64 967
European Union	48 045
Companies etc.	28 205
Ministry of Education & Science / Education	10 786
Miscellaneous	1 008

Main external contributors (in 1000 SEK)	2021	2020	2019
Knut & Alice Wallenberg Foundation (KAW)	51 771	52 314	54 505
The Swedish Research Council (VR)	51 471	53 095	51 480
European Union	48 045	37 277	29 865
Swedish Agency for Innovation Systems (VINNOVA)	22 028	20 658	17 871
The Swedish Foundation for Strategic Research (SSF)	12 243	16 987	20 619

BIBLIOMETRIC DATA

Publications

Year	Scopus (articles, conference papers)	research.chalmers.se (articles, reviewed)	research.chalmers.se (conference papers, reviewed)
2017	290	183	135
2018	190	140	86
2019	181	155	49
2020	197	170	50
2021*	218	150	77

* Preliminary data extracted April 2021

Field weighted citation impact, FWCI

FWCI = citations per publication, compared to global averages for articles published at the same time and in the same subject. To get more stable values, FWCI is calculated for a rolling four-year period. FWCI > 1 thus means "better than the world average". N = number of publications.

Year	N	FWCI
2013-2016	1076	1,2
2014-2017	1103	1,25
2015-2018	1013	1,22
2016-2019	929	1,22

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