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Dear reader,

the task to summarise the year 2020 is quite different than summarising activities of previous years. The world-wide pandemic has affected everyone, wave after wave. Everyday life and its aspects have had to adapt and change, and this is of course also very true for our academic work. For us, all our core activities from teaching, research, support and management have been carried out respecting social distancing. This, mostly meaning that we have worked from home and in a new isolated context. This is taxing for all of us, and I sincerely hope that we soon can return to what will be the new normal. New normal? Some of the ways of working we have had to explore, learn, and adapt to will stay on as they may turn out to be more sustainable, both on the personal and on the societal level, compared to how we did previously.

Despite the pandemic, and despite an additional financial challenge we are faced with at Chalmers, our department has a year full of activities and achievements that we are proud to summarise in this annual report. As Head of Department, I want to thank all colleagues for your very hard work, endurance and coping with the uncertainties that the pandemic has caused.

Mikael Fogelström
Head of Department
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 2020 employed 33 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 quantum thermodynamics, exotic phases in high-temperature 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 highlights in 2020 include a Nature publication on an experimental realization of coupled Giant Atoms, a concept developed by Dr Anton Frisk Kockum, permanent researcher at AQP and a co-author of the paper. This demonstrates a new quantum-computing architecture that makes it possible to both perform quantum computations and communicate quantum information between distant parts of the quantum processor, all with low losses.

The MSc thesis work of Timo Hillmann, supervised by permanent researcher Fernando Quijandria, led to a joint publication with Assistant Professor Giulia Ferrini, in Physical Review Letters. The work established a novel and experimentally accessible method to perform universal quantum computing in continuous variable with superconducting circuits. Timo Hillmann was also awarded an Excellence PhD position by the Excellence Initiative Nano at Chalmers and has joined AQP as a PhD student.

In 2020, we are also very proud that Professor Janine Splettstoßer was appointed the new leader of the Excellence Initiative Nano at Chalmers and that the mentorship program WISE-WWACQT, initiated by Assistant Professor Giulia Ferrini together with the networks Women in WACQT and Women in Science, was highlighted in Ny Teknik.

At the Electronics Materials and Systems Laboratory (EMSL), research is focused on electronics packaging and microsystems using carbon and silicon-based materials and processes to achieve superior device and system performance. The research at EMSL addresses also 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 group of select (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 European grants within Horizon 2020 program, which reflects its international recognition. 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.

Within the achievement of the micro- and nanosystem research area, a micromachine technique that can be useful to fabricate D-band antenna in a low cost and time efficient way has been demonstrated during the year. Three different micromachine techniques namely SU-8 microfabrication, PDMS molding and injection molding of OSTEMER were utilized.

In collaboration with University of Stuttgart (Germany), and Swarthmore College (USA), we have measured and reported the first complete set of elastic and viscosity coefficient for micellar lyotropic liquid crystals. These materials have turned out to possess a unique softness to so-called “twist deformations”, and therefore have a tendency for spontaneous reflection symmetry breaking under various confinement. The work was published in Proceedings of the National Academy of Sciences of the USA, 2020.

In SSF and VR projects, the DFT groups demonstrated during the last year strong performance of our recent developments in van der Waals density functional method for predictions of dielectric, X-ray, and neutron measurements of complex materials.

There is a growing awareness in the semiconductor industry that there are information processing problems which cannot be easily solved using the standard CMOS based technology. These problems do not necessarily scale according to Moore’s law. The field of unconventional computation developed as a response to this challenge, and our research group here is one of the internationally recognized players in the field. We are eying both CMOS substrates but also unconventional ones such as disordered materials. Our contributions to the field of unconventional computation are exemplified by powerful algorithms that exploit reservoir computing for realizing in situ and low-power information processing applications. The work culminated in several breakthroughs pertinent to (i) realizing powerful ionic sensing setups for monitoring patterns in ionic concentrations that are extremely hard to measure, and (ii) in developing powerful machine learning algorithms based on memristor networks with very few parameters that in some application instances compete with deep learning architectures who require millions of parameters and are much harder to train.
At the Microwave Electronics Laboratory (MEL) we perform application relevant research on active high-speed electronic components, circuits, and subsystems. Our research is typically performed in close collaboration with industrial partners, institutes, and governmental agencies and contributes to improved energy and spectrum efficiency, higher data capacity, improved reliability and accuracy in new and emerging wireless communication and sensor applications. Our research spans from semiconductor materials to devices, circuits and microwave subsystems.

In our research on wide bandgap semiconductors, 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. The highlights of 2020 include the establishment of the III-N molecular beam epitaxy system, demonstration of high-performance transistors on ultra-thin GaN-layers, and in collaboration with external foundry (OMMIC) highly integrated MMICs for low phase noise millimetre-wave frequency generation. The research is mainly conducted within a Vinnova competence centre (C3NiT), which we lead together with Linköping University, and the H2020-project Grace within the Clean Sky-program. During 2020, we were also awarded a 5-year SSF grant within the Sweden-Taiwan Collaborative Research Framework program.

The urge for increased energy efficiency and bandwidth in mobile communication applications is driving our research on novel power amplifier circuit solutions co-designed with tailored signal processing algorithms antenna arrays. Highlights from 2020 include the development of a flexible all-digital radio-over-fibre testbed which has enabled us to be one of the first to experimentally demonstrate the benefits of distributed MIMO as a candidate for improved communication in 6G.

**Chipset in Silicon-Germanium BiCMOS-technology developed for wireless and plastic fibre communication in the D-band (110-170 GHz).**

A chipset for transmitting and receiving data with very high data rate, 40 Gbps, was developed in an European Union project Car2TERA (www.car2tera.eu). The chipset, which includes amplifiers, I-Q modulator/demodulator, and x4 frequency multiplier for the local oscillator, can be used for high data rate communication and radar sensing in the in the D-band, 110-170 GHz. The chipset was designed by researchers at MC2, fabricated in Infineon’s 130 nm B11HFC BiCMOS-process featuring a maximum frequency oscillation frequency of 380 GHz, and successfully verified in the Kollberg laboratory during 2020. In a communication measurement-setup we measured data rates up to 40 Gbps with QAM 16 modulation. Due to the excellent scalability of this technology it is feasible to integrate many parallel channels in one chip and build a MIMO communication system. This would allow wireless communication with several 100 Gbps in a near future. Our next goal is to package the chips for further tests for wireless communication and radar sensing.
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.

**Cleanroom usage 2020**

- 187 users that booked equipment
- 58930 booked hours
- 37 customers
  - 14 Swedish companies where 9 used own personnel in the cleanroom
  - 4 foreign companies where 1 used own personnel in the cleanroom
  - 6 Swedish universities or institutes where 3 used own personnel in the cleanroom
  - 2 foreign universities or institutes where 0 used own personnel in the cleanroom
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.

Laser frequency comb technologies are developed for applications in fibre optic communication systems and ultrafast metrology. A highlight is the record conversion efficiency (~50%) with an integrated frequency comb based on compact silicon nitride chips. This relies on an arrangement of two linearly coupled micro-resonators, capable of generating many locked optical frequency lines.

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. We recently demonstrated the most sensitive optical receiver and showed that the simple QPSK modulation format along with the above amplifier is the best choice for space links as far as to Mars.

Highlights from the research on vertical-cavity surface-emitting lasers (VCSELs) include the development and demonstration of low-noise single-mode VCSELs, with linewidths as small as 6 MHz and RIN below the shot noise level, and the development of an accurate physics-based equivalent circuit model for datacom VCSELs as a tool for VCSEL design and analysis and driver IC design.

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 thin-film flip-chip UVB LED enabled by electrochemical etching, the world’s first blue-emitting high-contrast gratng VCSEL and the world’s shortest emission wavelength VCSEL.
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. 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. The research extends over a variety of topics at the forefront of condensed matter physics using nanodevices consisting of emerging 2D materials and van der Waals heterostructures, topological Dirac and Weyl materials, semiconductors, oxide heterostructures, nanomagnets, and superconductors. We combine the best of different materials to develop new concepts in device physics and applications in quantum metrology, topological quantum technology, thermoelectrics, quantum theory, radio astronomy, medical instrumentation, and spintronics.

In 2020, research at QDP has resulted in close to 50 publications in internationally recognized journals, where several important scientific results were reported. Furthermore, the division was awarded 5 new research grants from the Swedish Research Council (VR). We demonstrated gate-tunable spin-galvanic effects in "graphene-topological insulator van der Waals heterostructures", at room temperature\(^1\) and we observed unconventional charge-spin conversion in the Weyl-semimetal WTe\(^2\). We note that one-atom thin platinum was produced and chemical sensors with sub part-per-billion (ppb) detection limits to toxic compounds were fabricated\(^3\) and that in collaboration with TDK Micronas GmbH, we showed that epitaxial graphene Hall sensors display record-low magnetic field detection limits\(^4\).

Across the year, a new laboratory on floor D1 was established, where Dr Attila Geresdi and his group will do their experimental research. Most of the equipment is now up and running.

Record electron self-cooling in Cold-Electron Bolometers from 300 mK to 65 mK was achieved due to a hybrid superconductor-ferromagnetic nanoabsorber suppressing Andreev reflection and normal metal traps\(^5\).

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\(^{1}\) D. Khokhriakov et al., “Gate-tunable spin-galvanic effect in graphene-topological insulator van der Waals heterostructures at room temperature”, Nature Comm. 11, 3657 (2020).


\(^{5}\) A.V. Gordeeva et al., “Record electron self-cooling in cold-electron bolometers with a hybrid superconductor-ferromagnetic nanoabsorber and traps”, Scientific Reports 10, 21961(2020).
The Quantum Technology Laboratory (QTL) started first of January 2018. QTL has grown rapidly during the last three years due to the Wallenberg Centre for Quantum Technology (WACQT) and now employs about 40 people. The division consists of three groups and a fourth one will start next year. The research of the Delsing/Bylander group focuses on superconducting circuits, quantum computing and quantum physics. The focus of the Wieczorek group is mechanical quantum systems. The Gasparinetti group does research in two main areas, quantum thermodynamics and continuous variable quantum computing. Raphael van Laer will start as an Assistant Professor in March 2021 and form the fourth group. His activity lies at the border between quantum technology and photonics. His main project will be to create a quantum coherent interface between microwaves and optical photons.

Among the scientific results produced in 2020 we would like to emphasis the following results:

**Primary photon thermometry**
Placing a superconducting qubit at the end of an open transmission line can serve as a very accurate primary thermometer for the microwave field. This is important to measure the photon temperature in quantum computers.

**Photons generated from the Dynamical Casimir effect are entangled**
We have been able to show experimentally that the photons generated in the Dynamical Casimir effect are indeed entangled as predicted by theory.

**High Kinetic Inductance NbN Superinductors**
High quality superinductors have been fabricated and characterized. These devices have a characteristic impedance greater than the quantum resistance, $R_q \approx 6.5\ k\Omega$.

**Suspended photonic crystal membranes for integrated multi-element optomechanics**
We have been able to fabricate mechanical resonators from semiconductor heterostructures patterned with a photonic crystal. The devices allow us to make integrated multi-element cavity and optomechanical devices on chip.

**Electromagnetically induced acoustic transparency with a superconducting circuit**
Electromagnetically induced transparency is a phenomenon where a medium or an atom can be made transparent for light. We have shown that an artificial atom can also be made transparent for sound.

**High quality three-dimensional microwave cavities**
We have developed a method to reproducible make superconducting 3D microwave cavities with $Q$-values above 80 million. These long-lived cavities can be used for continuous variable quantum computing.

Editor’s Choice.
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, with the hope of gaining 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: superconducting electronics; graphene electronics; low noise devices and circuits; 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 that spans from material science, via device physics to microwave, millimetre wave and terahertz systems. Highlights from 2020 includes the first direct observation of plasma waves in graphene transistors at terahertz frequencies (Nature Light: Science & Applications) - a work carried out together with several research groups in Dresden and Frankfurt. In the PhD thesis by Xinxin Yang, an antenna array of THz graphene detectors on a flexible substrate (IEEE Trans. Terahertz Sci. Technol.) was demonstrated. Eunjung Cha presented her doctoral thesis on InP transistors opening up new frontiers for low-noise microwave amplification at very low dc power – a research work carried out within the Chalmers GHz centre. From 2020, the laboratory is enrolled in teaching an undergraduate course in electronic circuits at the engineering physics.
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.

Recently, we launched a new KAW-funded inter-disciplinary project 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.

During 2020, we demonstrated a record transmission rate using a chip-scale frequency comb. The petabit per second barrier was overcome with a chip-scale frequency comb. These results were the result of a collaboration between FORCE and the SPOC centre at Technical University of Denmark, in which the chips were fabricated at FORCE and the experiments were conducted at SPOC.
GigaHertz Centre

Centre Director Jan Grahn
jan.grahn@chalmers.se

GigaHertz Centre (GHz Centre) is a research collaboration 2017-2021 in microwave engineering between Chalmers and industry, hosted by MC2. In total 70 researchers at Chalmers and 13 companies are involved in GHz Centre projects:

- Efficient and linear mm-wave transmitters
- Electro-thermal effects in microwave communication and sensing
- Receivers for linear RF systems
- THz and very low-noise components

During 2020, we had a new company partner from US, Virginia Diodes Inc, working on 5 THz Schottky diode receivers for space applications.

After 4 out of 5 years planned collaboration, we start to see results from Chalmers and industry:

- 5 Chalmers students doing their PhDs in GHz Centre projects are now hired by wireless industry
- 60% of the scientific publications in GHz Centre are co-authored between Chalmers and industry
- 6 stories of industrial impact from research in GHz Centre has been documented, e.g. in 5G linearization, low-noise amplification of microwave photons and THz instrumentation for a future mission to Jupiter

Together with the antenna systems centre ChaseOn, hosted by Department of Electrical Engineering at Chalmers, GHz Centre is running a joint consortium with shared key functions. GHz Centre has together with ChaseOn formed an international centre with 25 companies covering a large part of the value chain in wireless, from components to systems. This stands out as a unique example on how a bottom-top initiative can strengthen Swedish research.

On 18 November, a Centre day for GHz Centre and ChaseOn was held online with more than 100 participants.

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

Company partners 2020:
Ericsson, Gotmic, Infineon Technologies, Keysight Technologies, Low Noise Factory, 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 Ermin Malic
ermin.malic@chalmers.se

The Vinnova Competence Centre 2D-TECH has finished its ramp-up phase by hiring 13 postdocs and PhD students. In the next years, we will develop an internationally visible Swedish hub for excellent research and industrial utilization of 2D materials.

Chalmers together with 16 companies has got the funding to build the new Vinnova Competence Centre 2D-TECH that stands for “2D-material based technology for industrial applications”. In 2020 we have started the centre under difficult conditions due to the Corona restrictions making networking very challenging. Nevertheless, we managed to fill 13 positions including 11 postdocs and 2 PhD students. We concluded the ramp-up phase and will start phase 1 of the centre in 2021.

Based on the research excellence at Chalmers and the technological needs of industrial partners, the Centre focus on four research and innovation lines: multi-functional composites, sustainable energy, electronics, and emerging materials. Target applications include e.g. new generation of highly efficient heat spreaders for electronics, lightweight structural batteries, transparent antennas, as well as more efficient radars and sensors for automotive and aerospace industries.

Furthermore, in 2020 we managed to obtain additional funding for 2D-TECH from Västra Götalandsregionen (VGR) and the Gender Initiative for Excellence (GENIE). This allowed us to convince Janine Splettstösser (MC2) and Julia Wiktor (Physics) to become part of 2D-TECH. Furthermore, we acknowledge support from Areas of Advance Materials and Energy as well as the Excellence Initiative Nano giving us more financial flexibility to cover the co-funding required by Vinnova.

Besides establishing the Vinnova competence centre 2D-TECH, we have continued running networking activities within the broader Graphene Centre at Chalmers including the webinar series, the PhD course on advances and challenges of 2D materials and the PhD Award for 2D material research.

Participants at the 2D-TECH kick-off
WACQT
Wallenberg Centre for Quantum Technology

Centre Director Per Delsing
per.delsing@chalmers.se

The Wallenberg Centre for Quantum Technology (WACQT) is a twelve-year, 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 and industry, but also in society. To achieve this, the Centre has an excellence program spanning all areas of quantum technology: quantum computing and simulation (Chalmers), quantum communication (KTH), and quantum sensing (Lund). The core project of the Centre is to build a Swedish quantum computer with 100 superconducting quantum bits at Chalmers. Thanks to WACQT, Chalmers is also a part of OpenSuperQ, a project in the EU quantum technology flagship with research goals aligned with the core project.

Currently, around 100 researchers are involved in WACQT. In addition to the research agenda, the Centre has three instruments to help increase and spread knowledge in quantum technology:

• The WACQT graduate school for all PhD students in the Centre.
• A guest researcher program that invites international academic and corporate scientists to interact with WACQT researchers.
• 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 2020 include results from the industrial collaboration with Jeppesen. In joint publications, researchers from Chalmers and Jeppesen, showed theoretically how a quantum computer can solve an instance of a real logistics problem in the aviation industry and experimentally demonstrated this quantum algorithm on a quantum computer with two quantum bits.
2020 will be reminded as the year when Covid-19 turned our lives upside down. Locally, at the Department of Microtechnology and Nanoscience - MC2, the crisis was bravely dealt with. People started working from home, new working routines were developed, meetings and courses took place on-line, and as such the organisation managed to deal with the social distancing requirements and still to deliver fantastic results.

MC2 continued to show that it is an attractive collaboration partner. The Wallenberg Centre for Quantum Technology, WACQT, organised a series of industrial webinars, where industrial leaders presented how quantum technology potentially can be used to solve some of their challenges. The GHz centre welcomed Virginia Diodes as a new partner. The new VINNOVA competence centre 2D-TECH, with 16 industrial partners, had its kick-off in late February. The centre organised a series of webinars where high profile speakers presented their 2D-materials' activities. The department was also engaged in the VINNOVA competence centre for III-nitride technology, C3NiT, in collaboration with Linköping University and 10 industrial partners.

One of our spin-offs, Optigot, was acquired by Nvidia, the market leader in graphic processors. The increased interest in frequency combs resulted in the development of an intensive on-line course for industry. Some elite cross-country skiers, including a double Vasaloppet winner, started using a special handle that measures the effect in their ski poles when skiing. The technology originates from a bachelor project run at MEL that resulted in the company Skisens. Researchers at the Quantum Device Physics laboratory, together with TDK Micronas, showed that graphene enables Hall sensors with record-low magnetic field detection limits, showing the potential of graphene Hall sensors to outperform commercial Hall elements.

Industry was also present at MC2 in the form of adjunct professors and as collaboration partners in many bilateral and multilateral projects. Industry continued also to use the state-of-the-art infrastructure at the department.

All the above contributed to fantastic results in the form of joint publications, students, mobility of individuals, increased industrial competitiveness, societal value, and many other successes, all comprising win-win relationships, with transfer of technology, knowledge and knowhow, between MC2 and its industrial partners.

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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 generation, detection, and analysis of electromagnetic signals in a wide spectrum ranging from classical radio waves far into infrared light. This spectrum includes several interesting applications, e.g., space science, medical research, wireless communication and radar systems, autonomous vehicles, and security and defence applications.

The laboratory includes on the one hand side instrumentation for generation and analysis of very advanced modulated signals in the microwave and millimetre wave frequency range and on the other hand side technology for generation and detection of signals in the hard to reach THz gap, 300 GHz to 3 THz.

During 2020, the Kollberg laboratory has received a grant on 7.8 MSEK for “Accessibility to infrastructure” from Vetenskapsrådet. The grant, with Jan Stake as principal investigator, will support equipment for precision CNC milling of THz waveguides, THz probes, THz and power reliability testing, and THz free-space characterization in collaboration with Marianna Ivashina’s group at the E2 department. The new equipment will be made accessible to the lab users according to the laboratory’s open access user model.

Likewise, many other institutions, the Kollberg laboratory has during 2020 faced challenges due to the pandemic. With reduced support and careful instructions to make measurements time effective to reduce time in lab, maintain social distancing and basic hygiene, we have managed to stay open during the full year for Chalmers users and established external users, but with limited possibility to receive new external users. At the end of the year, we could conclude a slight decrease in booked hours for Chalmers users but maintained volume of external industrial users.

Laboratory Director Dan Kuylenstierna
dan.kuylenstierna@chalmers.se
Undergraduate Education

Vice Head of Department responsible 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 and Electrical 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, on both bachelor and master level, and the contributions of MC2 faculty to courses in educational programmes at other departments steadily increase.

A new situation. In March 2020, as a consequence of the Corona pandemic, Chalmers was forced to practically “overnight” transfer all teaching to on-line format. Many of us heard about something called “Zoom” for the first time only a few days before Zoom teaching sessions, with teachers and students appearing in small boxes on a computer screen, became the new normal. For MC2, which deliver several courses with major hands-on, experimental activities, also in cleanroom processing, this was certainly a challenge. But our teachers made a fantastic effort. In fact, we have managed to deliver all our courses during the year, with appropriate, necessary modifications.

Lectures and exercises have been transformed into video-format, lab-exercises have been adapted to the covid19 related rules and recommendations, which have changed several times during the year. Some of our courses have also been opened for external participants, to meet needs of retraining of engineers in industry, in the wake of the impact of the pandemic.

We are grateful to the MC2 faculty for all their teaching contributions during the year, and also for sharing good examples of distance teaching and examination, among each other. Some of the changes in teaching format, now forced by the pandemic, will likely have significant implications also after the pandemic. Both teachers and students, all over the world, are now more used to digital solutions, on-line teaching activities, and multimedia tools and software. It will open new possibilities but also spark demands for development of traditional teaching - after corona will not be like before corona.

New courses. We are happy that the department of MC2 now deliver core courses in physics, mechanics, optics, mathematics, and electrical engineering in several bachelor programmes. This year MC2 for the first time delivered the Bachelor level courses in Electrical Circuits and Systems for the Engineering Physics programme (Jan Grahn) and in Mechanics for the Chemical Engineering with Physics programme (Mikael Fogelström). The fact that these courses, in addition to the transfer to MC2, had to be adapted to distance learning and new examination formats was of course a challenge, both for the new teachers and the students.

The new international master course on Quantum Computing (MCC155) was delivered fully online with 53 students, of which 25 from Aachen University in Germany, 2 from Delft University in the Netherlands, and 26 from Chalmers (Giulia Ferrini, Anton Frisk Kockum). This course was made accessible to the students also from other universities, and it illustrates how distance learning can increase collaboration between universities and add value to their own teaching programmes.

International collaboration on master level teaching. For the master programme in nanotechnology (MPNAT) we have seen a strong increase in number of students in the programme. 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.

Sieglinde Bogaert, a student of the Erasmus Mundus Nano program in collaboration with KU Leuven, did her master thesis at AQP with Anton Frisk Kockum as main supervisor in 2020. The thesis entitled "Quantum capsule neural networks" was awarded a prize by Imec for being the best master thesis at KU Leuven in the area of micro- and nano-electronics.

Pedagogical development. At the conference NU2020 – Sweden’s largest national conference on higher education held online in October, Per Lundgren presented his work on evaluating the use of multiple choice test items for assessing engineering skills under the headline "Assessing using multiple choice questions – right or wrong?".

Zoran Konkoli has written a compendium suitable for undergraduate courses in mathematical analysis, tailored specifically for second year IT/DATA students at Chalmers. It features a special mode of presentation, a dialogue between the teacher and a student, reminiscent of the old philosophical dialogues, where complicated mathematical constructs are illustrated as small code snippets.

Missions of trust. MC2 faculty members act as heads of several educational programmes; Electrical Engineering TKELT (Hans Hjelmgren), MPNAT (August Yurgens) and Computer Engineering 180p (Zoran Konkoli). Thilo Bauch is Chalmers coordinator for EMM-nano.

Dag Winkler and Åsa Haglund 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 “LP på distans” and “Digital höst” formed to provide support for the transfer of teaching and examination into digital format.

Per Rudquist is convener of the group of deputy heads of departments for undergraduate education at Chalmers.

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

Deputy Head of Department responsible for Graduate Education Magnus Karlsson
magnus.karlsson@chalmers.se

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, leading to the Doctor of Philosophy (PhD) degree. 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.

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 defence. A thesis is given green light to go up for defence only if TRC finds the scientific quality sufficient. If not, the student will be given more time to complete the work. During 2020, TRC consisted of the following three professors: Thomas Löfwander, Christian Fager and Sergei 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 6 Licentiate degrees during 2020. The theses are available electronically on the MC2 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.
Doctoral Theses

Gustav Andersson, Quantum acoustics with superconducting circuits
Vasileios Athanasiou, Theoretical simulations of dynamical systems for advanced reservoir computing applications
Andreas Bengtsson, Quantum information processing with tunable and low-loss superconducting circuits
Michael Bergmann, Thin-film ultraviolet light-emitting diodes realized by electrochemical etching of AlGaN
Eunjung Cha, InP High Electron Mobility Transistors for Cryogenic Low-Noise and Low-Power Amplifiers
Maria Ekström, Quantum acoustics with propagating phonons
FatemeHajiloo, Heat control in mesoscopic conductors - exploiting quantum effects and size confinement
Josef Hansson, Exploration of Metal Composites and Carbon Nanotubes for Thermal Interfaces
Ahmed Adel Hassona, Enabling Solutions for Integration and Interconnectivity in Millimeter-wave and Terahertz Systems
Hans He, Molecular Doping of Epigraphene for Device Applications
Ravikiran Kakarla, Ultralow noise pre-amplified receiver for free-space optical communications
Qi Li, Electrochemical capacitors for miniaturized self-powered systems: challenges and solutions
David Niepce, Superinductance and fluctuating two-level systems: Loss and noise in disordered and non-disordered superconducting quantum devices
Silvia Ruffieux, High-temperature superconducting magnetometers for on-scalp MEG
Ibrahim Can Sezgin, Evaluation of Sigma-Delta-over-Fiber for High-Speed Wireless Applications
Eva Simpanen, Longer Wavelength GaAs-Based VCSELs for Extended-Reach Optical Interconnects
Edoardo Trabaldo, Noise and electrical properties of YBCO nanostructures
Xinxin Yang, Characterisation and modelling of graphene FET detectors for flexible terahertz electronics

Licentiate Theses

Johan Bremer, Characterization and Compensation of Thermal Effects in GaN HEMT Technologies
Juan Cabello Sánchez, On-chip terahertz characterisation of liquids
Öskar Bjarki Helgason, Dissipative Kerr solitons in normal dispersion waveguides
Kevin Marc Seja, Transport in mesoscopic superconducting devices
Parastoo Taghkhani, Active Transmitter Antenna Array Modeling for MIMO Applications
Abdelhafid Zehri, Manufacturing and characterization of nanomaterials for low-temperature sintering and electronics thermal management applications
The main purpose and task of the PhD student council is to help PhD students with questions and problems they may have. The council consists of students from all laboratories at MC2, and has representatives in the MC2 Executive group, the MC2 Advisory council, the Doctoral Student Guild (DS), and the Graduate Student Association for Physics (FFF). This is to be aware of developments at MC2 and at Chalmers, and to be easily reachable by any PhD student in MC2.

Due to the pandemic, much of our work this year have been focused on the well-being of PhD students. We have looked at both professional and personal levels, ranging from quality of graduate education, through student-supervisor dynamics, to psychological health. There has also been much work monitoring and weathering the effects of the pandemic when it comes to graduate courses, teaching and research. This has taken the form of surveys sent out to the PhD students to find what problems were most pervasive and how to address them. This has also been brought up in the Executive group at MC2 and at other departments.

The budget deficit caused by pension fund interest rates has forced Chalmers to work on an “Finances in Balance” project. This affects the resources that students have access to and also the potential contract extensions due to departmental work, such as teaching, administration and maintenance. To make manifest the interest of graduate students, the council has taken, and still takes, part in the discussions that will decide what these changes are.

Regarding education, the council has been in contact with teaching staff at other departments and organized meetings to showcase the courses that could be taught by MC2 PhD students.

We are also working on a digital form of the Study Plan, which is a document containing the planned research and the progress over the duration of a PhD program. This is will be templated, standardized to a reasonable extent and integrated with course databases (such as Ladok) to make the document easier, more effective and convenient.

There is also a PhD student booklet in the making, containing all the information both necessary and useful for new PhD students. The goal is to be able to give out a document to newly hired PhD students that contains all that is needed to navigate both the Swedish society (housing market, banking, IDs, healthcare, public transportation…) and their academic life (how to enrol and plan your courses and teaching, how to prepare a thesis defence…).

The PhD Student Council at MC2 meets at a monthly basis and we invite anyone interested to join one of our meetings. You can also find more information about who we are and what we do on our website: https://www.dokt.chs.chalmers.se/mc2-phd-council/
Creating compact lasers at record-short wavelengths

Researchers at Chalmers University of Technology, with collaborators at Technische Universität Berlin, have demonstrated the shortest wavelength ever reported of a vertical-cavity surface-emitting laser (VCSEL). This can pave the way for future use in, for example, disinfection and medical treatment. The results were published in the scientific journal ACS Photonics.

A vertical-cavity surface-emitting lasers (VCSEL) is a compact semiconductor laser and has seen widespread application in, for example, facial recognition in smartphones and for optical communication in data centers. So far, these lasers are only available commercially with red and infrared wavelengths, but also other visible-emitting VCSELs, that could find applications in adaptive headlamps for cars or projection displays, will soon be commercialized.

The new demonstration is the shortest wavelength VCSEL ever reported and the electrochemical etch technique is also extendable to UVC wavelengths which are needed for sterilization applications to, for example, combat future pandemics and provide clean drinking water.

A 310 nm Optically Pumped AlGaN Vertical-Cavity Surface-Emitting Laser
Filip Hjort, Johannes Enslin, Munise Cobet, Michael A. Bergmann, Johan Gustavsson, Tim Kolbe, Arne Knauer, Felix Nippert, Ines Häusler, Markus R. Wagner, Tim Wernicke, Michael Kneissl, and Åsa Haglund
ACS Photonics 2021, 8, 1, 135–141
Online thesis defences

During 2020 the coronavirus pandemic changed many aspects of university life. Luckily, Ph.D. students are good at quickly adapt when circumstances change. With social-distancing restrictions, students and supervisors needed to rethink how to conduct research and manage the very last step of obtaining a doctoral degree - the thesis defence. Many defences were arranged online with the advantage that friends and colleagues from other countries was able to participate.

New book combines quantum physics and biology

Seven years of work is over. On 16 March, the book that unites quantum physics and biology is released. Among the authors are the MC2 professors Göran Johansson and Göran Wendin. “Not many physicians and biologists have worn quantum physical glasses before,” says Göran Johansson.

“Kvantfysiken och livet” (“Quantum physics and life”) with the imaginative subtitle “Våra innersta mekanismer och världarna omkring oss” (“Our innermost mechanisms and the worlds around us”) (Volante Förlag) is an interdisciplinary book that shows how the meeting between quantum physics and medical research can form the basis for the next scientific revolution.

“Life is always interesting and it is fascinating to think about how quantum physics comes in”, says Göran Johansson, professor of applied quantum physics, and head of the Applied Quantum Physics Laboratory at MC2.

Time to take the days as they come

It doesn’t mean a thing if it ain’t got that swing. It could be a fitting description of Ulf Södervall’s attitude to life. When he leaves Chalmers after 45 years, he gets more time to swing the golf clubs and live life. “I feel ready,” he says.

We meet Ulf in his office for a relaxed conversation about his career at Chalmers. After doing the military service in Dalarna and Linköping, the young Örebro son started to study technical physics at Chalmers in September 1975. Since then he has remained loyal to the university.

“It’s really a little crazy that it’s been so long. But now I feel ready, even though there are different aspects to it. I am prepared to live a little freer now, but will miss the environment and all the colleagues,” he says.
Honourable extension as Wallenberg Academy Fellow

Janine Splettstößer, professor of theoretical physics at the Applied Quantum Physics Laboratory, has got a five-year extension of her ongoing Wallenberg Academy Fellow appointment. As a fellow, she plans to work on a project which deals with the thermodynamics of nanoscale systems. “In particular, I am interested in non-equilibrium and quantum effects and how they can be exploited for possible future applications. For example, one might wonder whether certain non-equilibrium conditions make thermoelectric effects at the nanoscale more efficient.”

Janine and her group will work on a wide span of approaches: from developing theoretical methods, to proposing realistic devices and work in collaboration with experimentalists.

Contributes to new medical technology research lab

When a new medical technology research lab is built up at Sahlgrenska University Hospital, Dag Winkler, professor of physics and head of the Quantum Device Physics Laboratory (QDP) at MC2, will be one of the users.

“The idea is that the new 21-channel system we are now building will be used at the new lab and coexist with the microwave measurements and treatments”, explains Dag Winkler, who for many years also was head of department at MC2.

Winkler’s and his research colleagues’ acclaimed project NeuroSQUID, is now preparing for its next phase. The project is funded by the Knut and Alice Wallenberg Foundation and is a collaboration between researchers at Chalmers, The Sahlgrenska Academy and Karolinska Institutet. The project has been going on since 2014 and is led by Dag Winkler. Researchers at NeuroSQUID have developed a unique MEG instrument (magnetoencephalography) with seven channels for measuring and mapping the brain.

The new research lab is a major investment in clinical research, in collaboration between Sahlgrenska University Hospital, Chalmers, The Sahlgrenska Academy and Region Västra Götaland. New methods for diagnosis and treatment - and in the long run better care - will be results of the new lab, which is expected to be inaugurated in May 2021.
Graphene spin circuits – towards all-spin computing

Researchers at Chalmers University of Technology have demonstrated spin circuit architectures with large area graphene channels efficiently carrying and communicating the electronic spin information between nanomagnets arranged in different complex geometries consisting of multiple devices. The findings were published in the scientific journal Carbon.

Solid-state electronics based on utilizing the electron spin degree of freedom for storing and processing information can pave the way for next-generation spin-based computing. However, the realization of spin communication between multiple devices in complex spin circuit geometries, essential for practical applications, still remained challenging.

"Our experimental demonstration of spin communication in large area CVD graphene spin circuit architectures is a milestone towards large-scale integration and development of spin-logic and memory technologies", says Saroj Dash, associate professor and group leader, who supervised the research project.

Dmitrii Khokhriakov, PhD student at the Quantum Device Physics Laboratory, carved complicated graphene Y-junction and Hexa-arm spin circuit architectures utilizing nanofabrication techniques compatible with industrial manufacturing processes.

Two-dimensional spintronic circuit architectures on large scale graphene
Dmitrii Khokhriakov, Bogdan Karpiak, Anamul Md.Hoque and Saroj P.Dash
Carbon, volume 161, 2020, 892–899
New head of the Microwave Electronics Laboratory

Professor Christian Fager is new head of the Microwave Electronics Laboratory (MEL) at MC2 from 1 April. Fager is succeeding Professor Herbert Zirath, who has been head ever since the beginning in 2001. Now, he’s looking forward to continuing and further develop Zirath’s work.

“Like Herbert, I am very passionate about our collaborations with industry. I find it a great satisfaction to see how our research benefits, both through the people we educate, but also in the added value created when we work to find new and better solutions to relevant challenges”, says Christian.

Researchers facing the big challenges

Research into everything from galaxies to human health, developing the shipping industry, electric vehicles, material properties and sustainable cities. They may focus on widely different subjects, but their research contributes to sustainable development and generates academic success. In connection to 8 March, International Women’s Day, we acknowledged some researchers who are highly cited within their own fields of research.

Elsebeth Schröder from MC2 is one of them. She works on theoretical methods in physics on an atomic scale. In her research, she strives to describe how the nature of the electrons determines the material properties, to predict material structure and behaviour from computations. Materials is here to be understood in quite general terms, covering a range of systems, from oxide surfaces, over carbon-based filters, to DNA fragments.

What benefit does your research give to society?
“The method development that I contribute to is of great value to other researchers around the world. I and other researchers use the methods for problems that are important for materials production or have health-related aspects. For example, I have looked at the mechanisms of water purification of perfluorinated molecules and how the structure of DNA is affected by, for example, intercalation of carcinogenic molecules between base pairs in DNA”.

What are the biggest challenges?
“The greatest challenges lie in further developing the theoretical methods, so that we can become even better at understanding and predicting properties in materials. This involves both refining the methods and enabling application to even more complicated material systems”.
Quantifying nonequilibrium thermodynamic operations in a multiterminal mesoscopic system

We investigate a multiterminal mesoscopic conductor in the quantum Hall regime, subject to temperature and voltage biases. The device can be considered as a nonequilibrium resource acting on a working substance. We previously showed that cooling and power production can occur in the absence of energy and particle currents from a nonequilibrium resource (calling this an N-demon). Here we allow energy or particle currents from the nonequilibrium resource and find that the device seemingly operates at a better efficiency than a Carnot engine. To overcome this problem, we define free-energy efficiencies which incorporate the fact that a nonequilibrium resource is consumed in addition to heat or power. These efficiencies are well behaved for equilibrium and nonequilibrium resources and have an upper bound imposed by the laws of thermodynamics. We optimize power production and cooling in experimentally relevant parameter regimes.

Quantifying nonequilibrium thermodynamic operations in a multiterminal mesoscopic system
Fatemeh Hajiloo, Rafael Sánchez, Robert S. Whitney, and Janine Splettstoesser
Physical Review B 102, 155405 (2020)

Millions to the ICT of the future

Anders Larsson and Jan Stake at MC2 are two of the Chalmers researchers who receive funding from the Swedish Foundation for Strategic Research (SSF).

SSF distributes close to SEK 200 million to six different projects in a research effort for faster and energy-efficient Information and Communication Technology (ICT). The six projects are financed with between SEK 28 and 35 million each for five years, starting 2021. “Together, they have the potential to strengthen Sweden’s position in important areas for our industry and competitiveness,” says Jonas Bjarne, research secretary at SSF, in a press release.

Anders Larsson, professor at the Photonics Laboratory, is granted SEK 32 253 449 for the project “Optical interconnects for harsh computing environments”, which is about enabling more powerful computers and computing systems. Jan Stake, professor of Terahertz Technology, is co-applicant in a project led by Joachim Oberhammer at KTH Royal Institute of Technology.
Making the internet more energy efficient

Researchers at Chalmers completed a 5-year research project looking at how to make fibre optic communications systems more energy efficient. Among their proposals are smart, error-correcting data chip circuits, which they refined to be 10 times less energy consumptive. The project has yielded multiple scientific articles, in publications including Nature Communications.

Streaming films and music, scrolling through social media, and using cloud-based storage services are everyday activities. But to accommodate this digital lifestyle, a huge amount of data needs to be transmitted through fibre optic cables – and that amount is increasing at an almost unimaginable rate, consuming an enormous amount of electricity. This is completely unsustainable – at the current rate of increase, if no energy efficiency gains were made, within ten years the internet alone would consume more electricity than is currently generated worldwide. The electricity production cannot be increased at the same rate without massively increasing the usage of fossil fuels for electricity generation, which of course would lead to a significant increase in carbon dioxide emissions.

“The challenge lies in meeting that inevitable demand for capacity and performance, while keeping costs at a reasonable level and minimising the environmental impacts,” says Peter Andrekson, Photonics Laboratory and the leader of the 5-year research project ‘Energy-efficient optical fibre communication’, which has contributed significant advances to the field.

In the early phase of the project, the Chalmers researchers identified the biggest energy drains in today’s fibre optic systems. With this knowledge, they then designed and built a concept for a system for data transmission which consumes as little energy as possible. Optimising the components of the system against each other results in significant energy savings.

The recipe for these successes has been the broad approach of the project, with scientists from three different research areas collaborating to find the most energy-saving overall solution possible, without sacrificing system performance.
Ten million to develop communication systems of the future

Niklas Rorsman, research professor at the Microwave Electronics Laboratory at MC2, receives 10 MSEK in research grant from the Swedish Foundation for Strategic Research (SSF) for the project Advanced GaN Devices for mm and sub-mm-wave communication.

“We will try to optimize GaN transistors to operate at very high frequencies with the goal of being able to deliver enough output for the communication systems of the future. In the project, we will develop new materials and explore new component concepts to achieve this goal. We will be very dependent on the clean room and our measuring laboratory to be able to try and evaluate new ideas”, explains Niklas.

For Niklas Rorsman’s part, a golden opportunity now arises to extend his existing exchange with Taiwan, by means of personnel, materials, and knowledge. “Taiwan is an interesting country to work with. They are one of the world’s largest exporters of semiconductor technology”, says Niklas.

Ski star sharpens her skiing with technology from Chalmers

Power meters integrated in a ski-pole handle from Chalmers will contribute to skier Lina Korsgren’s third victory in Vasaloppet. The new handle has sensors that measure the power while poling and can be mounted on any pole.

The background to the handle is a master’s thesis, which was supervised in 2016 by Dan Kuylenstierna, associate professor at the Microwave Electronics Laboratory, and postdoctoral student Szhuo Lai at the same laboratory. After the end of the thesis work, the students (Henrik Gingsjö, Jeanette Malm, Theo Berglin, Mathias Tengström and Marcus Bengths) continued to develop the handle with support from Vinnova. In 2017, they took the victory in the business development competition Chalmers Ventures Startup Camp. This helped them to establish the company Skisens AB, with Dan Kuylenstierna as co-founder and co-owner.

Now the company has arrived at a product that opens to a wider market with more partners. Recently, they have thus started to collaborate with Lina Korsgren’s team, Team Ramudden, where Mattias Reck is hired as head coach via the company Guided Heroes.
Driven by curiosity after 50 years

Kjell Jeppson rather looks forward than back in time. It is now 50 years since he stepped in through the gates as a doctoral student at Chalmers. As a pensioner, he keeps up with orienteering and supervision. "I'm still driven by curiosity," he says.

Born in 1947, grew up in Guldheden with parents and younger sister, then a student at Landalaskolan, then high school followed by a Master of Science degree in electrical engineering at Chalmers from 1966. An obvious choice.

Chalmers was an important part of Kjell’s everyday life, in fact throughout his entire childhood. In high school he attended a class where 26 students out of 29 started at Chalmers eventually.

In May, 50 years ago, he began his doctoral studies at the then Department of Electron Physics, more or less hand-picked by the legendary professor Torkel Wallmark. During his doctoral studies, he spent a year at Rockwell International in Los Angeles. The dissertation took place in 1977 with the thesis “Design and characterization of MIS devices”.

As a curiosity, it can be mentioned that the thesis’s main article is still cited by other researchers 30-40 times a year.

Kjell Jeppson remained at Chalmers, now as an assistant professor, and later a senior lecturer and associate professor before being promoted to professor of microelectronics in 1996.

The great leisure interest since 30 years is orienteering. Kjell and his wife travel around the world and let the locations of the races control where they end up. Some recent examples are New Zealand, Switzerland, Estonia, Latvia, Lithuania, Belarus, Hungary and Croatia. In February every year there are training camps in Portugal.

Bright prospects for revolutionary optics research

The light sources of the future can be created with the help of lasers and artificial surfaces - meta surfaces - thinner than a wavelength of light. Optics research is facing a revolutionary development.

The research project “Metasurface-Emitting Lasers: Tomorrows Light Sources for Applied Photonics” has been granted SEK 38,100,000 over five years by the Knut and Alice Wallenberg Foundation.

Professor Mikael Käll is the Principal Investigator of the project and the work will be carried out in collaboration with Professor Åsa Haglund and Professor Anders Larsson both from Photonics Laboratory, Senior Research Engineer Ruggero Verre from the Nanofabrication Laboratory and Associate Professor Philippe Tassin, Department of Physics.

6 MC2 researchers receive funding from the Swedish Research Council

43 Chalmers researchers, of which 6 from our department, have learned about new grants after the Swedish Research Council published the successful applications. The Swedish Research Council will distribute a total of SEK 1.1 billion in natural and engineering sciences. The grants are for the period up to 2024.

The Council’s funding mostly goes to research in biology, physics, and chemistry, which receives nearly half of the research grants. 149 million of this year’s project grants will go to researchers at Chalmers.

Spin Hall effect in Weyl semimetal for Energy-efficient Information Technology

The discovery of topological Weyl semimetals in 2017 has revealed opportunities to realize several extraordinary physical phenomena in condensed matter physics. Now, researchers at Quantum Device Physics Laboratory, MC2, have demonstrated the direct electrical detection of a large spin Hall effect in this topological quantum material. Weyl semimetal takes advantage of its strong spin-orbit coupling and novel topological spin-polarized electronic states in its band structure. These experimental findings can pave the way for the utilization of spin-orbit induced phenomena in developing next-generation of faster and energy-efficient information technology and were published in the scientific journal Physical Review Research.

As our society is becoming more integrated with artificial intelligence (AI) and Internet-of-Things (IoT), the demand for low-power, nanoscale, and high-performance electronic devices have been increasing. Spintronic devices are promising for the next generation of information technology in order to lower the power consumption while increasing the performance and non-volatile properties. Recently, the current induced magnetization switching by spin-orbit torque (SOT) using the basic spin Hall effect is identified as a vital ingredient for non-volatile spintronic memory and logic devices. The SOT mechanism is specifically useful, as a spin current can be generated by just passing a charge current in heavy metals due to the spin Hall effect, without the use of an external magnetic field. However, there are several challenges related to the limited switching speed and high-power consumption in these devices.

A group led by Saroj Dash, Associate Professor, used electronic devices made from novel topological quantum material, called Weyl semimetals, which is like a three-dimensional version of graphene but have a strong spin-orbit interaction and novel spin-polarized surface and bulk electronic states in their band structure. The researchers at Chalmers take advantage of such novel properties to electrically detect a large charge-to-spin conversion, i.e. the spin Hall effect, in such a Weyl semimetal candidate WTe$_2$ at room temperature.

*Observation of charge to spin conversion in Weyl semimetal WTe$_2$ at room temperature*  
Bing Zhao et al.  
*Physical Review Letters* 123, 216801
Giant atoms merge quantum processing and communication

Researchers at Chalmers University of Technology in Sweden and MIT in the US, among others, have demonstrated a new quantum-computing architecture that makes it possible to both perform quantum computations and communicate quantum information between distant parts of the quantum processor, all with low losses. The results were published in the renowned scientific journal Nature.

"We showed that quantum bits can communicate through a waveguide without the quantum information being lost", says Anton Frisk Kockum, researcher at the Applied Quantum Physics Laboratory and one of the authors of the article.

A challenge for scaling up quantum computers is to enable communication between quantum bits (qubits) that are far apart. Coupling qubits to a long waveguide is usually detrimental, since it provides a channel through which quantum information can leak out. The solution the researchers found was to use “giant atoms”, a new regime of light-matter interactions.

This is the first time that anyone has even reported a number for the fidelity of a two-qubit operation with qubits strongly coupled to a waveguide, since the fidelity for such an operation would be low if the qubits were not giant. The ability to perform high-fidelity quantum-computing operations on qubits coupled to a waveguide creates exciting new opportunities.

“It is now possible to prepare a complex quantum state in the qubits, and then quickly adjust the interference effect in the giant atoms to turn on the coupling to the waveguide and emit this quantum state as photons that can travel a long distance”, says Anton Frisk Kockum.

Waveguide quantum electrodynamics with superconducting artificial giant atoms
B Kannan et al.
Nature 583, 775-779 (2020)
Mentoring program to stop the leaky pipeline of academia

28 mentees and 28 mentors have just started their journey together in a brand-new mentoring program at Chalmers University of Technology. The purpose is to support female researchers in their personal and professional development, and to create good connections between junior and senior academic women.

The mentoring program is an initiative by the two networks WiSE (Women in Science, based at the Department of Electrical Engineering), and WWACQT (Women in WACQT, within the Wallenberg Centre for Quantum Technology). The program is supported by the Gender Initiative for Excellence at Chalmers, Genie.

Academia is a leaky pipeline in the sense that many female researchers drop off to seek other career opportunities, before reaching senior positions. This is especially true in the technical fields, and that is also one of the reasons why the networks WiSE and WWACQT were founded, in 2011 and 2019 respectively.

“Our aim is primarily to promote personal and professional development for female PhD students and postdocs. The mentoring program will provide a framework for discussing challenges and problems in everyday research life, and thus foster an environment to make wiser career choices. Networking is a key component”, says Giulia Ferrini, representing WWACQT in the organizing committee of the mentoring program.

Areas of Advance Award for wireless centre collaboration

Collaboration is the key to success. Jan Grahn and Erik Ström, who have merged two Chalmers competence centres, GigaHertz and ChaseOn, to form a consortium with 26 parties, know this for sure. Now they receive the Areas of Advance Award 2020 for their efforts.

With the Areas of Advance Award, Chalmers looks to reward employees who have made outstanding contributions in cross-border collaborations, and who, in the spirit of the Areas of Advance, integrate research, education and utilisation. The collaborations aim to strengthen Chalmers’ ability to meet the major global challenges for a sustainable development.
Spin-galvanic effect in graphene with topological topping demonstrated

Researchers at Chalmers University of Technology, Sweden, have demonstrated the spin-galvanic effect, which allows for the conversion of non-equilibrium spin density into a charge current. Here, by combining graphene with a topological insulator, the authors realize a gate-tunable spin-galvanic effect at room temperature. The findings were published in the scientific journal Nature Communications.

Since graphene is atomically thin, its properties can be drastically changed when other functional materials are brought in contact with it, which is known as the proximity effect. Therefore, graphene-based heterostructures are an exciting device concept since they exhibit strong gate-tunability of proximity effects arising from its hybridization with other functional materials. Previously, combining graphene with topological insulators in van der Waals heterostructures, the researchers have shown that a strong proximity-induced spin-orbit coupling could be induced, which is expected to produce a Rashba spin-splitting in the graphene bands. As a consequence, the proximitized graphene is expected to host the spin-galvanic effect, with the anticipated gate-tunability of its magnitude and sign. However, this phenomenon has not been observed in these heterostructures previously.

Gate-tunable spin-galvanic effect in graphene-topological insulator van der Waals heterostructures at room temperature
Dmitrii Khokhriakov, Anamul Md. Hoque, Bogdan Karpiak & Saroj P. Dash
Nat Commun 11, 3657 (2020)

She made her way to space

As a child, she never dreamed of working on space exploration, but the goal was always to study at Chalmers. Following her studies in Engineering Physics, her Erasmus Mundus master i Nanotechnology and her PhD at EMSL, MC2, Sofia Rahiminejad was awarded the Wenner-Green fellowship to do her postdoc at NASA’s Jet Propulsion Laboratory in California, USA. She is currently employed in the Advanced Optical and Electromechanical Microsystems Group at Jet Propulsion Laboratory, working on MEMS phase shifters, switches, tunable mirrors and seismic sensors for space applications.

“We want to find water and life on other planets. Often, water is seen as a possible indication of life, but also a sign that we may be able to visit other planets and settle there in the future. One method used to look for these things is to send out spacecrafts that look at other planets, moons, and asteroids with radar. When you do this today, the entire vehicle has to move in order to map a surface. It runs slowly and requires a lot of energy. My work is to try to streamline the process of phase shifters controlled by micromotors, which in turn can be used to design electrically controllable antennas that do not need to move when mapping a surface.”
The most sensitive optical receivers yet for space

Communications in space demand the most sensitive receivers possible for maximum reach, while also requiring high bit-rate operations. A novel concept for laser-beam based communications, using an almost noiseless optical preamplifier in the receiver, was demonstrated by researchers at Chalmers University of Technology, Sweden.

In a new paper published in the scientific journal Nature: Light Science & Applications, a team of researchers describes a free-space optical transmission system relying on an optical amplifier that, in principle, does not add any excess noise – in contrast to all other pre-existing optical amplifiers, referred to as phase-sensitive amplifiers (PSAs).

The researchers' new concept demonstrates an unprecedented receiver sensitivity of just one photon-per-information bit at a data rate of 10 gigabits per second.

“Our results show the viability of this new approach for extending the reach and data rate in long-distance space communication links. It therefore also has the promise to help break through the present-day data-return bottleneck in deep-space missions, that space agencies around the world are suffering from today,” says Professor Peter Andrekson, head of the research group and author of the article together with PhD Ravikiran Kakarla and senior researcher Jochen Schröder at the Photonics Laboratory.

*One photon-per-bit receiver using near-noiseless phase-sensitive amplification.*

Kakarla, R., Schröder, J. & Andrekson, P.A.  
Meet some of our researchers

Fibre optic systems are what keep the internet going. We can't use our mobile phones and all their services if we don't have a backbone network which is supported by fibre optic systems. Professor Peter Andrekson has lived with fibre optics for 35 years, but he also values many other things in life. “In recent years I’ve learnt that you need to be able to do two things: delegate to people you can rely on, and be able to say ‘no’ to things you don’t think are that important,” he says.

Physicist, researcher and TedX speaker. It is important to Göran Johansson to talk to others about his research. He is also one of the driving forces behind the construction of Sweden’s first quantum computer. “The dream is to be able to solve a real problem with a quantum computer,” he says.

Professor Per Delsing is heading up the billion SEK project the Wallenberg Centre for Quantum Technology (WACQT), the aim of which is to build a functioning quantum computer within twelve years. “I have worked on fundamental research for a great many years, but it’s actually only now with WACQT that applications are starting to come from it, and that industry is interested”, he says.

Meet some of our researchers in the articles written by Michael Nystås.

Intelligent sensing substrate reveals intimate secrets hidden in ion dynamics of bodily fluids

Researchers at Chalmers University of Technology, with collaborators from the Hebrew University of Jerusalem (HUJI), have demonstrated a possibility to measure complex changes in ionic concentrations relevant for a series of neurophysiological disorders, such as multiple sclerosis (MS). The study appeared as a featured article in IEEE Sensors Journal.

The key idea is to operate an environment sensitive dynamical system in the reservoir computing mode and augment it with an auxiliary input channel. The concept of the auxiliary input channel is central to the approach used. Researchers refer to it as “the drive”. The drive signal aids the sensing substrate in communicating the accumulated information more clearly, e.g. in the same way a prompter helps an actor in the theatre.

On Sensing Principles Using Temporally Extended Bar Codes
V. Athanasiou, K. K. Tadi, M. Hurevich, S. Yitzchaik, A. Jesorka and Z. Konkoli,
Experimental platform for shaping the interaction between micromechanical motion and light

Researchers from Chalmers University of Technology have developed a novel experimental platform for the field of cavity optomechanics. The findings are a crucial step towards increasing light-matter interactions further in order to access new possibilities in the field of quantum technology. The work also shows the ability to fabricate two mechanical resonators on top of each other with a gap smaller than one micrometre.

How can light interact with matter? A rather evident way is via the radiation pressure force. However, this force is tiny. Or, have you already been pushed back by a laser pointer hitting you? But when we consider much smaller systems in the micro- and nano world, this force becomes appreciable and can actually be used to manipulate tiny objects. The radiation pressure force can even be enhanced in so-called cavity optomechanical devices. These devices exploit the interaction between light and micro- or nanomechanical resonators to alter the dynamical properties of either of the two systems.

Sushanth Kini Manjeshwar, PhD student at MC2 and the lead author of the article, fabricated high-reflectivity mechanical resonators in AlGaAs heterostructures in the world-class nanofabrication cleanroom at MC2. The raw material, an epitaxially grown heterostructure on a GaAs wafer, was supplied by the group of Professor Shu Min Wang at the Photonics Laboratory at MC2.

This is the first experimental work from the Wieczorek Lab at the Quantum Technology Laboratory at MC2, and it has been published as Editor’s Pick in the special topic on Hybrid Quantum Devices in the scientific journal Applied Physics Letters.

*Suspended photonic crystal membranes in AlGaAs heterostructures for integrated multi-element optomechanics.*

Sushanth Kini Manjeshwar et al

One atom thin platinum makes a great chemical sensor

Researchers at Chalmers University of Technology, with collaborators, have reported the possibility to prepare one-atom thin platinum and use it as chemical sensors. The results were published in the scientific journal Advanced Material Interfaces.

“In a nutshell, we managed to make a one-atom thin metal layer, a sort of a new material. We found that this atomically-thin metal is super sensitive to its chemical environment: its electrical resistance changes significantly when it interacts with gases”, explains Kyung Ho Kim, postdoc at the Quantum Device Physics Laboratory, and lead author of the article.

The spirit of the research is the development of 2D materials beyond graphene. “Atomically thin platinum can be actually useful for ultra-sensitive and fast electrical detection of chemicals. We have studied the case of platinum in great detail, but other metals like Palladium produce similar results”, says Samuel Lara Avila, Associate Professor at the Quantum Device Physics Laboratory, and one of the authors.

The researchers used the sensitive chemical-to-electrical transduction capability of atomically thin platinum to detect part-per-billion contents of toxic gases. They demonstrate this for detection of benzene, a compound that is cancerogenic to very small concentrations in ambient, and for which no low-cost detection apparatus exists.

Chemical Sensing with Atomically Thin Platinum Templated by a 2D Insulator
Kyung Ho Kim et al.
Tiny quantum computer solves real optimisation problem

Quantum computers have already managed to surpass ordinary computers in solving certain tasks – unfortunately, totally useless ones. The next milestone is to get them to do useful things. Researchers at WACQT, Wallenberg Centre for Quantum Communication, have now shown that they can solve a small part of a real logistics problem with their small, but well-functioning quantum computer.

All airlines are faced with scheduling problems. For example, assigning individual aircraft to different routes represents an optimisation problem, one that grows very rapidly in size and complexity as the number of routes and aircraft increases. Researchers hope that quantum computers will eventually be better at handling such problems than today’s computers. The basic building block of the quantum computer – the qubit – is based on completely different principles than the building blocks of today’s computers, allowing them to handle enormous amounts of information with relatively few qubits. However, due to their different structure and function, quantum computers must be programmed in other ways than conventional computers. One proposed algorithm that is believed to be useful on early quantum computers is the so-called Quantum Approximate Optimization Algorithm (QAOA).

The Chalmers research team has now successfully executed said algorithm on their quantum computer – a processor with two qubits – and they showed that it can successfully solve the problem of assigning aircraft to routes. In this first demonstration, the result could be easily verified as the scale was very small – it involved only two airplanes. With this feat, the researchers were first to show that the QAOA algorithm can solve the problem of assigning aircraft to routes in practice. They also managed to run the algorithm one level further than anyone before, an achievement that requires very good hardware and accurate control.

*Applying the Quantum Approximate Optimization Algorithm to the Tail-Assignment Problem Algorithm*
Pontus Vikstål et al.

*Improved Success Probability with Greater Circuit Depth for the Quantum Approximate Optimization Algorithm*
Andreas Bengtsson et al.
*Phys. Rev. Applied 14, issue 3 (2020)*
Quantum mechanical phase forms a crystal

Researchers at AQP, Chalmers and Montana State University, US have developed a theory that derives a so-called “phase crystal”, that elicits spontaneous magnetic fields and circulating currents. The theory predicts when a phase crystal can arise, explaining previous numerical results, and is presented in an article published in the scientific journal Physical Review Research.

Quantum mechanical states are described by a complex-valued wave function, which similar to a wave has both an amplitude and a phase. In contrast to a classical wave, the amplitude and phase of the wave function are related to purely quantum mechanical phenomena which lack an analogue in classical physics.

“A perfect example is superconductivity, which is a quantum-mechanical state that arises in certain materials due to electron pairing. The pairs have a quantum-mechanical wave function with an amplitude corresponding to the pair density, and a phase which is related to the pair momentum. The pairs move like an inviscid fluid through the material, with zero electrical resistance”, explains Patric Holmvall, researcher at the Applied Quantum Physics Laboratory at MC2, and the lead author of the article.

The researchers’ study shows that in certain superconductors with pathological edges that destroy superconductivity, the kinetic energy can change sign and become favourable as it “heals” the destroyed superconductivity.

Currents and magnetic fields usually only enter superconductors under external influence and perturbations, but now arise spontaneously. This is an example of spontaneous pattern-formation, where inhomogeneities which usually cost energy instead heal a destroyed system. The researchers’ studies show that phase crystals represent a unique class of inhomogeneous ground states.

Phase crystals

P Holmvall, M Fogelström, T Löfwander and A B Vorontsov
A New Spin on Topological Quantum Material

Researchers at QDP, with collaborators in Germany and China, have discovered a new spin polarization in Tungsten di-telluride (WTe$_2$), a topological Weyl semimetal candidate. These experimental findings can pave the way for the utilization of spin currents in developing the next generation of faster and energy-efficient spintronic and quantum technologies. The results are published in the journal Advanced Materials.

In the present experiment, researchers at Chalmers detected an unconventional spin current in Weyl semimetal WTe$_2$, which is parallel to the applied electric field. The generated spin polarization in WTe$_2$ is found to be different from the already known conventional spin-Hall and Rashba-Edelstein effects.

The spin polarization in WTe$_2$ is electrically detected by using both direct and its inverse phenomenon, obeying Onsager reciprocity relation. A robust and practical method for electrical creation and detection of spin polarization is demonstrated and utilized for efficient spin injection and detection in a graphene channel up to room temperature.

Unconventional Charge–Spin Conversion in Weyl-Semimetal WTe$_2$
Bing Zhao et al.
Advanced Materials, 2000818 (2020)

NVIDIA acquires OptiGOT

OptiGOT is a tech startup based on 20 over years of VCSEL (vertical-cavity surface-emitting laser) research at Chalmers University of Technology by Anders Larsson, Professor of Optoelectronics and Johan Gustavsson, Associate Professor of Optoelectronics. Both founders of OptiGOT together with the then doctoral student Erik Haglund, Doctor of Technology.

OptiGOT designs advanced VCSEL technology for high-efficiency data transfer, consumer sensing and LIDAR. The technology is ground-breaking and crucial for advanced testing, evaluation, and analysis of big data.
Cooling electronics efficiently with graphene-enhanced heat pipes

Researchers from Chalmers University of Technology have found that graphene-based heat pipes can help solve the problems of cooling electronics and power systems used in avionics, data centres, and other power electronics. The results, which also involved researchers in China and Italy, were published in the scientific Open Access journal Nano Select.

Electronics and data centres need to be efficiently cooled in order to work properly. Graphene enhanced heat pipes can solve these issues. Currently, heat pipes are usually made of copper, aluminium, or their alloys. Due to the relatively high density and limited heat transmission capacity of these materials, heat pipes are facing severe challenges in future power devices and data centres.

Large data centres that deliver, for example, digital banking services and video streaming websites are extremely energy-intensive, and an environmental culprit that emits more than the aviation industry. Reducing the climate footprint of this industry is therefore vital. The researchers’ discoveries here could make a significant energy efficiency contribution to these data centres, and in other applications too.

The graphene-enhanced heat pipe exhibits a specific thermal transfer coefficient which is about 3.5 times better than that of copper-based heat pipe. The new findings pave the way for using graphene enhanced heat pipes in lightweight and large capacity cooling applications, as required in many applications such as avionics, automotive electronics, laptop computers, handsets, data centres as well as space electronics.

* A lightweight and high thermal performance graphene heat pipe  
  Ya Liu et al.  
Electron–spin dynamics studied on their natural timescale

With the help of extremely short light pulses and coincidence technology, researchers from several Swedish universities have succeeded in following the dynamic process of when the electron’s spin – its rotation around its own axis – controls how an atom absorbs light. The new results were published in the scientific journal Nature Communications. “In fact, my contribution goes all the way back to my doctoral thesis from 1972 which explained the photo absorption cross section of the 4d-shell in xenon in the range 70-140 eV, studied by the present KAW collaboration,” explains Göran Wendin, one of the authors.

In the new study, the researchers have used attosecond light pulses and coincidence techniques to follow – in real time – how the electron spin (i.e. the angular momentum of the electron around its own axis) influences the absorption of a photon in a many-electron quantum system, the xenon atom. The study is using xenon, a heavy rare gas element that exists in small amounts in the atmosphere of the Earth. It is known to absorb soft x-rays of specific wavelength unusually efficiently. Physicists have named the effect a giant resonance and explained that it is caused by a strong collective response of the electron cloud when the atom is exposed to the x-rays. Especially intriguing is that the electron spin has a pronounced effect on the light absorption in this system.

The present analysis combines precision in both time and energy to show that the strong absorption is explained by an excited state living less than 50 attoseconds. The influence of the electron spin, however, is due to a ten times longer-lived nearby state, which can be reached by a change of electron spin (called spin flip). The spin-flipped state serves as a switch and determines the state of the remaining ion. The results provide new insight into the complex electron-spin dynamics of photo-induced phenomena and might be of considerable interest to applied science such as spintronics.

Attosecond electron–spin dynamics in Xe 4d photoionization
Zhong, S., Vinbladh, J., Busto, D. et al.
Nat Commun 11, 5042 (2020)

Prestigious funding for photonic research

Victor Torres Company, Associate Professor at the Photonics Laboratory at MC2, has been awarded a consolidator grant from The Swedish Research Council (VR). He is funded with 12 million SEK for the years 2020-2026.

The grant is funding his project “Multidimensional coherent communications with microcombs” and will strengthen Victor Torres Company’s group and help them establish a creative research environment.

“The great thing about this grant is that it covers a 6-year period. The grant will be used to ensure a smooth transition to the next generation of researchers of the knowledge that my team and I have created and take a bit of risks with a longer perspective in mind”, he says.
Organisation

Advisory Council
Representatives of professional
Jonas Hansryd, Ericsson Research
Åsa Hedn, ASH & partners AB
Paul Häyhänen, CIT
Jukka Pekola, Aalto University
Ann-Marie Wennberg, Sahlgrenska University Hospital

Representatives Chalmers
Andreas Divinyi, student
Matilda Hannes, student
Dag Wedelin, Computer Science and Engineering

Representatives, MC2
Susannah Carlsson, TA personnel
Mikael Fogelström, Head of Department
Åsa Haglund, teacher
Hans Hjelmgren, teacher
Nermin Trnjain, PhD student
Debora Perlheden/Annika Holtringer, administrative support

Prefect Group
Cristina Andersson
Ingrid Collin
Mikael Fogelström
Magnus Karlsson
Lena Lindgren
Peter Modh
Per Rudquist

Executive Group
Cristina Andersson
Peter Andreksson
Ingrid Collin
Per Delsing
Christian Fager/Herbert Zirath
Mikael Fogelström
Martí Guiterrez Latorre
Göran Johansson
Magnus Karlsson
Lena Lindgren
Johan Liu
Peter Modh
Per Rudquist
Jan Stake
Dag Winkler

Head of Department
Mikael Fogelström

Deputy Head of Department resp. for Graduate Education
Magnus Karlsson

Head of Administration and Finances
Ingrid Collin

Vice Head of Department resp. for Undergraduate Education
Per Rudquist

Vice Head of Department resp. for NFL Infrastructure
Peter Modh

Vice Head of Department resp. for Utilisation
Cristina Andersson

Director of Studies
Per Lundgren
## Financial Review

### Distribution of incomes to MC2 from different sources. (in 1000 SEK)

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### Main external contributors (in 1000 SEK)

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Bibliometric Data

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* Preliminary data extracted March 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.

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