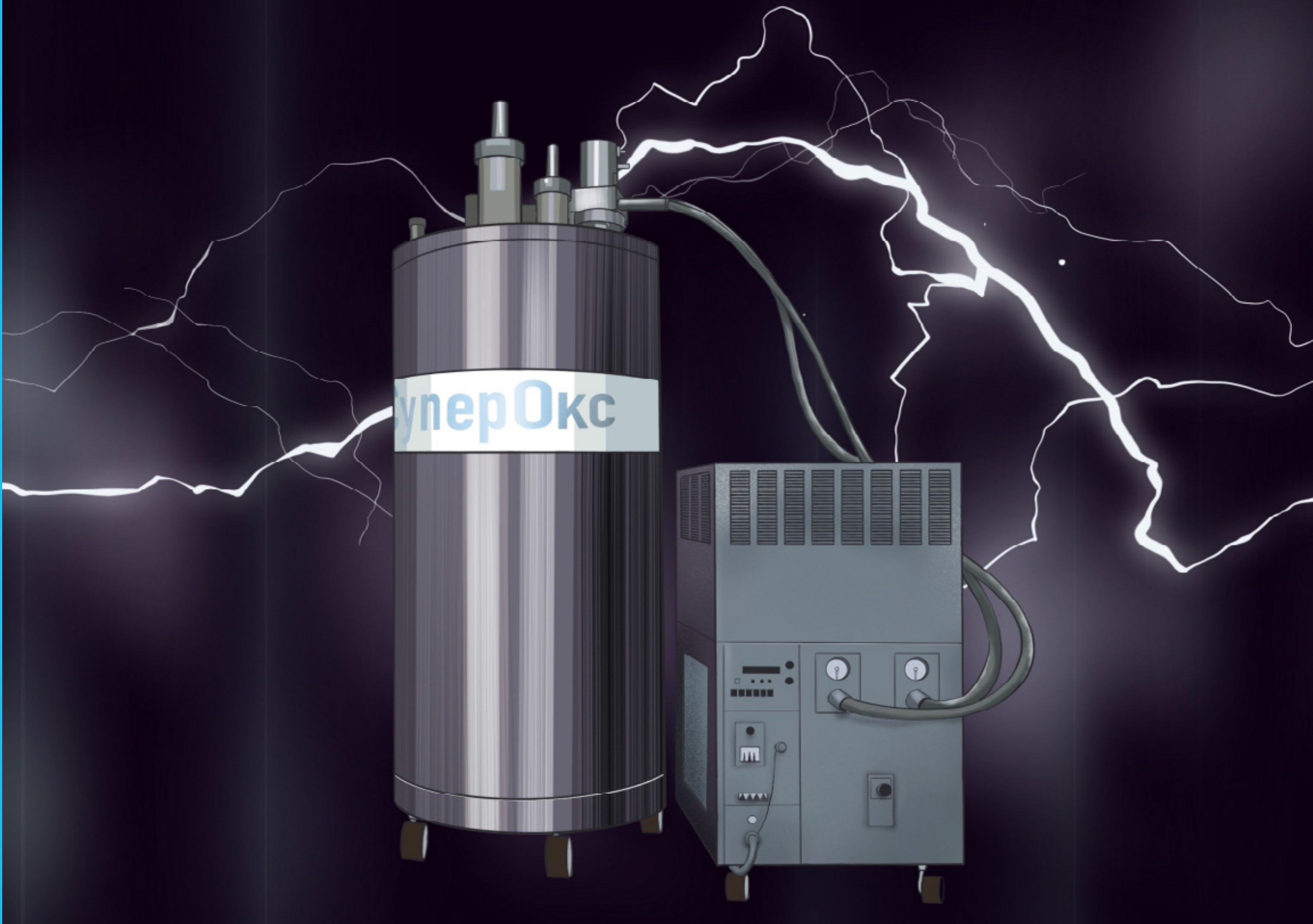
SUPERCONDUCTOR WEEK



JULY 03 2020

Editor's letter

Welcome to the new *Superconductor Week* !

With our newsletter in its 34th year, we decided to make a few changes. The most noticeable is our new look: especially the cover page and artistic renderings that accompany some of the articles. We've also added the Spotlight feature, an interview with someone engaged in cutting -edge work with superconductors, and a Luminary feature, a biographic look at someone in the past who had an influence on the field.

Two new partners have joined Superconductor Week: marketing director Sean McEvoy and contributing Writer Philip Neumann. Yuan Li has also been brought on board as artistic director.

With this new team we plan to reinvigorate the Superconductor Week brand and cover even more thoroughly developments in all fields of the industry, key research that might eventually lead to superconducting applications, and improvements to existing applications that might lead to the greater acceptance and wider use of superconductors.

One thing that impresses me, especially when attending the ASC and EUCAS conferences, is the almost community feel of the world of superconductivity. We are determined to broaden our role in this community, to become a clearinghouse for information on superconductors that will be equally of value to the business executive, the university researcher, and the student intrigued by the subject but with little background in the field.

With the changes we are making, some might wonder why a monthly newsletter is called *Superconductor Week*. When the newsletter was launched 34 years ago, it was a weekly but was primarily an aggregator of articles. With the original content we now provide, it made more sense a number of years ago to switch to larger but less frequent issues. But we have retained the name that we have been known by for over three decades. I like to think of the name *Superconductor Week* as demonstrating a quantum phenomenon: a unit of time that is both a week and a month.

To our subscribers, both old timers and newbies, I thank you for your support. To those who may be less familiar with *Superconductor Week*, we hope you enjoy this issue and will consider subscribing. To everyone, let us know what you think via editor@superconductorweek.com or *Superconductor Week*, 1606 44th St., NW, Washington, Dc 20007. We also welcome receiving press releases, article suggestions, and even article submissions.

Best wishes to all,

Douglas Neumann
Executive Editor

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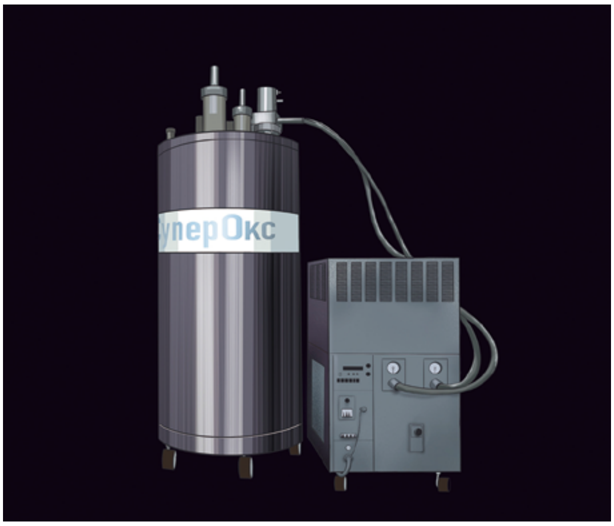
SuperOx SFCL Limits First Fault Current on Moscow Grid

Russian HTS wire manufacturer SuperOx has successfully installed a large 220 kV high temperature superconducting fault current limiter (SFCL) on the Moscow grid, at the 220/20 kV Mnevniki substation in the northwest Khoroshovo-Mnevniki District, supplying electricity to an area that includes four metro stations, numerous offices and residential buildings. This was the first superconducting device in operation on Russia's grid. The SFCL has a critical current of 3400 A at sub-cooled nitrogen conditions.



"This is the largest SFCL built to date by transmitted power," commented SuperOx CEO Sergey Samoilenkov. "This SFCL is rated to 220 kV and nominal current of 1200 A, thus three phases transmit 220*1.2* √3= 450 MW of electricity.

"The grid in Moscow is especially sensitive to fault currents, which have tended to increase with electrical consumption growth. The consumption of electricity has increased since 2000 by 59%.

"The Mnevniki substation already had traditional air core reactors installed for mitigating fault currents. Thus, it was chosen as an appropriate place for a first project – just by shunting reactors with the SFCL.

SFCL Seen as Critical for Dealing with Increasing Demand for Power

The electricity utility United Energy Company (UNECO) is one of the largest Russian infrastructure developers based in the Moscow region, and operates 27 HV substations with 8.31 GW transformer capacity and over 43 000 km of electricity lines. UNECO has shown increasing interest in more broadly using smart grid technology to upgrade the city's aged electricity grid, which must meet demand for consumption of about 100 TWh per year. In 2014, the utility requested SuperOx to propose an effective protection device for the 220 kV city grid.

SuperOx had been developing its own SFCL technology since 2013. The company provided UNECO with a number of prototypes, and the parties reached agreement on fabricating a 220 kV, 450 MW device with 2G HTS tape.

"Probably the biggest challenge was to design high voltage insulation of the device," Samoilenkov said. There was very little experimental data available at that time on the topic. The device is physically large and needed to be tested up to 440 kV withstand AC voltage and 950 kV lightning impulse.

"Nobody had done such tests before for such large liquid nitrogen equipment. These experiments are difficult and costly, so we needed proper engineering prior to building the device and later needed some iterations until we reached necessary high voltage performance."

Separate Cryostats Ensured Necessary Voltage Isolation

The design selected featured three cryostats with current limiting elements filled with sub-cooled pressurized liquid nitrogen, and a redundant closed-cycle cooling system. The project was officially initiated in 2016 with SuperOx as the main contractor, responsible for device fabrication, testing, civil engineering and commissioning onsite.

"Having separate cryostats is essential to ensure

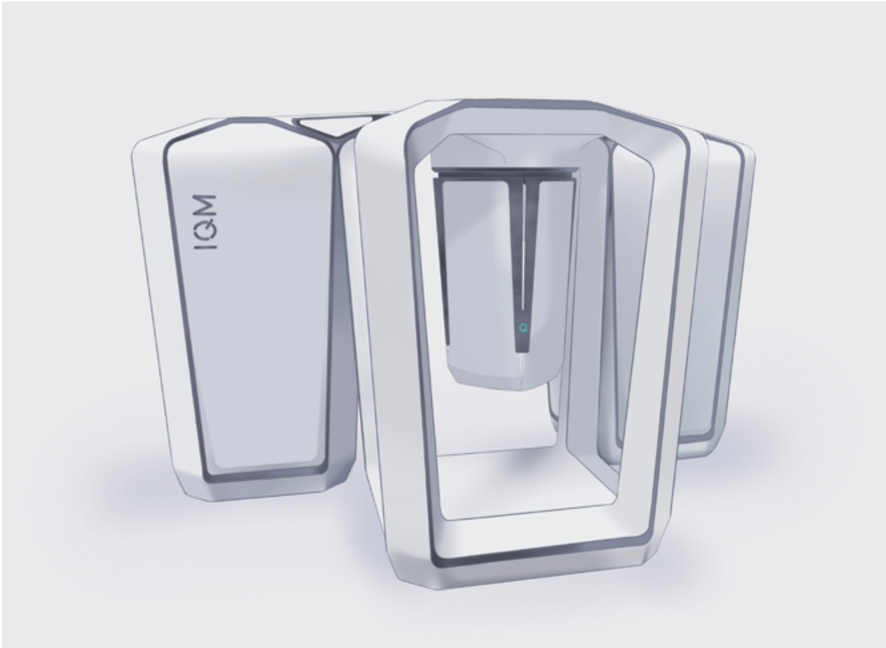
‣ the necessary high voltage isolation," Samoilenkov noted. "The cryostats are electrically grounded, so it is a 'dead tank' type of device."

The SFCL underwent a six-month testing period after installation. Since December 2019, it has been in ordinary operation, like any other equipment in the grid, requiring only regular maintenance of the cryogenic system and software upgrades.

Additional SFCLs on Moscow Grid Anticipated

In April 2020, the SFCL limited its first fault current while operating in a fully automatic mode. This fault event confirmed the design claims; in one millisecond the device transitioned into current-limiting mode and reduced the fault current value by a factor of 5. After the fault clearance, the SFCL self-recovered and resumed transferring electricity to customers.

SuperOx and UNECO are discussing the installation of two more SFCLs over the next two years and an additional six devices by 2025. The HTS wire manufacturer is also conducting evaluations for St Petersburg and other Russian regions with high electricity consumption.■



IQM Receives €17.5 Million from EIC Accelerator

Quantum computer hardware start-up IQM Finland Oy has been awarded a €2.5M grant and up to €15.0 million of equity investment to its currently open Series A funding round from the EIC Accelerator program for the development of quantum computers. Along with recent Business Finland grants of €3.3 million, the company has raised more than €20 million in less than a year, not including its initial €11.4 million seed round.

The cash injection comes at a time when European governments are earmarking funds for quantum computing. The Finnish government recently announced a €20.7 million initiative through its VTT state research center to develop a quantum computer.

IQM Well-placed to Take Part in Finnish and German Initiatives

Subsequently, as part of a stimulus plan to respond to the COVID-19 crisis, the German government announced that it would commit €2 billion to build at least two quantum computers (see *Currents* section, this issue). As a Finnish company with a recently established subsidiary in Munich, IQM is well placed to submit bids and participate in both projects.

With the help of this €20 million cash injection, IQM will hire one new quantum engineer per week over the coming year and begin to commercialize its technology through the co-design of quantum-computing hardware and applications. The company will also use the funding to support its recent establishment of a new underground quantum computing infrastructure development capable of housing the first European farm of quantum computers.

"This is a top-end room where can already put nine quantum computers if we wish and there is plenty of room to grow," commented IQM's chief scientist, Aalto University professor of quantum technology Mikko Möttönen. "We could, for example, reserve a section for five EU quantum computers and still have capabilities to have similar sections for others or grow the numbers in the future.

"This was a lucky opportunity for us. Typically, it takes many years to build something like this because of the requirements of low vibrations, cooling water, electricity, and good protection from external perturbations."

Munich Office Gives IQM a Foothold in Germany

IQM recently established a subsidiary, IQM Germany, in Munich (see *Superconductor Week*, Vol 34, No 3). The Bavarian capital was selected for IQM's expansion because it already hosts an ecosystem of stakeholders involved with quantum innovation.

"The most important reason why we ended up establishing the German office was that we would like to help everybody to have quantum computers and thought the best way to do this is through local activity and participating in local efforts," Möttönen said. "Germany was an obvious starting point for us since we have a German CEO and some German investors with experience as to how things work in Germany."

Co-design Business Model Meshes Quantum Software with Hardware

IQM was launched in mid-2019 with the objective of developing second-generation high-speed quantum processors that would reduce quantum computer error rates (see *Superconductor Week*, Vol 33, No 6). The company aims to become a hardware systems leader in the drive to create a quantum computer for practical applications by demonstrating the fastest qubit reset and readout in the industry.

IQM's technical goals are to create a co-design hub that tightens the interaction between quantum hardware and quantum software development. In particular, IQM Germany will develop an original co-design approach where quantum software is meshed with suitably designed quantum hardware and novel architectures.

Möttönen explained how IQM's co-design model works: "We have researchers in Germany designing tailor-made processors for certain applications along with optimal ways to operate them. This staff works closely with out hardware team that is fully located in Finland."

Series A Funding Round Still Open

IQM has not yet closed its Series A funding round. The company is still open to consider new committed investors who wish to participate in its business plan.

The EIC Accelerator (previously know as SME Instrument) is part of the European Innovation Council pilot that provides seed money to high-risk, high-potential small and medium-sized enterprises and innovators with the objective of helping them develop and bring onto the market new innovative products, services and business models that could drive economic growth. IQM was one of 72 companies selected for EIC funding out of a total of 3969 applicants.■

European Consortium to Develop Quantum Annealer under AVaQus

A European consortium has been awarded €3.0 million from the European Commission's Horizon 2020 FET Open for a three-year program under the AVaQus (Annealing-based VAriational QUantum processors) program to design and fabricate a five-qubit quantum annealer with high connectivity tunable interactions, and long coherence time. This project aims to set the stage for next-generation quantum computing systems capable of performing computations and simulations with far greater speeds and efficiencies than classical computers by utilizing recent developments in superconducting quantum circuits.

Researcher Pol Forn-Díaz, the head of the Quantum Computing Technologies group at the Institute for High Energy Physics (IFAE) in Barcelona is responsible for initiating and coordinating the project. "As coherent quantum annealing technology has continued its progress, an initial attempt at the FET Quantum Flagship was re-elaborated into a FET-Open proposal, since AVaQus targets truly innovative technologies with significant market potential," explained Form-Diaz.

Quantum Annealers Appropriate for Optimization + Quantum Simulation

Quantum annealers are believed to be more suitable for solving certain types of problems than classical processors, with a shorter time to market than universal quantum computers. "Quantum annealers are not universal quantum processors in the sense that they cannot just solve any type of quantum algorithm," commented Forn-Diaz. "But the problems they can solve, optimization + quantum simulation, are very much ubiquitous in our society, hence very relevant.

"The technological demands are less than gate-based quantum processors as the system remains at its lowest energy state all the time. This means the quantum annealer size, in number of qubits, can grow very rapidly."

If successful, the system developed by AVaQus would be the first superconducting annealer to perform quantum computation and simulation tasks with hardware designed for coherence. "[This] means that the qubits, and their control and readout circuitry will be designed with the purpose of maintaining a high level of quantum coherence of the qubits," clarified Forn-Díaz.

"By high coherence we mean that the qubit state will not decohere during the duration of the computation. In other words, we will be using the same kind of superconducting qubit technology that is already working well in gate-based digital quantum processors."

Forn Diaz noted that quantum annealing may have a positive effect on coherence: "The hardest problems are ones where the solution, encoded in the lowest energy state of the system, is just marginally below the higher excited levels, and the tiniest amount of noise will take you away from your optimal point. Another area where coherence seems to help is the speed at which the annealing algorithm can run, as there is a connection between quantum tunneling, which affects the speed at which you can anneal, and low dissipation in the system, something you get when qubits are highly coherent."

Annealers Use Adiabatic Quantum Computing Techniques

The majority of research on quantum systems is centered on universal gate-based quantum computers, an approach that requires sizable arrays of qubits to correct for noise-induced error for operation. Leading quantum computer companies, including IBM, Google and Intel, are currently focused on Noisy Intermediate Scale Quantum (NISQ) devices that are able to function without error correction.

"Quantum annealers are different from gate-based quantum processors in that they use adiabatic quantum computing techniques, which do not require quantum gates, to solve problems," explained Forn-Díaz. "The computation is performed by evolving the system with all interactions among qubits switched off into a state in which interactions dominate and generate strong correlations, all while keeping the system in its ground state. Pictorially,

▸ initially all qubits are equal and don't know anything about each other, but at the end of the computation certain qubits influence their neighbors, resulting in a very complicated arrangement of positive and negative interactions, leading to a highly entangled ground state."

Noisy Processes Less Damaging to Annealer

According to Forn-Diaz, the analog quantum computing of an annealer may be less prone to errors than universal quantum computing systems: “We do not claim that our qubits will be more resistant to quantum gate errors, because there are no gates used in annealing. What we mean is that the type of errors that plague gate-based quantum processors will not affect us all that much because the way in which information is processed is completely different. In particular, the annealer never leaves the ground state of the system, and therefore the noisy processes that induce decoherence in gate-based processors appear to be less damaging to the operation of a coherent quantum annealer.”

To date, Burnaby, British Columbia-based D-Wave Systems has been the primary commercial developer of quantum annealing devices. In spite of their significant technological accomplishments, the extent to which D-Wave’s computing technology qualifies as quantum technology has generated debate by some academics. In particular, some researchers question whether the company’s system has shown quantum entanglement, an indicator that it relies on quantum effects.

“Their device is not a coherent annealer, in the sense that the coherence time of qubits is much shorter than the total computational time of their system,” Forn-Diaz pointed out. “Some refer to D-Wave devices as incoherent quantum annealers.

“There is an IARPA-funded project in the US involving groups from around the world named QEO (quantum enhanced optimization) led by MIT that is also aiming at building a coherent quantum annealer. The project is about midway (out of five years) and has so far reported work using 1-2 coherent qubit prototypes.”

Innovations to Include Qubit-qubit Interactions

Forn Diaz explained how the AVaQus team plans to improve upon existing designs: “We want to implement novel types of qubit-qubit couplings which are mathematically harder to deal with for classical computers. In this way, the problems a coherent annealer can solve will be less likely to be solved in a classical computer. The challenge is in identifying such problems.

“For that, AVaQus will have three theory/software teams addressing this important front. In annealers you need very large qubit-qubit interactions as compared to gate-based approaches. Also, the interactions must be switchable and adjustable, something that Google recently introduced in their device whereby they claimed quantum supremacy.

“In the AVaQus approach, the coupling circuits we aim at developing introduce additional physical effects. If we think of qubits as spin-1/2 particles, it would be as if we would want to have spins interact with more than one component of their spin.

“Normally, in annealers and in gate-based processors, the interaction operates along one component, say XX. We want to implement couplings like XX + ZZ, which turn out to be very tough to deal with by classical processors and may lead to the long-sought quantum advantage if one is able to wire up together a sufficiently large amount of qubits.

“In no way can we think of outperforming classical processors with five qubits. However, this five-qubit demonstrator will set the path to scaling up to a large-size device that should be the goal of the following generation of devices in a follow-up project.”

Annealer Development and Rollout

The system will incorporate applications of small-scale quantum annealing algorithms that can be employed for simulations and optimization in logistics, navigation, traffic, finance, quantum chemistry, and machine learning. The qubits will employ aluminum circuits and either silicon or

▸ sapphire as substrates. The annealer will need to be cooled via dilution refrigeration to a temperature of 10 mK.

The researchers intend to work in two parallel lines of development, each one using a different qubit and coupler type, namely low impedance and high impedance circuits. At the end of the project, one of the goals is to assess which of the two types of qubits is more suitable to scale-up the device in a later project.

AVaQuS is a consortium of eight European partners consisting of five research centers: IFAE, the Karlsruhe Institute of Technology (KIT), the French National Center for (CSIC), and three quantum startup companies: Delft Circuits in the Netherlands, Qilmanajaro Quantum Tech, S.L. (QILI) in Spain, and Heisenberg Quantum Solutions (HQS) in Germany. They are slated to launch the AVaQus project on October 1, 2020.

OpenSuperQ from the FET Flagship on Quantum Technologies (FET-QT) and the QuantERA-funded project SiUCs (Superinductor-based Quantum Technologies with Ultrastrong Couplings), also coordinated by IFAE, will be collaborating with the AVaQus initiative. Delft, CRNS, and Glasgow will be responsible for designing and fabricating the enabling quantum and classical hardware, while IFAE and KIT will design and validate different types of qubit circuits operating as coherent quantum annealers. HQS, QILI, and CSIC will work on developing quantum software and applications that will eventually run on the coherent quantum annealer, as well as on studying highly connected topologies in larger-scale future devices.■

Grid Unit Accounts for 78% of AMSC Revenues for FY2019

AMSC has announced in its FY2019 earnings release that Grid unit revenues rose by 44.6% to $49.6 million, compared to $34.4 million in revenues realized in FY2018. The net operating loss of the segment was $13.5 million, compared to a loss of $10.6 million the previous year.

All four Grid business lines, the superconducting Ship Protection System (SPS) and Resilient Electric Grid (REG) products and the non-superconducting D-VAR and VVO products, showed an increase in revenues. Reduced margins due to changes in the product mix resulted in a higher net operating loss. Margins are lower on the SPS and REG products while production ramps up.

For Q4 FY2019, Grid revenues increased by 19.0% to $12.9 million from the $10.8 million achieved during Q4 FY2018. Grid revenues constituted 71.3% of AMSC's aggregate quarterly revenues and 77.7% of aggregate annual revenues.

"AMSC's annual revenue was less than one-third Grid just a few years ago," commented Daniel P. McGahn, Chairman, President and CEO of AMSC, during the quarterly earnings conference call. Grid revenue is now more than two-thirds of our business. As we enter fiscal 2020, our D-VAR backlog is at record levels.

"Our VVO team is preparing for expected higher volume shipments this fiscal year. Our REG team is planning to deliver the REG hardware to Chicago this year on schedule. We are manufacturing SPS for the San Antonio Class ship platform, LPD, with first delivery is expected in 2021."

AMSC Anticipates SPS Deployment on 13 Ships

McGahn noted that SPS was now the Navy's baseline degaussing design for the San Antonio Class ship platform, LPD. In FY2019, AMSC announced an SPS delivery contract with Huntington Ingalls for the deployment on LPD 30. The company ended the fiscal year with two SPS orders secured, one for LPD 28 and the other for LPD 30.

▸ "We are preparing for the next SPS order, and are planning for the concurrent manufacture of multiple SPS orders," McGahn said. "LPD 31 is the U.S. Navy's 15th San Antonio Class ship. The Navy awarded Huntington Ingalls a $1.5 billion contract to construct this ship in March of 2020.

"LPD 29 is the U.S. Navy's 13th San Antonio Class ship, which is under construction at Ingalls. In February 2018, the Navy signed a $1.4 billion contract with Huntington Ingalls for the construction of LPD 29."

AMSC is working the Navy to understand the program timing for both LPD 29 and LPD 31, and anticipates the potential for SPS deployment on a total of approximately 13 future ships in this class. This could represent a potential revenue stream of about $130 million for this class of ship.

REG Cable to be Delivered in 2021

"Fiscal 2019 was an important year for REG." McGahn said. "DHS approved the scope of AMSC's REG project with Commonwealth Edison, which allowed us to proceed with the project and the manufacturing of the REG system. We are partnering with Nexans to fabricate the REG cable, utilizing AMSC's proprietary Amperium superconductor wire, and anticipate the system should be operational in 2021 on schedule."

McGahn noted that AMSC and ComEd are proceeding with the engineering assessment of a proposed second REG system in Chicago. This second project would interconnect multiple existing substation within Chicago's central business district and is expected to be larger in scope than the REG project that is underway.

"We are also developing opportunities to deploy our REG product in other utilities across the country," McGahn noted. "We are very pleased by the strong support we are seeing. We've announced five cities and have developed a pipeline of many more.

"These projects do take time to mature. With the first system secured, we believe that future deployments of REG will be derisked. U.S. utilities are focused on the execution of this first Chicago project, Chicago is focused on the execution of this first Chicago project and we are focused on execution of this critical project."

Subsequent to the earnings release, AMSC entered into a contract for Nexans to manufacture a medium voltage HTS cable for the project at its specialized superconductor facility in Hannover. AMSC and Nexans have a history of collaboration. Both companies participated in the AmpaCity project, which commissioned a one-kilometer long, 10,000 volt HTS cable in Essen, Germany (see *Superconductor Week*, Vol 26, No 2) and, afterwards, agreed to jointly market REG systems in the U.S. and Canada (see *Superconductor Week*, Vol 26, No 23).

Aggregate Net Loss Declined in FY2019

AMSC's aggregate revenues, including its Wind unit, for Q4 FY2019 rose by 13.5%, to $18.1 million from $14.6 million in Q4 FY2018. The company reported a loss of $5.9 million ($0.27 per share) compared to a loss of $8.4 million ($0.41 per share) last year.

For FY2019, AMSC realized $63.8 million in revenues, 13.5% higher than the $56.2 million in revenues achieved during FY2018. The company reported a loss of $17.1 million ($1.03 per share) compared to net income of $26.8 million ($1.29 per share) during FY2018. In FY2018, AMSC recorded as income a $25.0 million payment from the Sinovel settlement, which was reached in July of that year (see *Superconductor Week*, Vol 32, No 6).

Cash, cash equivalents and restricted cash at the end of the quarter declined to $66.1 million, compared with $66.3 million at the end of the previous sequential quarter. AMSC's share price declined by 8.6%, from $7.91 to $7.23, on the day after the earnings release.

For Q1 FY2020, AMSC expects that its revenues will be in the range of $18 million to $20 million. Net loss is expected not to exceed $6.2 million, or $0.28 per share.

The company expects operating cash flow to be a burn of $4 million to $6 million in the first quarter of fiscal 2020. Cash, cash equivalents, marketable securities and restricted cash should be no less than $60 million.■

Münster and FZ Jülich Show Energy Quantization in YBCO Nanowire

Researchers at the University of Münster and the Jülich Research Center (FZ Jülich) have demonstrated energy quantization in an HTS nanowire with phase-slip dynamics (doi.org/10.1038/s41467-020-14548-x). Additionally, they showed how the absorption of a single photon changes the phase-slip and quantum state of the nanowire. The findings provide evidence that this method is a promising candidate for realizing superconducting quantum circuits and could pave the way for a new class of superconducting nanowire devices, such as qubits, resonators, and single-photon detectors, with superior characteristics for quantum sensing and computing.

"One of our motivations for this work stems from the expectation that nanowire single-photon detectors fabricated from YBCO will be faster than similar detectors from low-temperature superconductors because the energy relaxation processes in high-temperature superconductors happen on shorter timescales," explained Matvey Lyatti, now at the Russian Academy of Sciences and co-author of the paper. "In our studies we indeed managed to observe the response of nanowires to single optical photons. Surprisingly, for nanowires with widths below 100 nm, we found that their behavior cannot be explained by conventional models developed for low-temperature superconductors.

"The unconventional behavior resembled that of Josephson junctions with quantized energy levels but occurs at a much higher temperatures of 12-13 K. This is very surprising, because nanowires and Josephson junctions are completely different physical objects.

"Fortunately, we have a team with competencies in Josephson junction physics, high-T_C superconductors, and superconducting single-photon detectors. Due to the joint expertise, we untangled this puzzle and demonstrated that indeed the YBCO nanowire features quantized energy levels at temperatures below 12-13 K and the lifetime in the excited state exceeds 20 ms at 5 K. "

Quantum Phase Slips Attractive for Quantum Applications

Most superconducting quantum circuits are based on tunnel Josephson junctions. However, the Josephson effect also occurs in structures with non-tunneling conductivity, which are also considered as superconducting weak links.

Nanowires with quantum phase slips caused by fluctuations of the order parameter are interesting superconducting weak links with direct conductivity, which can be used in superconducting quantum circuits. These nanowires exhibit long-lived excited states, which result from their low sensitivity to charge noise and critical current noise, and may make them attractive for quantum applications.

"It is expected that phase-slip nanowires are less sensitive to the charge noise and critical current noise than Josephson junctions resulting in better coherence time," Lyatti pointed out. "In a nanowire, a current flows along a uniform channel, while in the Josephson junction the current crosses an artificial structure – the tunnel barrier, which is a thin layer of insulator separating two superconductors. The barrier itself, and interfaces between tunnel barrier and superconductors, can contain defects that are the origin of losses decreasing the coherence time."

Lyatti also noted additional advantages of phase slips over Josephson junctions: "Phase-slip nanowires are easier to fabricate than low-T_C Josephson junctions. The number of nanofabrication process steps is three times less. Already the first YBCO phase-slip nanowire, i.e., in our work, has shown a significantly longer lifetime in the excited state than even the most advanced qubits based on low-T_C Josephson junctions."

YBCO Nanowires: Much Higher Resonant Frequency than LTS Qubits

The team fabricated sub-100-nm-wide superconducting $YBa_2Cu_3O_{7-x}$ (YBCO) on an STO substrate. When the nanowire conducted electricity, phase-slips occurred, with fluctuations of charge carrier density causing variations in the supercurrent. When the researchers examined the processes in the nanowires at temperatures below 20 K, they discovered that the wires entered a quantum state between 12 and 13 K.

"A superconducting quantum circuit enters the quantum regime when its losses are very low and its characteristic energy is larger than the thermal energy," explained Lyatti. "The first condition is satisfied at temperatures well below the critical temperature, T_C, of a superconductor (T_C = 93 K for YBCO and 1.2 K for aluminum which is the most popular material for LTS qubits) when almost all charge carriers have formed Cooper pairs that can carry a current without dissipation. Roughly speaking, the operating temperature should be below ~0.1 T_C.

"The characteristic energy of the superconducting quantum circuit, which can be considered as an LC resonator, is adjusted by a proper choice of a capacitance C and inductance L of the circuit. The resonant frequency, f_C, of LTS qubits is typically chosen in the range of 5-10 GHz, such that the superconducting circuit enters the quantum regime at temperatures of $T_{cr} \approx hf_C/2\pi k$ = 40-80 mK, where h and k are Planck and Boltzmann constants, respectively. Our YBCO nanowires have a significantly higher resonant frequency of 1.6 THz which results in the crossover temperatures between the classical and quantum regimes of 12-13 K, i.e., 2-3 orders of magnitude hotter than their LTS counterparts."

The team performed electrical transport measurements and measured their switching-current statistics under equilibrium and non-equilibrium conditions. The lifetime of the nanowires in the excited state exceeded 20 ms at 5.4 K, which is at least one order-of-magnitude longer than in LTS tunnel Josephson junctions.

The researchers also showed that the absorption of a single-photon changed the quantum and phase-slip states of YBCO nanowires. "When a single optical photon is absorbed by a YBCO nanowire it creates non-equilibrium quasiparticles in the nanowire by destroying a number of Copper pairs," Stated Lyatti. "When these unpaired non-equilibrium quasiparticles are generated, the losses in the nanowire increase significantly."

Photon Absorption Changes Nanowire State

If the nanowire is in an excited energy state and absorbs an optical photon, it immediately switches to the ground energy state because of the increased losses. Therefore, it is possible to switch the nanowire quantum state from the excited to the ground energy state by absorbing an optical photon.

"We consider the phase-slip state as the number of nonstationary phase-slip processes that persist in the nanowire," added Lyatti. "When the nanowire is in a superconducting state and absorbs an optical photon, superconductivity is locally suppressed across the nanowire's width by disrupting a number of Copper pairs. Depending on the value of the bias current, either superconductivity can recover from this local perturbation and the nanowire switches back to the superconducting state or a part of the nanowire starts to periodically oscillate between the superconducting and resistive states.

"Here, the superconducting phase slips by 2π during each oscillation, a non-stationary process referred to as a phase-slip process. Therefore, the absorption of a photon can start the phase-slip process in the nanowire, thus changing its phase-slip state from zero to one. The variation of the phase-slip state then results in a step-wise voltage change, appearing in the current-voltage characteristic of the nanowire after the photon absorption event."

The researchers are now gearing their efforts towards developing a YBCO nanowire qubit with nondestructive readout and improved sensitivity to photons.

This work was supported by ER-C Project No. C-088 and the Ministry for Innovation, Science, and Research of North Rhine-Westphalia.■

Aalto and Lund Fabricate Calorimeter for Quantum Measurement

Researchers at Aalto and Lund Universities have created a nanoscale electron calorimeter that provides a highly efficient noninvasive measurement of energy transport in superconducting quantum circuits in the microwave regime (https://doi.org/10.1038/s41467-019-14247-2). The device may become an important tool for detecting the energy in quantum jumps, which can help address key issues in quantum thermodynamics.

"There is active ongoing research at Aalto University and the centre of excellence QTF (Quantum Technology Finland) to develop detectors for single micro-wave quanta in superconducting circuits," commented Aalto professor Jukka Pekola and researcher Karimi Bayan by email. "This experiment is part of that effort to demonstrate the ultimate energy resolution limits. Quantum jumps are relaxation events of qubits or other quantum circuits, where these circuits emit an energy equal to the qubit energy to the measuring device, the calorimeter."

Quantum Thermodynamics Measures Energy Relaxation in Quantum Systems

The research field of quantum thermodynamics deals with the question of how heat and thermodynamics coexist with quantum physics. It has primarily dealt with theory, although recently experimental inquiries have begun to explore how quantum states interact with their environment.

Measuring quantum states requires sensitivity to exceptionally small energy changes that have to be differentiated from background noise. The measurement must also avoid interfering with the quantum state and causing decoherence.

"[Quantum thermodynamics] is basically fundamental science to understand energy relaxation in quantum systems to the tiniest details, and the possible use of this understanding to devise systems that can better maintain their quantum states intact," Pekola and Bayan said. "In our systems, we have the opportunity to measure these individual energy packets, unlike in most other realizations. Still, the energy resolution required to do this is demanding but within our reach.

Testing Reached the Theoretical Limit of Accuracy

The nanoscale electron calorimeter the team developed consists of a 1 µm long copper absorber that is subjected to the fluctuating heat current from a phonon bath situated below. The absorber is coupled to two superconducting aluminum leads via tunnel barriers.

The metal-to-metal contact to another superconducting aluminum lead pointing down at an inclined angle provides the proximity effect for the thermometer and a fixed chemical potential for the absorber. Exchanging energy with the phonon bath at temperatures of 10-300 mK, the device was tested to the limit of accuracy as established by theory

"The measurement itself is non-invasive in the sense that the junction that measures the temperature is kept unbiased, that is, in equilibrium, apart from the tiny ac-excitation by which the supercurrent is detected," Pekola and Bayan said. "Of course, connecting the absorber itself to the quantum system destroys the quantum state at a rate depending on how strongly this absorber is connected to the qubit, even when not measured by the thermometer.

"The fabrication technique is somewhat unique, although most laboratories working on mesoscopic superconductivity can reproduce the thermometer. The RF-measuring set-up is also a little unique due to its operating frequency range, although probably the thermometer could be adjusted to other frequencies and more common resonators as well."

The team plans to follow up on this research by seeking to improve the signal-to-noise ratio by better amplifiers and different read-out schemes.

This work was funded through Academy of Finland grants 297240, 312057 and 303677 and from the European Union's Horizon 2020 research and innovation program under the European Research Council (ERC) program and Marie Sklodowska-Curie actions (grant agreements 742559 and 766025).■

LAMM Florence Induces Quantum Tunneling Control in Single-Molecule Magnets by a Superconducting

A team of physicists at the Laboratory of Molecular Magnetism (LAMM) of the University of Florence demonstrated that the superconducting transition of lead to the condensate state switches a single molecule magnet from a blocked magnetization state to a resonant quantum tunneling regime (doi.org/10.1038/s41563-020-0608-9). Their findings highlight how single-molecule magnets interact with various kinds of superconductors. Researchers from the University of Stuttgart, the Synchrotron SOLEIL, the University of Modena and Reggio Emilia, the University of Grenoble-Alpes, and ETH Zürich also participated in the research.

"This study is part of a broader research activity focused on spintronics for quantum information processing," explained LAMM researcher and paper co-author Giulia Serrano. "The combination of superconductors and magnetic materials gives access to novel quantum phenomena such as the creation of local electronic states or boosting spin-related effects.

"These experiments represent the first approach to couple classes of materials as different as superconductors and single molecule magnets. Although previous works showed promising interaction between spins of paramagnetic molecules and superconductors, this study revealed an unexpected sensitivity of the single molecule magnet layer to the superconducting transition in the intermediate superconductive state, when a progressive transition of the substrate to the condensate state occurs."

Single-molecule Magnets Affect T_C's of Adjacent Superconductors

Single-molecule magnets can switch between two states, a "spin-up" state and a "spin-down" state. When sufficiently cooled, they retain their magnetism even in the absence of a magnetic field. This phenomenon occurs because the magnets would need to overcome an energy barrier in order to reverse their magnetization. This magnetic memory effect could have applications in spintronics and quantum computing systems, as the spins may act as stable qubits.

Molecular magnets working in conjunction with superconductors have recently drawn increased research attention. A recent study of Yu-Shiba-Rusinov states demonstrated that monolayers of paramagnetic molecules could influence the temperature at which an adjacent layer of material becomes superconducting, an effect attributed to the paramagnetic monolayers creating local states in the superconducting bandgap.

"The use of magnetic molecules is promising thanks to the rational design of molecular structures allowing the tuning of both their magnetic properties and their interaction with substrates," Serrano added. "Single molecule magnets featuring magnetic instability and resonant quantum behavior at low temperatures have been thoroughly explored in thin molecular films on surfaces. Their peculiar behavior is altered by the specific nature of surface-molecule interactions leaving room for the development of new multifunctional hybrid systems."

XMCD Enabled Surface Magnetization Probing

The Florence team conducted the experiments in an ultrahigh vacuum chamber. They employed a thermal sublimation technique to deposit the tetrairon molecular clusters onto the surface of lead. They then analyzed the magnetism of the molecular layer using synchrotron light and X-ray magnetic circular dichroism.

"X-ray magnetic circular dichroism (XMCD) allows us to directly probe the magnetization of samples at the surface," Serrano pointed out. "In this case, it probed the magnetization of a molecular layer of single molecule magnets. By measuring the XMCD signal while sweeping the magnetic field, it is possible to measure a magnetic hysteresis loop, which gives insights into the magnetization dynamics of the molecular layer."

The Meissner effect causes superconducting lead to expelling magnetic flux from its interior, which cancels the external magnetic field of the molecular magnet and unblocks its magnetization state, switching to a resonant quantum tunneling regime. At H_C, the lead superconductor activates the resonant quantum tunneling of the spin of the molecular magnetic core, which consists of four iron atoms, the central one antiferromagnetically coupled with the three peripherical ones. The quantum tunneling allowed the quantum particles to penetrate energy barriers which would not otherwise be possible.

"Quantum tunnelling is the process by which quantum particles can penetrate energy barriers normally insurmountable to classical objects," Serrano explained. "Occurring at zero magnetic field and at particular resonant magnetic fields, it causes magnetization reversal of the molecular spin. In other words, it allows spin flipping from its 'up' to its 'down' state, or vice versa, without 'jumping' the energy barrier dividing the states but directly crossing it. In this sense, we talk of 'blocked magnetization state' when the spin is blocked in its up, or down, state and of 'resonant tunnelling regime' when it is free to spin flip by quantum tunneling effect."

The researchers discovered that the interplay between single-molecule magnets and superconductors goes in both directions- a material undergoing a superconducting transition can influence the spin dynamics of adjacent single-molecule magnets. They studied clusters of iron atoms incorporated into the structure of a complex model containing trialcohol ligands. The iron atoms maintain a propeller-like arrangement, which protects the high spin of the iron magnetic core, even at very low temperatures.

In this transition, the number of switching events increases as more regions of the material become superconducting. This can be interpreted as a gradual decrease of magnetization value in the hysteresis loop of the single molecule magnet.

Findings May Apply to Quantum Communication Systems

The team purports that this magnetization switching mechanism may open new possibilities for using such hybrid systems in quantum communications systems. Additionally, the single-molecule magnets can be used as local sensors for probing superconductivity.

"Although this is still basic research, the observed phenomena give new perspectives to the potential applications of SMMs in sensors and quantum information technologies," noted Serrano. "As already pointed out, they can be used for a local nanoscale probe of the superconducting state, but, on the other hand, the superconducting transition can be used to bias the magnetization state of SMMs qubits.

"This investigation lays the basis of a novel research line aiming to a deep understanding of single molecule magnets interaction with different kinds of superconductors. In particular it would be interesting to study superconductors with complex domain structures, such as vortex states, and analyse their effects on single molecule magnets. Furthermore, for thin films superconductors, a possible mutual influence of the superconductor magnetic flux distribution with the magnetic field locally generated by the single molecule magnet can be foreseen."

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Rice Examines Nematicity of Detwinned FeSe

A Rice University-led research team has detailed the electronic structure of fully detwinned iron selenide (FeSe) across the nematic phase transition, essentially laying out a band structure map that acts as a visual summary of measurements of a single crystal of FeSe as it cools and transitions into a superconducting state (doi.org/10.1103/PhysRevX.9.041049). Their work provides an accurate basis for future theoretical models of superconductive pairing in FeSe. Also participating in the study were scientists from Lawrence Berkeley National Lab, Peking University, SLAC National Accelerator Lab, Renmin University of China, and the University of California Berkeley.

"The goal of the research on iron-based superconductors is to understand the pairing glue of superconductivity," pointed out Rice professor Ming Yi, who co-authored the paper. "In iron-based superconductors, the nematic phase appears in proximity to superconductivity. We use FeSe to understand what nematicity does to change the landscape of electrons in reparations for superconductivity."

Nematicity May Contribute to Electron Pairing Glue

Fe based superconductors have been rigorously researched since their discovery in 2008. A common procedure is to sandwich an atom-thick later of iron between other elements. At higher temperatures, the atoms in the iron layer are arranged in squares, but with sufficient cooling, they shift to a rectangular arrangement.

This alteration causes nematicity, or direction-dependent electron behavior, which is the breaking of rotational C4 symmetry when a sample is pulled in a certain direction. Nematicity is believed to play a significant role in superconductivity, though a detailed characterization of this process has thus far eluded researchers. In FeSe, nematicity arises disentangled from magnetic order, which provides a unique platform to study its effect on superconductivity.

"Nematicity appears in almost all the iron-based superconductor families where superconductivity appears," says Yi. "The fluctuations associated with nematicity could contribute to the pairing glue."

Nematic Order Results from Broken Rotational Symmetry

In most Fe-based superconductors, the nematic order is strongly coupled to a collinear antiferromagnetic order with an onset simultaneously or slightly below the structural transition. There is ongoing debate concerning the driving mechanism behind the strong coupling between spin, orbital, and lattice degrees of freedom.

"Susceptibility is the measurement of the material's response to a certain perturbation," explained Yi. "Magnetic susceptibility is the measure of how strongly it becomes magnetized given a magnetic field you subject it under.

"Nematic susceptibility is measured from resistivity along two perpendicular directions. In a rotationally C4 material, the resistivity along these two directions must be the same because they are rotationally symmetric. In a nematic sample, they will no longer be the same, hence the resistivity is said to be anisotropic. The sample spontaneously breaks the rotational symmetry, even without the pull, and goes into a nematic order when the nematic susceptibility diverges, which means an infinitesimally small pull will induce a gigantic response."

Detwinning Facilitated Nematic Order Measurements

Understanding nematicity is necessary for formulating a theoretical model of superconductivity in Fe-based materials. Unfortunately, the multiorbital nature of Fe-based superconductors and twinning in the nematic state have proven to be significant challenges preventing a unified description of the electronic structure in the nematic state.

Twinning is a property found in crystals that causes the atomic structure to rotate 90 degrees at random times. This means that the long-axis rectangles formed by the atoms will run side-to-side half of the time and up-and-down the other half.

Twinning in iron FeSe has made it extremely difficult to obtain reliable measurements of nematic order in the material until very recently. In 2014, Pengcheng Dai and Tong Chen of Rice pioneered a method of detwinning the fragile crystals by gluing them atop a sturdier layer of barium iron arsenide and applying some pressure. This technique causes the nematic layers in the material to snap into alignment.

"In this work, what we hoped to do with detwinning was to align the samples without changing their intrinsic properties as a way to measure the intrinsic properties of the sample without the annoying twinning effect," explained Yi. "But with stronger strain, one could offset the delicate balance between nematicity and superconductivity. There is already evidence that straining certain samples could modify the temperature where the sample becomes superconducting."

The Mystery of the "Missing Electron"

There is also a problem of a "missing electron" : one of the two electron Fermi pockets observed in the normal state escapes detection entering the nematic phase. The cause of this phenomenon has eluded researchers, but is believed to be crucial to forming a model for superconductivity in Fe-based materials.

"If you imagine electrons filling electronic states in a material like pouring wine into a glass, the electrons that can participate in superconductivity are those that are near the surface of the wine in the glass," noted Yi. "This wine-air boundary is called the Fermi level.

"In FeSe, it was found that a certain type of electron that used to be near the surface went missing-in-action in the superconducting state, and the lack of their participation directly affected the observed superconducting properties. It was not clear what had caused them to go missing before superconductivity appeared, although various proposals in the literature speculated on the cause."

Nematic Order Moved Electrons Away from the Fermi Level

In their study, the team took high quality angle-resolved photoemission spectroscopy (ARPES) measurements of the electronic structure of completely detwinned FeSe. "ARPES is a technique that probes the so-called momentum space and maps out the velocity map of the electrons," clarified Yi. "In solids, electrons live in so-called bands, which describe the allowed energy states in momentum space, and can be more directly measured by ARPES instead of a scanning probe."

Using this technique, the researchers were able to clearly follow the missing electron pocket from the normal state into the nematic state and observed its disappearance via shrinking, characterized as an upshift in energy. "It turns out that the reason they went missing was the nematic order," said Yi. "It causes the electronic states to rearrange themselves in a way that moved these electrons away from the Fermi level, hence prohibiting them to participate in superconductivity."

The team used an electron detector to track the speed and direction of electron traffic when emitted from the crystal, which may provide insight into the quantum mechanical laws that dictate the traffic patterns at larger scales. The data showed a magnitude of nematic shifts in FeSe that are comparable to shifts observed in more complex Fe-based superconductors that feature magnetic order. The team hypothesized that the nematicity observed could be a universal feature of all Fe-based superconductors.

"Understanding how nematicity changes the electronic structure is vital to understanding the landscape of electrons before the onset of superconductivity," concluded Yi. "This is not only important for FeSe, but for iron-based superconductors in general that also have nematicity appearing close to superconductivity.

"Our study provided a clear mapping of this process that was enabled by the detwinning technique. The next step is to understand amongst the remaining electrons that can participate in superconductivity, what their respective roles are."

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Currents

As part of its COVID-19 recovery package, the German government has pledged to promote the development and production of quantum technologies in Germany and use them to build a new industrial pillar in terms of both hardware and software. The federal government has agreed to allocate €2.0 billion for the construction of two quantum computers.

CERN has demonstrated an innovative transmission line that has set a new record for the transport of electricity. The link, which is 60 metres long, has transported a total of 54 000 amperes (54 kA, or 27 kA in either direction).

The line has been developed for the High Luminosity LHC, the accelerator that will succeed the Large Hadron Collider and is scheduled to start up at the end of 2027. Such links will connect the HL-LHC's magnets to the power converters that supply them.

The line is composed of cables made of superconducting magnesium diboride (MgB_2). On this occasion, the line transmitted an intensity 25 times greater than could have been achieved with copper cables of a similar diameter.

Last year, an initial prototype transmitted a 40 kA intensity over a distance of 60 meters. The link that is currently being tested is the forerunner of the final version that will be installed in the accelerator. It is composed of 19 cables that supply the various magnet circuits and could transmit intensities of up to 120 kA.

Under the leadership of the French research lab ONERA (the French National Research Center), a consortium of 33 key aviation industry and research stakeholders is researching hybrid electric propulsion for commercial aviation. The Investigation and Maturation for Hybrid Electric Propulsion (IMOTHEP), a four-year Research and Innovation project, recently received a €10.4 million grant from the European Commission under the Horizon 2020 framework program.

The airline industry has come under pressure to reduce the environmental impact of commercial flight. While the automotive industry has been making the shift towards electric motors, the prospects of a similar transition for aircraft still seems a long way off with many technological and safety barriers to overcome. However, switching from conventional to electrical propulsion would greatly improve aircraft efficiency and reduce carbon emissions and steps are being taken to realize these aspirations.

IMOTHEP boasts an impressive collection of participants: aircraft manufacturers Airbus and Leonardo; engine manufacturers Safran, GE Avio, MTU, ITP, and GKN; aeronautic research organizations ONERA, CIRA, DLR, AIT, ILOT, INCAS, and NLR; educational organizations Université de Lorraine, ISAE/Sup'Aéro, University of Strathclyde, TU Braunschweig, Politecnico di Bari, Chalmers University, and University of Nottingham; the think tank Bauhaus Luftfahrt; and Eurocontrol, an intergovernmental air traffic management organization.

The consortium is spearheading an investigation of hybrid electric aircraft technologies and designing propulsion architectures that utilize synergies between propulsion and airframe. They plan to analyze potential technologies and technical issues at the relevant scale and address the challenges of climate change requirements as they pertain to commercial aircraft technology.

Superconductivity may play a key role in zero emission flights. One of the primary challenges for electric flight is fabricating electric engines small enough that can still carry a load of passengers and cargo great distances without running out of fuel.

A commercial aircraft with a full load requires an energy per unit mass of at least 40 kW/kg, whereas most electric motors on the market can only manage about 5 kW/kg. Simply put, electric engines are too bulky and lack sufficient power density, but the integration superconducting elements could significantly increase the amount of electricity the motors are able carry.

Researchers are looking at liquid hydrogen as a power source for fuel cells. Electrically propelled airplanes could carry hydrogen for dual use as both a fuel and coolant. Liquid hydrogen, however, is an extremely explosive element and

▸ represents a safety challenge which will need to be addressed.

Some of this work focuses on improving the efficiency of electric motors by minimizing cooling through novel motor coil design. Researchers propose designing coils out of superconducting YBCO and applying advanced analytics tools to guide the design process.

It may take many years before fully electric flights become a reality, and in the meantime the consortium is developing hybrid propulsion systems which utilize combustion as an energy source and electric motors for propulsion. These hybrid systems could save somewhere in the neighborhood of 10%-20% of the energy required for conventional aviation methods.

Igor Mazin, Professor of Practice for Advanced Studies in Theoretical Physics, Quantum Science and Engineering Center, Physics and Astronomy at George Mason University, has received $450,000 from the U.S. Department of the Navy to create a quantitative, material-dependent theory of Ising superconductivity. Ising superconductivity is a recently discovered unconventional superconductivity phenomenon. One of its signatures is exceptional resilience of the superconducting state with respect to external magnetic field.

The goals of this research are to create a quantitative, material-oriented theory and study specific Ising superconductors, as well as their interfacing with magnetic materials. This research is expected to have ramifications for the theory of superconductivity and inspire new experimental studies.

Researchers from the Indian Institute of Technology (IIT) Roorkee fabricated superconducting films of two thicknesses on (100) oriented $SrTiO_3$ (STO) substrates using the target composition of $Fe_{1.05}Te_{0.50}Se_{0.50}$ (doi.org/10.1063/1.5129605). They investigated the structural and transport properties of the fabricated thin films and discovered the enhancement in superconducting properties with increasing thickness.

Because of their high J_c and high upper critical fields, iron-based thin film superconductors have a number of potential applications. High quality epitaxial thin IBS films could be useful for the production of Fe-based superconducting devices such as superconducting quantum interface devices (SQUIDs), coated conductors, and Josephson junctions.

Following the discovery of superconductivity in bulk Fe-based compounds, efforts have been made to prepare thin films of different classes of iron-based superconductors on various substrates. The basic properties of these materials are hard to study in bulk single crystalline samples due to the small size of grown crystals, but the thin films help in understanding them.

Owing to the thermal fluctuations developed via short coherence length, large anisotropy and high T_c, these materials exhibit a broadening and shifting of resistive transitions in external magnetic fields, which is a topic of growing interest. These thermal fluctuations are responsible for the thermally activated flux flow (TAFF), which leads to the tail in resistive transition induced via the motion of vortices.

The team fabricated thin films with nominal composition of $Fe_{1.05}Te_{0.5}Se_{0.5}$ on (100) oriented STO substrates using pulsed laser deposition. The used target material of $Fe_{1.05}Te_{0.5}Se_{0.5}$ was synthesized using the solid state reaction route. One thin film, S1, was prepared with 8000 laser shots, the other, S2, with 16000 shots.

The ρ-T measurements of the two grown films show T_C of 12.10 K for S1 and 12.62 K, for S2, respectively. The upper critical field value was estimated to be highest for S2 under both Ginzburg-Landau theory and the Werthamer Helfand Hohenberg model.

The activation energies suggest the presence of planer and point defects, and the q values point towards the 3D behavior. Vortex pinning occurs at a higher temperature for the S2 film compared to S1, which suggests that S2 has better superconducting properties.

Spotlight

Georg Hoffstaetter is a professor of physics and researcher at Cornell University whose work is primarily centered around accelerator and beam physics. He is the director of Cornell University's Energy Recovery Linac group and used to head its Superconducting Radio Frequency group. He has worked on a number of accelerators, most recently on the Cornell-BNL ERL Test Accelerator (CBETA). Hoffstaetter was gracious enough to discuss some of his projects and experiences with *Superconductor Week*.

Superconductor Week (SCW): Where are you from?

Georg Hoffstaetter (GH) : I was born in Mannheim, Germany, and I received my diploma in Physics at the Technical University Darmstadt with research on electron microscopy with Prof. Harald Rose. Then I went to Michigan State University with a stipend from the German National Merit Foundation.

SCW: When did you decide that you wanted to become a physicist?

GH: In the 12th grade I gave myself a year to decide between chemistry, physics, medicine, or computer science. I checked out careers in these fields, and decided I wanted to become a physics professor, and always stuck to it.

SCW: So you did your physics diploma at Darmstadt and then you went to get your masters at MSU in '92?

GH: I found a professor, Martin Berz, at MSU's National Superconducting Cyclotron Laboratory (NSCL) who was working on a new computation technique for analyzing particle optics, referred to as Differential Algebra. I wanted to work there for nine months, but they offered me a PhD position and I stayed longer than expected. Since receiving my PhD in '94, I taught at universities and did research in the physics of particle accelerators.

SCW: At that point, had you already narrowed your focus?

GH: Particle optics for electron microscopes already narrowed my focus to the physics of particle accelerators, large and small. For my PhD I investigated particle optics for large storage rings. When I subsequently went to Hamburg I focused on polarized beams. I got my Germany Habilitation for research on polarized beams and wrote a book on the topic. All this work falls under the focus area of accelerator physics. I was assistant professor in Darmstadt for two years, then I returned to DESY (German English Electron Synchrotron) for a permanent position. Under Dr. Ferdinand Willeke, I worked on the luminosity upgrade for HERA (Hadron Electron Ring Accelerator), an electron proton collider, which was the highest energy accelerator in the world at the time. I moved to Cornell University as associate professor in 2002 to work on Energy Recovery Linacs (ERLs) with Dr. Maury Tigner. Of course, that was after 9/11 and some project funding was delayed; by the time we got funding to pursue actual hardware development it was early 2005. We developed the concept for a high energy x-ray facility based on energy recovery linear accelerators. We had funding from the NSF to build components to check whether this concept would work, to see if we could build a superior x-ray facility based on energy recovery linacs.

▸ SCW: Did your current laboratory, CLASSE (Cornell Laboratory of Accelerator-Based Sciences and Education) already exist as an organization at the time?

GH: CLASSE was formed in 2007. It was conceived as an organization that includes everything at Cornell that is driven by particle accelerators, including high energy physics and x-ray science. It was with this lab in mind that we worked on a new x-ray accelerator. It would have been a very large project, costing something like $750 million. Our funding, largely from the NSF, was about $50 million altogether to test what could produce the high currents and the narrow beams needed for a new generation of x-ray accelerators, and what we could do so with reasonably low energy consumption by means of energy recovery. We built an electron source, a superconducting linac, that takes electrons from the source to the energy recovery linac, and a superconducting linac for the energy recovery process. The full x-ray ERL would have had 64 such linac units. Our charge from the NSF was to build and to test these components as a proof of principle for x-ray ERLs, to show that such an x-ray source could work and would outperform current x-ray sources. We achieved that in 2013 and 2014. After that success, there was a review of different concepts for the next generation of x-ray sourses, and with community input, the funding agencies decided that the LCLS-II would be built. It became clear that we would not build such a large x-ray source and the focus of our work changed. We continued to study ERLs, but for other applications. For example, we obtained industry funding to study the use of ERLs in computer-chip production, because ERL can be used to drive a free electron laser that produces EUV radiation for the lithography of computer chips.

SCW: Why did Cornell build an ERL accelerator?

GH: After prototyping components of an x-ray ERL, it was natural too construct an actual Energy Recovery Linac with them. That's when we teamed up with Brookhaven National Laboratory (BNL) to develop CBETA, the Cornell-BNL ERL Test Accelerator. This is a new kind of accelerator, because standard acceleration techniques that are usually used are either a linear or circuit. In a linear accelerator, you take a bunch of electrons, about one billion in about a cubic millimeter, and you accelerate them in in a straight line. When the beams are narrow, one obtains a high energy density. In a linear accelerator, one can optimize the particle motion to make the beam as dense as possible. This density is limited by the electrostatic forces that push electrons apart. But for ring accelerators this density is even more limited, because particles with different energies get a different bending rate in the ring, and so the beam widens. Therefore, accelerators that include rings typically cannot make beams as dense as linear accelerators. On the other hand, in a linac you cannot accelerate very high currents, because there is only a limited amount of power available to accelerate a limited number of particles. In a linac you can accelerate in a straight line, achieving high beam densities, but then you have to throw the beam away, so you waste the rest of the energy after using the beam. How much energy you can put into the beam of a linac therefore largely depends on how much electrical power you can afford.

SCW: How much power does it take to load up for one firing?

GH: The applications we consider run continuously; they don't fire. In ring accelerators, beams circulate for millions of turns, leading to a nearly continuous beam current. The x-ray beams from such an accelerator are produced for hours on end. Typically, the instantaneous power of the circulating electron beam of such sources is in the gigawatt range, which is a good fraction of the power of a nuclear power plant. You cannot provide that much power continuously to a linear accelerator. First of all, there is an ethical problem using so much power when power saving options are available, but there is also the problem that transporting that much power into a one square mm beam would melt components. And then there is the problem of course that the cost would be prohibitive. So, linear accelerators are great to make narrow beams, but their current cannot be very high. If you want to have a high current, you need a ring accelerator, in which you accelerate the beam to high energy and then store it for millions of turns. However, the beam will not be very dense after circulating many times. ERLs are a new accelerator technology in between rings and linear accelerators, where we accelerate a bunch of particles in a linac to achieve high density, but we don't discard the particles afterwards but recirculate them to win their energy back. We throw the particles away, but their energy is extracted to accelerate new high-density bunches. So every particle bunch is used only once, but its energy is recycled. That's why the particle beam can be very dense as in linacs, but additionally it can have a high current as in rings.

SCW: And the concept for this type of accelerator was first formulated in 1965.

GH: The idea was first published by Maury Tiegner from Cornell. At the time people just started to think about superconducting accelerator structures; he realized, 'Hey, if we have an accelerating structure that is superconducting and can store energy for a long time, we might use it to recapture the beam's energy, store it in a superconducting cavities and reuse it to accelerate new particles.' But it took 50 years to really realize this idea.

SCW: Why was that?

GH: Because adequate superconducting structures are hard to produce. An accelerating structure is basically a metal tank into which you send a cell phone wave, in the metal tank the wave gets reflected on the other end. If you then add a second wave at just the right time, the reflected and the new wave add to twice the strength. After another reflection at the end of the cavity, you add a third wave. So with a rather small cell phone antenna you can keep adding waves just at the right time for more than a billion times, increasing the strength of the wave by billion.

SCW: Are you using pure niobium as the superconductor or something different?

GH: We are using pure niobium. At the moment, pure niobium is still the most reliable technology. But nitrogen doping or a niobium-3-tin surface may become good options soon.

SCW: What cryomodule are you using and how does it function?

GH: We built two cryomodules ourselves. A cryomodule is simply a refrigerator to keep the superconducting accelerating cavities with their antennas for radio waves, at cryogenic temperature. The cavities immersed in a helium bath at 2 K to keep the niobium superconducting. For the cryomodule itself, the main problem is building the refrigerator; it is a cryogenic engineering problem.

SCW: Why did you decide to use permanent magnets instead of electromagnets in your system?

GH: First of all, a big priority in this new accelerator is saving energy, so we wanted to pioneer using permanent magnets to have no electricity costs at all for the main magnetics that steer the beam, but there are many positive side effects. One is that we want to use a special optics, the so called FFA optics, that has a very large energy acceptance. With these special optics we get four beams bent around a curve by the same angle, even though the beams have an energy difference of a factor of four. It might seem surprising because the angel usually depends on energy. But we shape the field of these permanent magnets in such a special way that beams with very different energies can follow the same curve through the same chain of magnets. For the ERL we have built, seven different beam, with four different energies all go though the same chain of about 200 permanent magnets. This had never been done before but is of course more economical than having each beam go through its own chain of magnets.

A final advantage of the permanent magnets is that they don't influence their neighbors, while electromagnets have very complicated cross-talk between neighboring electromagnets, as the coil of one electromagnet can magnetize the steel of a neighbor.

SCW: The particles accelerate during four passes, but then begin the deceleration passes. Are there physical limits to accelerating beyond four passes? Or is 150 megaelectronvolt the highest energy you are attempting to achieve?

GH: For our accelerator, the limit is about 150MeV because our permanent magnets have the appropriate strength to bend 150MeV electrons around a curve that just barely fits into our experimental hall. For higher energies one would not need more turns but either stronger magnets or a larger experimental hall.

SCW: How are the seven lanes for the particles traveling at different speeds kept separate?

GH: The beams with the four different energies are separate by about three centimeters; they go through the same, sufficiently wide beam pipe. The three decelerating beams each have the same energy as one of the accelerating beas. And two beam with the same energy travel along the same lane in CBETA.

SCW: You initially tested the accelerator with one pass last year, why didn't you carry out a test with multiple turns at that time?

GH: (laughing) Because it is really hard. You have these metal tanks, the superconducting cavities, in which you store radio waves that oscillate back and forth 1.3 billion times per second. You send the electrons through at exactly the right time, when the electric force points forward to accelerate electrons. To recover the energy you send the particles around the loop and bring them back to the cavity exactly at the right time when the force points backwards. This decelerates the electrons and stores their energy in the electric field of the cavity. Last June we adjusted the time window for deceleration accurately after the first turn. And in December we adjusted this time window for the fourth turn. The hardware to change the time window for deceleration from the first to the forth turn was installed during August and September.

SCW: What kind of a window is that in real time?

GH: The electrons travel at the speed of light, for all practical purposes, and the speed of light in simple units is one foot per nanosecond or the billionth part of a second. Since our circumference is about 200 feet, it takes 200 ns for one turn. Because it takes the force in the cavity about 0.8 ns to oscillate from acceleration to deceleration, and we need to be accurately timed to at least 1% of the oscillation, the return time has to be accurate to about eight parts per trillion of a second.

SCW: How might this system be used for the electron ion collider?

GH: When the NSF decided that the big light source would not be built, we had all the components to build an ERL. We had built the two SRF accelerators and the electron source, and we were therefore ready to build an ERL. Just at that time, it became clear that Brookhaven National Laboratory needed to test that ERLs especially the multi-turn energy recovery linacs can be made to work, because they will be needed in their electron-ion collider. That's when we teamed up with BNL. We contributed our already tested components and contributed the permanent magnets to construct CBETA, the first 4-turn SRF ERL at Cornell University. We wrote a white paper for this Cornell-BNL ERL Test Accelerator in the winter of 2015, then we tried to obtain funding. Finally, New York State provided the funds to assemble and commission this new accelerator.

SCW: Can you imagine or speculate as to some applications for this, commercially or otherwise?

GH: The main ERL application that Brookhaven National Lab (BNL) needs is hadron cooling for their Electron-Ion Collider (EIC). The electron-ion collider is the nations largest accelerator currently under construction. It will cost around $2 billion and is to be constructed at BNL on Long Island. To get high interaction rate during the nuclear physics collisions, the proton and ion beams have to be very narrow. They collide with an equally narrow electron beam to produce a large rate of collisions. These beams circulate in storage rings and are naturally not very narrow. As particles scatter off each other, the beams get wider and the interaction rates get reduced. To counteract, keeping the beam narrow, you can superimpose the proton or ion beams with electron beams of the same speed. Then, roughly speaking, the electron beams contracts the protons back together. This so-called hadron cooling is currently the most impotant application of ERL technology. There are actually two hadron coolers in the EIC and both require ERLs. Other applications or ERLs are of industrial nature, for example lithography of computer chips; you can shoot the high current of an electron beam against a laser beam and then, like colliding billiard balls, the electrons give some of their energy to the photons of the laser, changing laser light into x-rays. Such an ERL for high energy x-rays is considered a compact x-ray source because the ERL is much smaller than a typically one kilometer long conventional accelerator for x-rays. Other applications for ERLs are mostly in the fields of nuclear or high-energy physics. For example, there are ideas for a dark matter search, where you use the dense, high current electron beam of an ERL and shoot it though a narrow jet of gas. The electrons collide with the nuclei of the gas, which can produce new particles, possibly those that make up dark matter in the universe.

SCW: How do you plan to follow up on your initial successful tests?

GH: My research team wants to contribute to the EIC in major ways. For example, we are contributing to the design of the ERL for its hadron coolers, taking our ideas and what we have learned about ERLs to design optimal hadron coolers for the EIC. With CBETA, we would like to perform proof of principle tests for these coolers.

SCW: What kind of advice would you offer to someone aspiring to working in science?

GH: In general, search your heart to find what you love, find something you can be enthusiastic about, because you can only be exceptional if you love your work. I think that's the first most important search in a research career. ■

Luminary

Shoucheng Zhang（张首晟）
1961-2018
Theoretical Physicist and Businessman

Shoucheng Zhang was born and raised in Shanghai, China, and enrolled in his hometown's prestigious Fudan University at the very young age of 15. Two years later, he moved to West Germany to obtain a bachelor's degree at the Free University of Berlin, and after this moved on to Stony Brook University in New York to complete his doctoral studies in condensed matter physics. After completing a post-doc fellowship at the University of California at Santa Barbara's Kavli Institute for Theoretical Physics and working at IBM for a few years, he settled into a long-term position at Stanford University, where he conducted his most groundbreaking research.

He and his colleagues' discovery in 2005 of a new state of matter, the quantum spin Hall insulator, earned him numerous accolades. His group also successfully predicted how a quantum spin Hall insulator could be produced in an experimental setting using stacked layers of cadmium telluride and mercury telluride. This discovery of such topological insulators has the potential to revolutionize semiconductor production. Shoucheng, with the coherence and elegant simplicity typical of such a great thinker, used an apt metaphor to describe the movement of electrons along topological insulating materials: "Right now, inside conventional semiconductors, it's like you have a Ferrari in a crowded marketplace. It keeps bumping into its surroundings, so it dissipates all of its energy. But there are no collisions in topological insulators. They're like a highway system for electrons."

Shoucheng's group predicted numerous novel topological states of matter and topological effects, including the Bi_2Se_3 family of 3D topological insulators, the topological magneto-electric effect, time-reversal invariant topological superconductors, and the realization of a chiral topological superconductor and of chiral Majorana fermions using the quantum anomalous Hall state in proximity with a superconductor. Most of these predicted properties have now been experimentally observed. Later, Shoucheng and his group at Stanford wrote three theoretical papers where they successfully showed how to test Ettore Majorana's theory of Majorana fermions without the need of external forces having the same mass with the opposite charge of the electron.

In addition to his contributions to science, Shoucheng also co-founded Danhua Venture Capital, investing over $100 million into high-tech startup companies. As a member of the U.S. National Academy of Sciences and a foreign member of the Chinese Academy of Sciences, he strove to promote collaboration and friendship between his native China and his adopted home country throughout his life. ■

Patents

Cryogenic electronic packages and assemblies
Massachusetts Institute of Technology
March 10, 2020
U.S. Patent No. 10,586,909
A cryogenic electronic package includes a circuitized substrate, an interposer, a superconducting multichip module (SMCM) and at least one superconducting semiconductor structure. The latter is disposed over and coupled to the SMCM, and the interposer is disposed between the SMCM and the substrate. The SMCM and the at least one superconducting semiconductor structure are electrically coupled to the substrate through the interposer. A cryogenic electronic assembly including a plurality of cryogenic electronic packages is also provided.

Superconductor-based transistor
PsiQuantum Corp.
March 10, 2020
U.S. Patent No. 10,586,910
The various embodiments described herein include methods, devices, and systems for fabricating and operating transistors. In one aspect, a transistor includes: a semiconducting component configured to operate in an on state at temperatures above a semiconducting threshold temperature; and a superconducting component configured to operate in a superconducting state while: a temperature of the superconducting component is below a superconducting threshold temperature; and a first current supplied to the superconducting component is below a current threshold; where the semiconducting component is located adjacent to the superconducting component; and, in response to a first input voltage, the semiconducting component is configured to generate an electromagnetic field sufficient to lower the current threshold such that the first current exceeds the lowered current threshold, thereby transitioning the superconducting component to a non-superconducting state.

Gradiometric parallel SQUIDs
IBM Corp.
March 10, 2020
U.S. Patent No. 10,586,911
Techniques regarding parallel gradiometric SQUIDs and the manufacturing thereof are provided. For example, one or more embodiments described herein can comprise an apparatus, which can comprise a first pattern of superconducting material located on a substrate. Also, the apparatus can comprise a second pattern of superconducting material that can extend across the first pattern of superconducting material at a position. Further, the apparatus can comprise a Josephson junction located at the position, which can comprise an insulating barrier that can connect the first pattern and the second patterns of superconductor material.

Self-monitoring superconducting cables having integrated optical fibers
North Carolina State University
March 17, 2020
U.S. Patent No. 10,593,444
Disclosed are various embodiments for a self-monitoring conducting device that responds to strain and temperature changes. In one example, a self-monitoring conducting device comprises a superconducting cable having a core and one or more layers of HTS tape architecture surrounding the core. The self-monitoring conducting device further includes optical fibers integrated within the superconducting cable. The optical fibers can monitor a state of the superconducting cable along its length.

Low loss architecture for superconducting qubit circuits
IBM Corp.
March 17, 2020
U.S. Patent No. 10,593,858
A technique relates to a structure. A first surface includes an inductive element of a resonator. A second surface includes a first portion of a capacitive element of the resonator and at least one qubit. A second portion of the capacitive element of the resonator is on the first surface.

Quantum information processing with Majorana bound states in superconducting circuits
Massachusetts Institute of Technology
March 17, 2020
U.S. Patent No. 10,593,879
In a weak link of two s-wave superconductors coupled via a time-reversal-invariant topological superconducting island, a Josephson current can flow due to Cooper pairs tunneling in and out of spatially separated Majorana Kramers pairs (MKPs), which are doublets of Majorana bound states. The sign of the resulting Josephson current is fixed by the joint parity of the four Majorana bound states that make up the MKPs on the topological superconducting island. This parity-controlled Josephson effect can be used as a read-out mechanism for the joint parity in Majorana-based quantum computing. For a topological superconducting island with four terminals, the superconductor leads can address a Majorana superconducting qubit formed by the charge ground states of the topological superconducting island's terminals. Cooper pair splitting enables single-qubit operations, qubit read-out, as well as two-qubit entangling gates. Hence, topological superconducting islands between superconducting leads may provide an alternative approach to superconducting quantum computation.

Radial-gap type superconducting synchronous machine, magnetizing apparatus and magnetizing method
National University Corporation, Tokyo University of Marine Science and Technology
March 17, 2020
U.S. Patent No. 10,594,197
A radial-gap type superconducting synchronous machine is prepared which includes a rotor having, on its peripheral side, a convex magnetic pole which includes, at its distal end part, bulk superconductors. When viewed in the direction of the rotational axis of the rotor, the magnetic pole center side of the bulk superconductors is disposed nearer to a stator than the magnetic pole end side of the bulk superconductors. A ferromagnet is disposed on the rotational axis side of the bulk superconductors. A magnetizing apparatus is disposed outside the bulk superconductors in the radial direction of the rotor. Magnetization of the bulk superconductors is performed by directing magnetic flux lines from the magnetizing apparatus toward the bulk superconductors.

HTS generator with increased rotational inertia
American Superconductor Corporation
March 24, 2020
U.S. Patent No. 10,601,299
A HTS rotating machine having a longitudinal axis and having a first rotational inertia. There is a cylindrical stator assembly disposed about the

▸ longitudinal axis and a cylindrical rotor assembly disposed within the stator assembly. The rotor assembly is configured to rotate within the stator assembly about the longitudinal axis. The rotor assembly includes at least one HTS winding assembly which, in operation, generates a magnetic flux linking the stator assembly. There is a cylindrical electromagnetic shield disposed about the at least one HTS winding assembly having a second rotational inertia. There is a cryogenic cooling system for cooling the at least one superconducting winding assembly of the rotor assembly. The second rotational inertia is at least 80% of the first rotational inertia.

Photon detection device and photon detection method
National Institute of Advanced Industrial Science and Technology, Tokyo
March 31, 2020
U.S. Patent No. 10,605,655
Provided are a photon detection device and a photon detection method being practical, capable of performing photon detection in which no after-pulse is generated and generation of a dark count is suppressed, and capable of obtaining a high counting rate with low jitter. The device includes: a photon detection section having a long plate-shaped superconducting stripline whose plate surface is a photon detection surface, and a bias current supply section supplying a bias current to the superconducting stripline; and a single flux quantum comparator circuit capable of detecting magnetic flux scattered from the superconducting stripline upon photon detection.

Superconductor article with directional flux pinning
University of Houston System; SuperPower, Inc.
March 31, 2020
U.S. Patent No. 10,607,753
A method and composition for doped HTS tapes having directional flux pinning and critical current.

Capacitively coupled superconducting integrated circuits powered using alternating current clock signals
Microsoft Technology Licensing, LLC
March 31, 2020
U.S. Patent No. 10,608,044
Capacitively coupled superconducting integrated circuits powered using alternating current clock signals are described. An example includes a first clock line coupled via a first capacitor to a first superconducting circuit including a first Josephson junction, where the first capacitor is configured to receive a first clock signal having a first phase and couple a first bias current to the first superconducting circuit. The superconducting integrated circuit further includes a second clock line coupled via a second capacitor to a second superconducting circuit including a second Josephson junction, where the second capacitor is configured to receive a second clock signal having a second phase and couple a second bias current to the second superconducting circuit, and where the second phase is different from the first phase.

Method of making a superconductor device
Northrop Grumman Systems Corp.
March 31, 2020
U.S. Patent No. 10,608,159
The method comprises forming a base electrode in a first dielectric layer, forming a junction material stack over the base electrode, forming a hardmask over the junction material stack, etching away a portion of the junction material stack to form a Josephson junction (JJ) over the base electrode, and depositing a second dielectric layer over the hardmask, the JJ, the base electrode and the first dielectric layer. The method additionally comprises forming a first contact through the second dielectric layer to the base electrode to electrically couple the first contact to a first end of the JJ, and forming a second contact through the second dielectric layer and the hardmask to electrically coupled the second contact to a second end of the JJ.

Cryocooled SQUID measurement apparatus
Korea Research Institute of Standards and Science
April 7, 2020
U.S. Patent No. 10,613,160
A cryocooler SQUID system includes a cryocooler including a cold head, a cold head chamber in which the cold head is disposed, a sensor chamber including a SQUID sensor cooled to a low temperature by the cryocooler; and a connection block connecting the cold head and a thermal anchor disposed in the sensor chamber to each other to cool the SQUID sensor in the sensor chamber.

Superconducting magnet device
Mitsubishi Electric Corporation
April 7, 2020
U.S. Patent No. 10,614,940
A superconducting magnet device with which device breakage caused by a quench can be avoided while helium consumption is reduced. A sheet-like convection-preventing member is disposed at least either above or below a heat transfer member transferring to gaseous helium heat transferred from the outside, so as to cover a helium gas release tube for the gaseous helium, and thus heat exchange performance during transportation is improved. In the case where the quench occurs, the convection-preventing member is lifted upward in the release tube, thereby ensuring to provide a flow path for the gaseous helium and avoiding excessive increase of the internal pressure.

Persistent current switch and superconducting coil
Hitachi, Ltd.
April 7, 2020
U.S. Patent No. 10,614,941
Provided is a high-performance persistent current switch with a superconducting coil in which a decrease of a critical current or a critical magnetic field is suppressed. A means for solving the problem is with a persistent current switch provided with a superconducting coil in a switch unit. A superconducting coil includes a winding portion which is formed using a superconductor thin film formed on an outer circumferential face of a base member. The winding portion includes a first and a second winding portion which are formed in a double helical shape to be parallel to each other. A terminating end portion of the first winding portion and a starting end portion of the second winding portion, which are adjacent to each other, are connected to each other.

Vertical silicon-on-metal superconducting quantum interference device
IBM Corp.
April 7, 2020
U.S. Patent No. 10,615,223
Techniques related to vertical silicon-on-metal superconducting quantum interference devices and method of fabricating the same are provided. Also provided are associated flux control and biasing. A superconductor structure can comprise a silicon-on-metal substrate that can comprise a first superconducting layer, comprising a first superconducting material, between a first crystalline silicon layer and a second crystalline silicon layer. The superconducting structure can also comprise a first via comprising a first Josephson junction and a second via comprising a second Josephson junction.

▸The first and second via can be formed between the first and second superconducting layers, comprising a second superconducting material. An electrical loop around a defined area of the second crystalline silicon layer can comprise the first via comprising the first Josephson junction, the second via comprising the second Josephson junction, the first superconducting layer, and the second superconducting layer.

Superconducting photon detector
PsiQuantum Corp.
April 14, 2020
U.S. Patent No. 10,620, 044
In one aspect, a photon detector includes: a first waveguide configured to guide photons from a photon source; a second waveguide that is distinct and separate from the first waveguide and optically-coupled to the first waveguide; and a superconducting component positioned adjacent to the second waveguide and configured to detect photons within the second waveguide.

Method for producing a semifinished product for a superconducting wire
Bruker EAS GmbH
April 14, 2020
U.S. Patent No. 10,622, 537
The semifinished product includes at least one NbTi-containing structure, such as a NbTi-containing rod structure. This structure may be produced in layers by selective laser melting or selective electron beam melting of a powder that contains Nb and Ti. In the production of at least some layers of the NbTi-containing structure, during the production of an irradiated area provided for a material deposition of a respective layer, at least one process parameter of the selective laser melting or electron beam melting is varied in one or a plurality of first zones of the irradiated area as compared to one or a plurality of second zones of the irradiated area. The present techniques simplify introduction of artificial pinning centers into the NbTi-material of a superconducting wire or a semifinished product for such a superconducting wire.

Superconducting bi-directional current driver
Northrop Grumman Systems Corp.
April 14, 2020
U.S. Patent No. 10,622, 977
One example includes a superconducting bidirectional current driver. The current driver includes a first direction superconducting latch that is activated in response to a first activation signal to provide a first current path of an input current through a bidirectional current load in a first direction. The current driver also includes a second direction superconducting latch that is activated in response to a second activation signal to provide a second current path of the input current through the bidirectional current load in a second direction opposite the first direction.

Superconductive cable
LS Cable & System LTD.
April 21, 2020
U.S. Patent No. 10,629, 333
A superconductive cable including: a former; one or more superconductive conductor layers provided outside the former; an insulating layer configured to surround the superconductive conductor layers; and one or more superconductive shield layers provided on an exterior of the insulating layer. The superconductive conductor and shield layers are formed of superconductive wire rods, and each superconductive wire rod includes a metal substrate layer and a plurality of superconducting layers deposited on the metal substrate layer using a superconductive material. In the superconductive wire rods of an outermost superconductive conductor layer among the superconductive conductor layers and an innermost superconductive shield layer among the superconductive shield layers, each of the metal substrate layers and the superconducting layers are disposed in opposite directions.

Superconducting magnet having a variable electrically resistive layer and method of use
The Florida State University Research Foundation, Inc.
April 21, 2020
U.S. Patent No. 10,629, 347
A superconducting magnet, which provides a barrier to current flow transverse to the length of the superconductor at operational temperature and voltages, while also providing a magnetic quench protection mechanism for the superconducting magnet. The superconducting magnet comprising a plurality of winding turns of superconductive material wound into a coil and a variable electrically resistive layer varying with either temperature or voltage positioned between at least of portion of the plurality of winding turns of the superconductive material, wherein the variable electrically resistive layer has a negative temperature coefficient of resistance or is a semiconductor with a threshold voltage greater than operational voltages.

Thermally isolated ground planes with a superconducting electrical coupler
Northrop Grumman Systems Corp.
April 21, 2020
U.S. Patent No. 10,629, 535
An integrated circuit comprises a first ground plane associated with a first set of circuits that have a first operational temperature requirement, and a second ground plane associated with a second set of circuits that have a second operational temperature requirement that is higher than the first operational temperature requirement. The second ground plane is substantially thermally isolated from the first ground plane. A superconducting coupler electrically couples the first and the second ground planes while maintaining relative thermal isolation between the first ground plane and the second ground plane.

Fastener-driving tool having a superconductor power source
Illinois Tool Works Inc.
April 28, 2020
U.S. Patent No. 10,632, 602
The present disclosure provides various embodiments of a fastener-driving tool that includes a battery-charged supercapacitor as a power source. The fastener-driving tool includes first and second spaced-apart, conductive rails and a partially conductive piston slidably mounted on the rails. The rails and the piston are electrically connected to one another. The supercapacitor is electrically connected to the first rail. When the supercapacitor discharges electrical current, it flows from the supercapacitor, into the first rail, through the piston into the second rail, and from the second rail. The electrical current induces magnetic fields in the rails and the piston, and the combination of the electrical current and the magnetic fields induce a Lorentz force that acts on the piston to move the piston toward a nosepiece to drive a fastener.